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The effect of gait velocity on calcaneal balance at heel strike; Implications for orthotic prescription in injury prevention

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ABSTRACT

Exercise related lower limb injuries (ERLLI), are common in the recreational and competitive sporting population. Although ERLLI are thought to be multi-factorial in aetiology, one of the critical predisposing factors is known to gait abnormality. There is little published evidence comparing walking and running gait in the same subjects, and no evidence on the effect of gait velocity on calcaneal pronation, even though this may have implications for orthotic prescription and injury prevention. In this study, the walking and running gait of 50 physically active subjects was assessed using pressure plate analysis. The results show that rearfoot pronation occurs on foot contact in both running and walking gait, and that there is significantly more rearfoot pronation in walking gait ($p < 0.01$). The difference in the magnitude of rearfoot pronation affected foot orthoses prescription. A 63% fall in computerized correction suggested by RSscan D3D™ software prescription was seen, based on running vs. walking gait. The findings of this study suggest that in the athletic population orthoses prescription should be based on dynamic assessment of running gait.

1. Introduction

Public health initiatives and a change in the attitude of many of the general population toward exercise since the 1970s means many people have become aware of the positive effects of aerobic exercise. Figures vary between countries but between 20% and 60% of people regularly engage in some form of activity [3–5]. Whilst running and jogging are associated with many benefits, it is believed that the increasing numbers of people participating in such activities has lead to a corresponding increase in lower limb injuries [6].

As lower limb injuries cause significant morbidity and time away from sport, research has attempted to identify potential risk factors. Extrinsic factors such as playing or training surface, skill level, competition level, alongside intrinsic factors such as previous injury, fitness level, gait biomechanics [1] and joint instability, have all been proposed as contributory factors [2,7]. Specific biomechanical gait variables such as the rate of impact loading, the magnitude of propulsive forces and the magnitude and rate of pronation, are intrinsic risk factors which have all been implicated in lower limb injury [8].

Orthotics are commonly prescribed in an attempt to correct gait abnormalities in the lower limb [9]. This is perceived to reduce potential for injury. Collins et al. in a comprehensive systematic review [10] have shown that orthotics can be effective in both injury prevention [11–13] and in treatment [14] in at least 70% of the athletic population [15].

Initially orthotics were prescribed on the basis of multiple static measures of the foot. Even though these measures evolved over time the published literature indicates there is still a "*low correlation between static measures and dynamic foot function during locomotion*" [16]. It is suggested that the use of dynamic measurement may be superior to the traditional static measures of foot position in identifying contributory mechanisms to injury. One method of prescribing orthotics based on dynamic assessment is by using pressure plate analysis and associated software (RSscan footscan® and D3D™ orthoses) in the design of an in shoe orthoses. This adopts a semi customised prescription resultant on correction being applied at a number of fixed locations. RSscan footscan® software will prescribe a subject a D3D™ orthotic based on the balance of lateral and medial pressures at four different zones of the foot during foot contact [16].

To date most studies have assessed gait at either walking or running pace but there is little information comparing running and

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walking gait in the same subject. There is no literature, as far as the authors are aware, comparing the effect of gait velocity on rearfoot pronation vs. supination at heel strike, even though this may have implications for orthosis prescription. This study aims to determine if there is a difference in rearfoot pronation between walking and running, and if so whether it leads to altered D3D™ orthosis prescription.

2. Methods

Subjects were recruited from the University of Melbourne student population, based on a power calculation that indicated a sample size of 50 would be needed to detect a difference between the repeated measures for two data sets, $p < 0.05$ with 80% power and $\alpha = 0.05$.

Inclusion criteria confirmed being physically active (exercise $\geq 3\times$ a week for at least 20 min per session), and subjects were excluded if they had an existing orthotics prescription, or if they had had a lower limb injury within the past 2 months. Subjects were recruited from the student population of University of Melbourne and athletes from a professional rugby league club.

The study was approved by the Human Research Ethics Committee, University of Melbourne ID number 0717597, and all subjects gave their informed consent.

Subjects were asked to walk and run barefoot along a 16-m long, 0.02-m thick EVA foam runway. Embedded in the runway was a RSscan footscan® pressure plate (RS Scan Lab Ltd., 1 m × 0.4 m × 0.02 m, 8192 sensors, 500 Hz). In order to conceal the location of the pressure plate the entire length of the runway was covered with a 0.005-m rubber track cover. Subjects performed sufficient practice trials to familiarise themselves with the testing procedure before five trials on each foot for both running and walking were collected. Subjects ran at a self-determined pace and a coin toss was performed to determine if the order in which the subject would walk and run, or run then walk. A trial was considered valid when a full heel strike pattern was captured by the pressure plate per run. A single foot strike was recorded per trial to maximize sampling frequency. In addition to plantar pressure data, velocity was measured between timing gates (Jaycar Electronics, Melbourne, Australia) so that the difference of an individual's velocity between running and walking gait could be calculated.

The captured plantar pressure data was analysed using RSscan footscan® System 7.9 software. Heel contact was measured between 0% and 7.5% of foot contact. The software divided the foot into 10 separate anatomical regions (Fig. 2), two of which are medial heel (HM) and lateral heel (HL). The pressures acting on these two areas are then compared during heel contact. Where HM > HL rearfoot pronation is occurring, whereas if HM < HL rearfoot supination is occurring. If the D3D™ software detects excessive rearfoot pronation, or supination, it prescribes a orthoses with a "+ or − C correction" corresponding to a medial or lateral heel wedge of between 2° and 4°. The validity of the software has been tested previously [17] for both its test–retest reliability and its mathematical modelling data [18].

By comparing the forces simultaneously acting in these two areas it can be determined if the rearfoot is pronating or supinating (Fig. 1). The average peak force on contact, and angle of the axis dividing HM and HL were also calculated.

The terms pronation and supination are used to allow a more visual interpretation of the results, the relevant plantar pressures are extrapolated to give the biomechanical properties, the reader can interpret pronation to represent medial loading and supination to represent lateral loading about the midline of the calcaneum.

Statistical analysis was performed using SPSS Statistical Package version 13.

3. Results

The anthropometric characteristics of the 50 recruited subjects are summarised in Table 1. A comparison of the measured velocities for running and walking gait are shown in Table 2. During both running and walking, at 2.5%, 5%, and 7.5% of foot contact, on average HM force was greater than HL force indicating calcaneal pronation. When HM/HL force ratios were compared, at all three comparison points the ratios were higher in walking, indicating that there is increased rearfoot pronation in during walking (Table 2). At 2.5%, 5%, and 7.5% of foot contact the HM/HL force ratio was 267%, 113%, and 92% higher in walking respectively. Chi-squared analysis demonstrated that the difference between the two sets was significant with a p value of 0.01.

The peak force on contact was higher during running gait. The average peak force for running was 1523 N as opposed to 880 N for walking. This equates to a 73% increase in average peak force on contact during running.

When the angle of axis of the foot was compared between walking and running it was found that during running the angle was reduced. The average angle of axis was 13.3° for walking and 3.8° for running.

When the D3D™ orthoses prescription for each tested foot was compared there was a reduction in C correction prescription when prescription was based on running gait. When orthoses were prescribed after analysis of walking gait 56.2% of feet were prescribed a C correction. When orthoses were prescribed after analysis of running gait the figure dropped to 20.8%, which is a 63% reduction in C correction prescription.

No subjects were lost to follow-up or dropped out of the study.

Table 1
Anthropometric characteristics of subjects ($N = 50$).

	Average	S.D.
Height	1.78 m	0.10
Weight	79.5 kg	14.7
Body mass index	24.9	3.3
Shoe size (UK)	9.5	2.7

Body mass index = weight (kg)/(height (m))^2.

Table 2
Velocity and force distributions in comparison groups ($N = 50$).

	Walking	Running
Average velocity	3.51 m s^{-1}	1.33 m s^{-1}
Velocity range	0.68–1.82 m s^{-1}	1.39–6.67 m s^{-1}
HM/HL force ratio		
At 2.5% of foot contact	11	3
At 5% of foot contact	16	7.5
At 7.5% of foot contact	25	13

HM: medial heel; HL: lateral heel.

4. Discussion

This study demonstrates that during both running and walking, HM force was greater than HL force indicating calcaneal pronation and there was a statistically significant difference between the D3D™ orthotics prescribed to a subject at running velocity compared to walking velocity.

In this study calcaneal pronation occurred upon heel contact, which is in agreement with current evidence [6]. There is a discrepancy between these findings and other researcher's findings with regard to the magnitude of pronation. Dugan and Bhat [6] stated that there is increased pronation in running, which is contradicted by the fact that HM/HL force ratio's were significantly higher in walking. Dugan et al. may have been referring to midfoot pronation, whereas this study measured rearfoot pronation.

A change in muscle activation between walking and running gait may explain the differences rearfoot pronation. In running, certain muscles are more active on foot contact to limit rearfoot pronation. It has been proposed that tibialis posterior, soleus, medial and lateral gastrocnemius all act to limit rearfoot pronation [19]. EMG studies have shown that the major peak of soleus, gastrocnemius lateralis, and gastrocnemius medialis is on foot contact/early stance in running as opposed to mid-late stance in walking [20,21]. The earlier peak in activity of these muscles limits pronation as they change the nature of the foot on foot contact. During walking the foot has a flexible and limp structure, whereas during running the muscles act to change the foot into a rigid, firm structure. This limits rearfoot pronation as a rigid foot is less likely to move once foot contact occurs. Peroneus longus, peroneus brevis and tibilais anaterior also play a role in increasing the rigidity of the foot. O'Conner et al. proposed that the peroneal muscles may be active during early stance to increase joint stiffness [19]. The major peak of peroneus longus has been shown

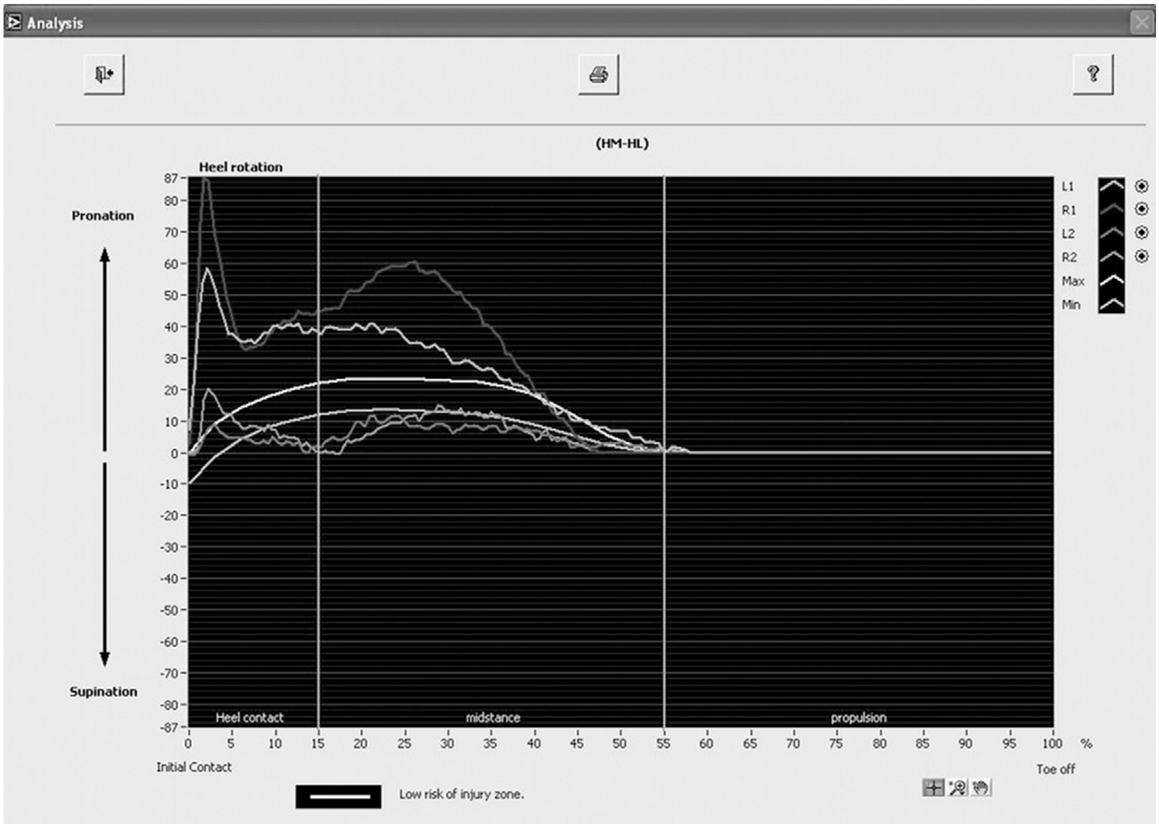

Fig. 1. An example of a subjects HM/HL force ratio comparison screen.

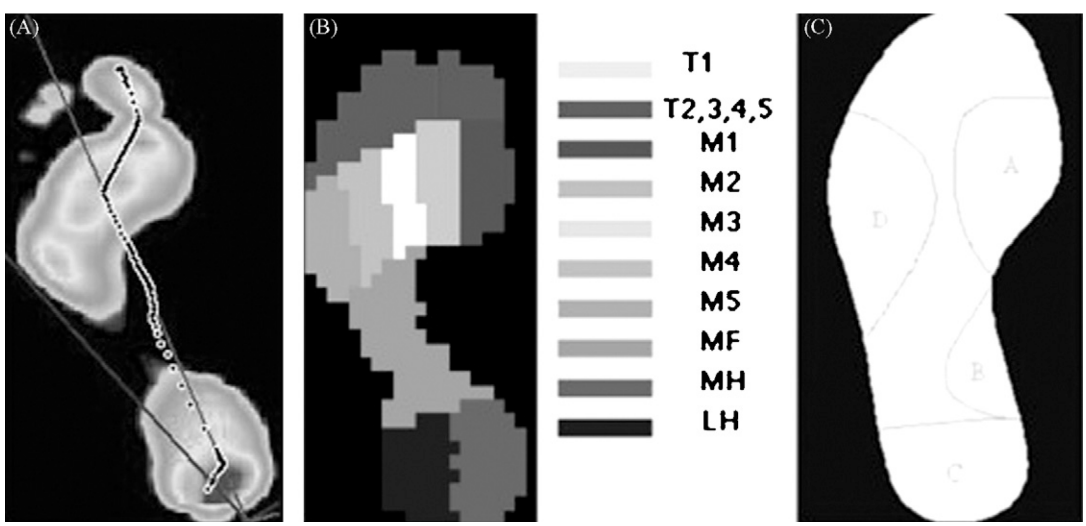

Fig. 2. (A) An example of a recorded trial. (B) The 10 areas of the foot analsed by RS footscan®. (C) The four potential areas of D3D™ orthotic correction.

to shift from mid-late stance in walking to early stance in running [20,21]. This is relevant as it gives the potential mechanism for change of gait pattern.

The difference in rearfoot pronation between walking and running leads to an altered orthosis prescription. If prescription is based on running assessment there is a 63% drop in C correction prescription in our study. It has already been established that static measures of the foot are poor predictors of dynamic foot function [22,23], whereas it has been shown that the RSscan footscan system produces orthosis which successfully modify foot kinematics [16]. This would suggest that when prescribing orthotics, dynamic assessment is superior to the traditional static methods.

A number of limitations to this study may exist. The study employed a single system of dynamic assessment some may contend that the measured differences are due the software as opposed to changing gait velocity as well as the fact that a large variance in velocities was recorded. The RSscan footscan system has however been shown to accurately measure plantar pressure [17,24,25]. The use of one system of orthosis prescription may limit findings, in that there is no allowance for individual variance. The large variance in the way orthoses are prescribed, both nationally and internationally, includes the common prescription method based on the experience of a podiatrist [15]. This study aimed to employ an objective and reproducible assessment method and hence the RSscan footscan system was employed.

5. Conclusion

This study would suggest that in athletes who predominantly compete and train at greater than walking gait, any biomechanical or podiatric assessment should be based on running gait.

If orthotics continues to be prescribed after only static assessment or dynamic assessment of walking gait, the current findings suggest that the subject may receive less than optimal prescription, or worse over prescription. Aside from the financial concerns, there is a potential for the incorrectly prescribed orthotics to cause iatrogenic injury. Whilst it is accepted that a greater proportion of bipedal time is spent walking, in the athlete where correction is more specific this is of particular relevance.

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Conflict of interest

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References

[1] Hreljac A. Etiology, prevention, and early intervention of overuse injuries in runners: a biomechanical perspective. Phys Med Rehabil Clin North Am 2005;16(3):651–67.
[2] Stanish WD. Overuse injuries in athletes: a perspective. Med Sci Sports Exerc 1984;16(1):1.
[3] Australian Bureau of Statistics. Participation in sport and physical activities. Canberra; 2003.
[4] Rowe N, Beasley N, Adams R. Driving up participation: the challenge for sport [cited 20.12.2008]; available from: www.sportdevelopment.org.uk/dupfuture2.pdf.
[5] van Bottenburg M, Rijnene B, van Sterkenburg J. Sport participation in the European Union: trends and differences. Mullier Institute; 2005.
[6] Dugan SA, Bhat KP. Biomechanics and analysis of running gait. Phys Med Rehabil Clin North Am 2005;16(August(3)):603–21.
[7] Murphy DF, Connolly DA, Beynnon BD. Risk factors for lower extremity injury: a review of the literature. Br J Sports Med 2003;37(February(1)):13–29.
[8] Hreljac A. Impact and overuse injuries in runners. Med Sci Sports Exerc 2004;36(May(5)):845–9.
[9] Razeghi M, Batt ME. Biomechanical analysis of the effect of orthotic shoe inserts: a review of the literature. Sports Med 2000;29(6):425.
[10] Collins N, Bisset L, McPoil T, Vicenzino B. Foot orthoses in lower limb overuse conditions: a systematic review and meta-analysis. Foot Ankle Int 2007;28(March(3)):396–412.
[11] Mundermann A, Stefanyshyn DJ, Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. Med Sci Sports Exerc 2001;33(November(11)):1939–45.
[12] Simkin A, Leichter I, Giladi M, Stein M, Milgrom C. Combined effect of foot arch structure and an orthotic device on stress fractures. Foot Ankle 1989;10(August(1)):25–9.
[13] Esterman A, Pilotto L. Foot shape and its effect on functioning in Royal Australian Air Force recruits. Part 2. Pilot, randomized, controlled trial of orthotics in recruits with flat feet. Mil Med 2005;170(July(7)):629–33.
[14] Finestone A, Novack V, Farfel A, Berg A, Amir H, Milgrom C. A prospective study of the effect of foot orthoses composition and fabrication on comfort and the incidence of overuse injuries. Foot Ankle Int 2004;25(July(7)):462–6.
[15] Ball KA, Afheldt MJ. Evolution of foot orthotics. Part 1. Coherent theory or coherent practice? J Manipulative Physiol Ther 2002;25(February(2)):116–24.
[16] Dixon SJ, McNally K. Influence of orthotic devices prescribed using pressure data on lower extremity kinematics and pressures beneath the shoe during running. Clin Biomech (Bristol Avon) 2008;23(June(5)):593–600.
[17] De Cock A, Willems T, Witvrouw E, Vanrenterghem J, De Clercq D. A functional foot type classification with cluster analysis based on plantar pressure distribution during jogging. Gait Posture 2006;23(April(3)):339–47.
[18] Hagman F. Can plantar pressure data predict foot motion? Eindhoven; 2005.
[19] O'Connor KM, Hamill J. The role of selected extrinsic foot muscles during running. Clin Biomech (Bristol Avon) 2004;19(1):71–7.
[20] Cappellini G, Ivanenko YP, Poppele RE, Lacquaniti F. Motor patterns in human walking and running. J Neurophysiol 2006;95(6):3426–37.
[21] Gazendam MG, Hof AL. Averaged EMG profiles in jogging and running at different speeds. Gait Posture 2007;25(4):604–14.
[22] Hamill J, Bates BT, Knutzen KM, Kilpatric GM. Relationship between selected static and dynamic lower extremity measures. Clin Biomech 1989;4:217–25.
[23] Hunt AE, Fahey AJ, Smith RM. Static measures of calcaneal deviation and arch angle as predictors of rearfoot motion during walking. Aust J Physiother 2000;46(1):9–16.
[24] De Cock A, De Clercq D, Willems T, Witvrouw E. Temporal characteristics of foot roll-over during barefoot jogging: reference data for young adults. Gait Posture 2005;21(June(4)):432–9.
[25] De Cock A, Vanrenterghem J, Willems T, Witvrouw E, De Clercq D. The trajectory of the centre of pressure during barefoot running as a potential measure for foot function. Gait Posture 2008;27(May(4)):669–75.

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