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Original article

The association between loss of ankle dorsiflexion range of movement, and hip adduction and internal rotation during a step down test☆

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ABSTRACT

A pattern of excessive hip adduction and internal rotation with medial deviation of the knee has been associated with numerous musculo-skeletal dysfunctions. Research into the role that ankle dorsiflexion (DF) range of motion (ROM) play in lower limb kinematics is lacking. The objective of this cross-sectional, observational study was to investigate the relationship between ankle DF ROM, and hip adduction and hip internal rotation during a step-down test with and without heel elevation in a healthy female population. Hip and ankle ROM was measured kinematically using a ten-camera Optitrack motion analysis system. Thirty healthy female participants (mean age = 20.4 years; SD = 0.9 years) first performed a step-down test with the heel of the weight bearing foot flat on the step and then with the heel elevated on a platform. Ankle DF, hip adduction and hip internal rotation were measured kinematically for the supporting leg. Participants who had 17° or less of ankle DF ROM displayed significantly more hip adduction ROM ($p = 0.001$; Cohen's d effect size = 1.2) than the participants with more than 17° of DF during the step-down test. Participants with limited DF ROM showed a significant reduction in hip adduction ROM during the elevated-heel step-down test ($p = 0.008$). Hip internal rotation increased in both groups during the EHSD compared to the step-down test ($p > 0.05$) Reduced ankle DF ROM is associated with increased hip adduction utilised during the step-down test. Ankle DF should be taken into account when assessing patients with aberrant frontal plane lower limb alignment.

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1. Introduction

Aberrant lower limb alignment has been associated with iliotibial band syndrome (Ferber et al., 2010), patellofemoral pain syndrome (Levinger et al., 2006, 2007; Molgaard et al., 2011), tibial stress fractures (Milner et al., 2006), posterior tibial tendon dysfunction (Ness et al., 2008), anterior cruciate ligament (ACL) tears (Powers, 2010) and osteoarthritis of the knee (Chang et al., 2005). The typical pattern described as being involved in the cause of such conditions is excessive hip adduction and internal rotation, relative medial deviation of the knee and tibial abduction, resulting in what is commonly termed dynamic knee valgus (Powers, 2010). Tibial external rotation (Hewett et al., 2006; Bell et al., 2008), anterior translation of the knee (Hewett et al., 2006) and hind foot eversion or navicular drop (Hewett et al., 2006; Powers, 2010) have also been implicated in this movement pattern. Dynamic knee valgus is the resultant medial collapse during a loading task, resulting in internal torsion at the hip, knee and ankle (Hewett et al., 2006; Levinger et al., 2007; Bell et al., 2008; Magalhaes et al., 2010). Specific causal relationships between the hip, knee, ankle and foot mechanics have yet to be confirmed by explanatory studies.

There has been an abundance of research into the role of hip biomechanics in frontal (hip abduction and adduction) and transverse (hip internal and external rotation) plane lower limb alignment (Willson et al., 2006; Magalhaes et al., 2010; Powers, 2010; Willy and Davis, 2011). Excessive knee valgus angles/moments have been shown to be related to diminished hip muscle strength. Particularly weakness or aberrant motor control of the hip abductors and external rotators have been implicated in contributing to numerous knee injuries (Claiborne et al., 2006; Willson et al., 2006; Jacobs et al., 2007; Hollman et al., 2009). These deficits are more

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common in females as their biomechanical profile increases their risk of acquiring ACL tears (Jacobs et al., 2007; Sigward et al., 2008). While these studies examined the relationship between hip and knee alignment, they did not consider the role of the ankle and foot in closed-chain functional loading activities.

Less research has been conducted to investigate the influence of limited ankle dorsiflexion (DF) range of motion (ROM) on frontal and transverse plane lower limb alignment. Bell et al. (2008) found that ankle ROM and strength rather than hip ROM and strength were associated with dynamic knee valgus during a controlled squat. In the above study, the dynamic valgus was corrected by the addition of a heel lift, suggesting the role of limited ankle DF in dynamic knee valgus during a loading task. Fong et al. (2011) found that a reduction in ankle DF is associated with an increased risk of ACL injury due to decreased knee-flexion, increased dynamic knee valgus and larger ground reaction forces during landing. An association between limited ankle DF ROM and patella-femoral pain syndrome has been described by Piva et al. (2005) while Vesci et al. (2007) found that limited ankle DF, as opposed to hip muscle strength, appeared to contribute to dynamic knee valgus during a double leg squat task. Runners with a history of tibial stress fractures have greater peak hip adduction, and rear foot eversion (pronation) angles during the stance phase of running compared to healthy controls (Milner et al., 2006). Interestingly, there was no difference in peak knee angles or hip internal rotation between the groups. The authors hypothesized an association between hip adduction and rear foot eversion, but did not examine the role that ankle DF ROM may play. Malliaras et al. (2006) linked a reduced DF ROM with an increased risk of patellar tendinopathy. The study included volley ballers and associated a range of less than 45° of DF with an increased risk of patellar tendinopathy of between 1.8 and 2.8 times. It was reasoned that reduced shock absorption and increased patellar tendon load was causative, but the possibility of increased tibial torsion due to compensatory subtalar pronation was not considered. Lower limb alignment in the frontal and transverse planes was furthermore not considered.

As ankle DF has been identified in previous studies to be implicated in dynamic knee valgus, elevating the heel may reduce the required DF ROM and hence reduce the compensatory dynamic knee valgus. If this is the case, elevating the heel with a heel raise may be a useful tool to investigate the role of ankle DF in causing dynamic knee valgus occurring during the step-down test. A standard step-down test simply assists in identifying aberrant kinematics during a functional loading task whereas an elevated-heel step-down (EHSD) test differentiates between the contribution of ankle DF ROM and other contributors after the standard step-down test has been performed. The EHSD test is not a replacement test, but a follow-up test to identify the source of the problem.

Research has either looked at hip and knee biomechanics, or at ankle biomechanics, but to date, there is no available literature investigating the ankle and hip biomechanics simultaneously to determine the simultaneous relationship during a common loading task, such as a step-down, in a healthy population. Therefore, the primary aim of this study was to investigate the relationship between ankle DF ROM, and hip adduction and hip internal rotation during a step-down test in a healthy, female population. A secondary aim of this study was to establish whether elevating the heel during a step-down results in altered hip adduction and internal rotation. We hypothesized that females with decreased DF ROM will show increased hip adduction and internal rotation compared with females with optimal ankle DF ROM while performing the step-down test. We furthermore hypothesized that females with decreased ankle DF ROM will show reduced hip adduction and internal rotation during the EHSD when compared with the step-down.

2. Methods

2.1. Study design

A cross-sectional, observational study design was used. The study methods in terms of enrolment, assessment, allocation and analysis is shown in Fig. 1.

2.2. Participants

A consecutive sampling method was followed. Students were invited via e-mail and those who volunteered to participate were included in this study if they were female, between 18 and 30 years of age and were free of current or recent (in the preceding six months) lower limb injuries. Participants were excluded if they had a history of lower limb skeletal diseases that could affect lower limb alignment, for example congenital foot deformities, congenital hip abnormalities, spinal skeletal abnormalities, scoliosis, Perthe's disease, or any history of ankle, knee, hip or spinal surgery. Ethical clearance was obtained from the human research ethics committee of the associated institution in the spirit of the Helsinki Declaration (ethical clearance number M110112). All participants gave written informed consent and had the right to withdraw from the study at any time without suffering any repercussions.

2.3. Instrumentation

Data collection was conducted in the Physiotherapy Movement Analysis Laboratory of the University of the Witwatersrand. Ten high speed, digital Optitrack V100:R2 cameras (Natural Point, Inc., OR, USA) were used to collect kinematic data at 100 Hz. Data were captured using Arena software (Natural Point NaturalPoint, Inc., OR, USA) and was exported into Matlab (Version 7.2, The Mathworks, Inc., Natick, USA) where kinematic variables were determined. The accuracy of a low cost system such as the one used in this study, compares well to that of the Vicon with a 0.655 cm average maximum error (Richards, 1999). Body joint centres were calculated using algorithms similar to the Plugin Gait model based on Kadaba et al. (1990) and Gutierrez et al. (2003).

2.4. Procedure

Once participants were screened for inclusion and exclusion criteria, lower-limb dominance was established by noting the limb of choice when the participant was asked to kick a ball. Each participant was then briefed regarding the testing procedure with specific reference to the technique and timing of the step-down test. The participant was allowed to practice the movement until the research assistant was satisfied with the timing of the task. Thereafter, retro-reflective markers were applied to 21 predetermined anatomical points as shown in Fig. 2 (Davis et al., 1991).

The dominant leg was chosen to be the supporting leg. The starting position for the step-down test was standing on a 25 cm

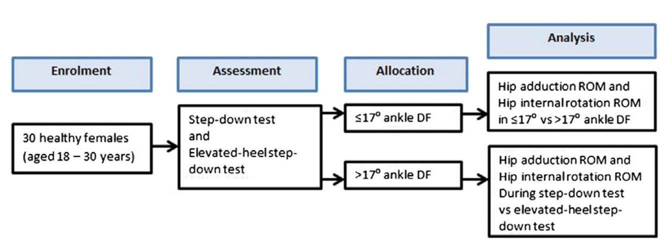

Fig. 1. The study methods in terms of enrolment, assessment, allocation and analysis.

high step. To allow for the ankle to move into an end range ankle DF position the height is slightly higher than the 20 cm high step used by Bolgla et al. (2008). The participant was required to step down with the non-dominant leg, touch the big toe to the ground and return to the starting position. The timing of this task was standardized to two seconds for the descent, one second for the toe to touch the ground and two seconds to return to the start, and was as monitored with a timer. Further instruction was to keep the heel of the dominant supporting foot flat. Participants were allowed one practice trial, where after three test trials were performed. The same procedure was followed for the EHSD, except that the starting position was with a 35 mm platform under the participant's heels (Fig. 3). There is no standard height for elevating the heel during the EHSD, but the authors argued that a 35 mm elevation will put the ankle in ±15° of dorsiflexion which will reduce the contribution of ankle dorsiflexion ROM during the EHSD with ±15°.

2.5. Data analysis

The variables of interest were ankle DF angle, hip adduction angle and hip internal rotation of the supporting leg during a forward step-down test as well as the 'elevated heel' step-down test. Leg orientation was described as: flexion/extension (α), abduction and adduction (β) as well as internal/external rotation (γ) occurring at the weight bearing hip joint which was measured. The angles used in this study are relative to the proximal body segments and not relative to the global coordinate system. Positions for ankle DF, femoral medial rotation and hip adduction of the supporting leg were analysed on the frame showing the lowest point of descent of the opposite leg (the instance where the toe touched the floor).

Eighteen degrees has been shown to be a normative value for ankle dorsiflexion (standard error of the measurement = 1.195) (Moseley and Adams, 1991; Moseley et al., 2001) and therefore, for the purpose of this study, subjects with 17° or less were considered to have limited dorsiflexion. The sample was divided into two groups – those with an ankle DF ROM less than or equal to 17° and those with more than 17° of ankle DF as measured kinematically at the lowest point of descent measured at the supporting ankle. Data were assessed for normality using Shpiro-Wilk's test. For

Fig. 3. Starting position of the elevated-heel step-down test with a 35 mm platform under the participant's heels.

parametric data (ankle DF ROM and hip adduction), the independent t-test was used to establish between-group differences while for non-parametric data (hip internal rotation), the Mann–Whitney U test was used. Due to the small numbers (n = 10 and n = 20), the Wilcoxon matched pairs test was used to establish the within-group difference during the step-down and the EHSD. Cohen's *d* effect sizes were calculated for between group difference

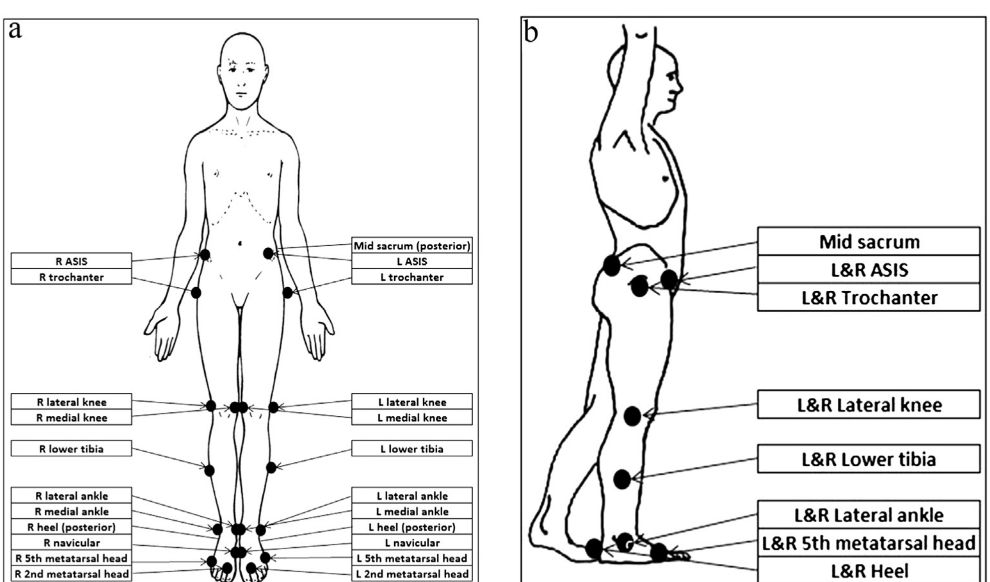

Fig. 2. Predetermined anatomical positions of retro-reflective markers (a) anterior view (b) lateral view.

in hip adduction (parametric data) and effect sizes of 0.2, 0.5 and 0.8 were interpreted as small, medium and large, respectively (Cohen, 1992). Statistical significance was set at $p < 0.05$. Statistical analysis was conducted using Statistica® Version 10 (StatSoft Inc, Tulsa, USA).

3. Results

3.1. Demographics

Thirty healthy female students (mean age = 20.4 years; SD = 0.9 years) participated in this study. Ten participants had less or equal to 17° (mean = 14.5°; SD = 2.5°) and 20 participants had more than 17° of ankle DF ROM (mean = 22.1°; SD = 2.7°; $p < 0.001$).

3.2. Relationship between ankle and hip ROM during the step-down test

Participants who had 17° or less of ankle DF ROM displayed significantly more hip adduction ROM than the participants with more than 17° of DF during the step-down test ($p = 0.001$; 95% CI 2.04, 11.06) and a large effect size of 1.2 (Cohen's d) was found (effect size 90% CI −2.03–0.64). No statistically significant difference between the two groups was found in terms of hip internal rotation ROM (Table 1 and Table 2).

3.3. Relationship between ankle and hip ROM during the EHSD test

Participants with limited DF ROM showed a significant reduction in hip adduction ROM during the EHSD test, but there was no such reduction found in the group with optimal DF ROM (Table 1, Table 2 and Fig. 4). Both groups showed reduced hip internal rotation during the EHSD compared to the step-down test.

4. Discussion

The results of this study show an association between reduced ankle DF ROM and an increase in adduction of the hip during a functional loading (step-down) test. The group of participants with equal or less than 17° of DF ROM had greater dynamic knee valgus during the step-down test, as indicated by significantly greater hip adduction ROM (18.3° vs 11.8°; $p = 0.001$; Cohen's $d = 1.2$). Furthermore, when the group of participants with DF ROM equal or less than 17° performed the EHSD test, their hip adduction decreased significantly (18.3° vs 13.8°; $p = 0.008$), possibly indicating a decrease in dynamic knee valgus. No statistical significance in hip internal rotation ROM existed between the two groups in terms of the step-down test, while greater hip internal rotation ROM, was observed in both groups during the EHSD. This implies that hip adduction and hip internal rotation should be assessed independently and not viewed as a combination movement dysfunction when one assesses an individual to have dynamic knee valgus during a step-down task.

The association between an increase in hip adduction ROM and decreased DF ROM during a functional loading task such as the step-down test emphasizes the importance of the kinetic chain in lower limb alignment. The effect size of this finding was large (Cohen's $d = 1.2$) and this six and a half degree difference between the two groups can be considered not only statistically, but also clinically significant. In the kinetic chain, the relative angle, magnitude and direction of one motion-dependent body segment has an effect on another segment which lead to differences in the way these segments interact (Putnam, 1993). Bell et al. (2008) and Vesci et al. (2007) also indicated the association between decreased ankle DF ROM and lower limb alignment, specifically medial knee deviation and dynamic knee valgus, respectively. This finding is significant in a clinical context where limited DF ROM is associated with ACL injury (Fong et al., 2011), patella-femoral pain syndrome (Piva et al., 2005) and patellar tendinopathy (Malliaras et al., 2006). DF ROM may therefore play a role in the prediction of musculoskeletal injuries, but further research involving longitudinal methods is needed.

Hip internal rotation ROM increased in all participants, regardless of ankle DF ROM, during the EHSD test. This is most probably due to the hip flexion movement that occurs during a step-down, increasing the moment arm of hip internal rotators. This increased internal rotation torque may be due to an increased leverage of some of the hip internal rotator muscles. This moment arm increases 8-fold as the hip flexion angle increases from 0° to 90° (Delp et al., 1999). In fact, a position of only 20° hip flexion doubles the internal rotation moment arm of the anterior fibres of gluteus medius. Furthermore, once hip flexion increases significantly during movement, the hip external rotators reverse their rotary action and become hip internal rotators (Delp et al., 1999; Neumann, 2010). This may occur as early as 45° of hip flexion (Neumann, 2010). For these reasons, it is likely that hip internal rotation ROM will increase in all participants during a loading test that requires an increase in the hip flexion angle such as the step-down test.

This study is limited in that it was performed on a healthy population. Future studies need to investigate the incidence of a loss of DF ROM and how it relates to aberrant frontal and transverse

Table 1
Descriptive statistics of participants with equal or less than 17° and those with more than 17° of ankle DF ROM during the step-down and EHSD tests (n = 30).

		Step-down		EHSD	
		≤17° Ankle DF ROM (n = 10)	>17° Ankle DF ROM (n = 20)	≤17° Ankle DF ROM (n = 10)	>17° Ankle DF ROM (n = 20)
Hip adduction (degrees)	Mean	18.3	11.8	13.8	10.2
	Standard Deviation	±5.9	±4.1	±5.1	±4.7
	95% Confidence Interval	14.64; 21.96	9.16; 14.34	10.14; 17.46	7.61; 12.79
	Median	20	11.5	16	9
	Range	20	14	16	16
	Percentile (10%–90%)	9.5; 25	6.5; 16.5	4.3; 19.8	5.5; 17.5
Hip internal rotation (degrees)	Mean	3.7	9.8	7.9	12.8
	Standard Deviation	±24.2	±14.4	±23.8	±16.2
	95% Confidence Interval	0.01; 7.32	7.18; 12.35	4.25; 11.56	10.20; 15.37
	Median	15.5	14	18.5	18.5
	Range	63	58	63	63
	Percentile (10%–90%)	−36; 26.3	−17.8; 19.8	−31; 30.8	−21; 24.8

EHSD – elevated heel step down; DF – dorsiflexion; ROM – range of motion.

Table 2
Comparison of hip adduction and hip internal rotation between and within the ≤17° Ankle DF ROM and the >17° Ankle DF ROM groups.

	T-statistic	z-statistic	p-value
Hip internal rotation: ≤17° Ankle DF ROM group vs > 17° Ankle DF ROM group during the step-down test[a] (n = 30)	–	0.07	0.95
Hip adduction: ≤17° Ankle DF ROM group during the step-down test vs during the EHSD[b] (n = 10)	0.00	–	0.008*
Hip adduction: >17° Ankle DF ROM group during the step-down test vs during the EHSD[b] (n = 20)	66.00	–	0.145
Hip internal rotation: ≤17° Ankle DF ROM group during the step-down test vs during the EHSD[b] (n = 10)	4.00	–	0.017*
Hip internal rotation: >17° Ankle DF ROM group during the step-down test vs during the EHSD[b] (n = 20)	19.00	–	0.001*

* Statistical significance ($p < 0.05$).
[a] Mann Whitney U: This sample size exceeds 25 therefore the z-statistic is used instead of the U-statistic (Portney and Watkins, 2009).
[b] Wilcoxon matched pairs test: T-statistic could not be converted into a z-statistic as the sample was less than 25 (Portney and Watkins, 2009).

plane alignment during functional loading in an injured group. Other variables affecting the kinetic chain such as femoral anteversion or retroversion, tibial torsion, and foot pronation or supination, should be simultaneously considered in future studies. Females differ from males in terms of kinematics (Jacobs et al., 2007) due to the hormonal changed during the menstrual cycle (Cesar et al., 2011). To ensure a homogenous group, only females were included in this study. Results can therefore not be generalised to a male population. The role of the foot should also be taken into consideration when investigating at lower limb alignment and inclusion of this variable is recommended for future research.

5. Conclusions

The findings from this study shows that females with reduced ankle DF ROM (≤17°) display more hip adduction during a step-down task than females with optimal ankle DF ROM (>17°). Furthermore, females with reduced ankle DF ROM displayed less hip adduction during a step-down task with the heel was elevated by 35 mm (EHSD) than with the heel flat, while this was not found amongst females with optimal ankle DF ROM. Females with reduced ankle DF ROM may use hip adduction to compensate for limited ankle DF ROM by increasing hip adduction ROM during functional loading tasks such as the step-down. No difference in hip internal rotation utilized during the step-down test was found between the two groups, although hip internal rotation increased in both groups during the EHSD. The increase in hip internal rotation may be due to an increase in amount of hip flexion required during the EHSD.

The results from this study further imply that dynamic knee valgus should not be considered as a consequence of a combined hip adduction and internal rotation (transverse and frontal plane), but the two planes of movement should rather be considered as two separate entities as they do not always behave congruently. Additionally, ankle DF ROM should be assessed clinically when assessing patients with dynamic knee valgus during loading tasks.

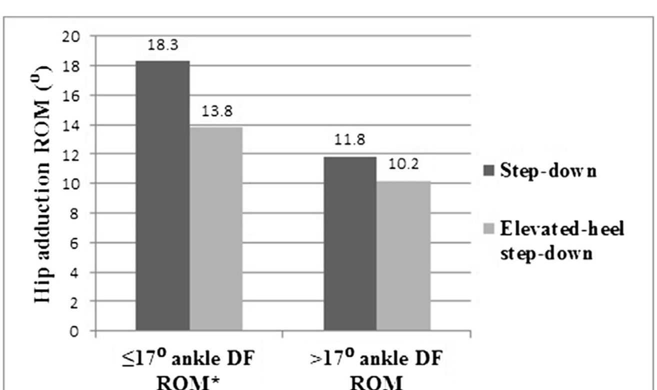

Fig. 4. Hip adduction ROM during step-down (SD) and elevated-heel step-down (EHSD) in females with reduced (≤17°) and females with optimal (>17°) ankle DF ROM (*p = 0.008).

6. Key points

6.1. Findings

The findings from this study shows that females with reduced ankle DF ROM (≤17°) display more hip adduction during a step-down task than females with optimal ankle DF ROM (>17°).

6.2. Implications

The implications of this study are that the EHSD may be useful in evaluating the effect of limited ankle DF ROM on hip adduction during functional loading such as the step-down test.

6.3. Caution

A major limitation of this study was that it was performed on a healthy, female population and results cannot be generalised to a patient or male population.

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