Effect of sex and lateral ankle sprain history on dorsiflexion range of motion asymmetry during the weight bearing lunge test

ABSTRACT

Background

Reduced dorsiflexion range of motion (DFROM) which is commonly seen following lateral ankle sprain (LAS) has the potential to influence lower extremity biomechanics which have been linked to an increase injury risk in the female athlete. Current research on the effect of sex and LAS history on DFROM is limited.

Hypothesis/Purpose:

This study had three aims 1) determine the effect of sex, leg dominance and LAS history on DFROM, 2) determine the effect of sex and LAS history on magnitude of asymmetry and 3) the association of sex on direction of asymmetry.

Study Design:

Cross-Sectional Study

Methods

DFROM was measured bilaterally whilst performing the weight bearing lunge test (WBLT) in 105 healthy individuals all participating in multidirectional sports. A 3-way mixed ANOVA was carried out to determine the interaction between sex, LAS history and leg dominance on

DFROM and a 2-way ANOVA for the effect of sex and LAS history on asymmetry. A chi-square test was used to determine the association of sex and direction of asymmetry.

Results

This study found no significant effect of sex, LAS history and leg dominance on DFROM ($P>0.05$). Main effects were significant for sex and LAS on DFROM. The mean asymmetry for all participants was reported as 12.25±14.76cm. No significant effect of sex and LAS history on magnitude of asymmetry was reported. There was a significant association of sex and direction of asymmetry ($\chi2(1) = 11.26$, $p = .00$). 65.2% of males were shown to have higher DFROM of their non-dominant limb compared to 75% of females who were higher in their dominant limb.

Conclusion

Findings from this study suggest that DFROM is affected by sex and LAS history. Females have increased DFROM compared to males and those with LAS history are more likely to have a decreased DFROM. This study also suggests that interlimb asymmetries in DFROM are present in athletes, therefore practitioners should exercise caution when using bilateral comparisons in injury and return to play assessments.

Level of Evidence:

2b.

Key words

Dorsiflexion, lateral ankle sprains, Sex differences, biomechanics, weight bearing lunge test

INTRODUCTION

It has been well documented that the female athlete is at an increased risk of sustaining knee injuries such as patellofemoral pain (PFP) [1] and anterior cruciate ligament (ACL) ruptures [2, 3]. Currently, two biomechanical patterns have been linked to knee injury risk: dynamic knee valgus (DKV) (adduction and internal rotation of the hip, knee abduction and rotation of the tibia) and reduced knee flexion [2, 4]. Females have been shown to demonstrate more knee valgus, less knee flexion and more femoral adduction when performing 'at risk' activities such as landing or cutting which could predispose them to a higher risk of injury[5-8]. A plethora of research has focused on the influence of the kinetic chain on lower extremity biomechanics, with much of the research focusing on the hip [9-12], but there is a growing body of evidence linking decreased ankle dorsiflexion range of motion (DFROM) to these 'at risk' movement patterns [13-19]. These kinetic chain patterns can be identified as the top-down approach (hip and trunk) and the bottom-up approach (ankle) [20].

Decreased DFROM is a common problem among athletes, especially after LAS and has been shown to affect sagittal plane movement which may result in compensatory frontal and transverse plane motion and loading, especially at the knee. Individuals have been shown to have greater knee flexion displacement, increase knee valgus and greater ground reaction forces during bilateral and unilateral squatting [21, 22] landing tasks [16, 23, 24] and change of direction tasks [25] which have been linked to an increase in injury risk, especially in the female athlete. Furthermore, females have been shown to be more one-leg dominant in comparison to males and are more likely to injure their non-dominant limb[26-28] therefore, understanding the effect of sex and leg dominance on DFROM would be useful to help inform future sex-specific prevention and rehabilitation strategies. Currently, there is a plethora of research which has investigated the effect of sex, limb dominance and LAS history on DFROM. Current research have all found no effect of sex on DFROM [29, 30 31, 32] in a variety of different sports and levels. Miller at al [29] and Senanayake et al [32] report a significant effect of previous ankle injury on DFROM but did not provide further analysis on sex differences and so there exists a gap in the current evidence which will be explored further in this study.

Unilateral restrictions in DFROM may lead to asymmetrical loading and result in interlimb asymmetries which may influence lower extremity biomechanics. Current evidence is conflicting regarding the extent of asymmetries in DFROM. It has been previously suggested that a threshold of 10-15% asymmetry may increase risk of injury but the literature to support this focusses on return to sport after ACL reconstruction [33]. This has since been challenged and no clear evidence which supports asymmetry and increased risk of injury [34],[35] Furthermore the use of an arbitrary asymmetry threshold has its limitations and it has been argued that asymmetry should be based on the metric, task, population and muscle group studied [36]. It has also been suggested that practitioners should monitor magnitude (% difference between limbs) alongside direction of asymmetry (which limb is stronger/greater range of motion) over several testing sessions as these have been to vary considerably over several test sessions using the same test. However where data has only been collected during one single testing session, an inter participant threshold can be established to determine what can be considered as a true asymmetry [37] . To date there is no known study which investigates sex differences and LAS history on DFROM asymmetry. Normative data from Hoch and McKeon[38] report interlimb asymmetries of 1-2cm in 35 healthy participants and Rabin et al [39] found asymmetries of 10° in 23% of male military recruits. Arede et al [40] and Islin et al, [41] report frequent asymmetries of over 10% in male soccer players but argue that differences occur due to the functional demands of the sport. However, in comparison, several studies found no asymmetry in

DFROM [42, 43], but this could be due to methodological differences between the studies and how asymmetry has been calculated. There is a dearth of literature on DFROM asymmetry in the female athlete. As DFROM has been postulated as a predisposing factor to influence lower extremity biomechanics, an understanding of between limb differences in DFROM is required to determine population and task specific asymmetry thresholds for asymmetry. Therefore, the aims of this study were to 1) determine the effect of sex, leg dominance and LAS history on DFROM, 2) Determine the effect of sex and LAS history on magnitude of asymmetry and 3) the association between sex and direction of asymmetry.

MATERIALS AND METHODS

Participants

105 healthy participants (68 males, 37 females, age:27.8 ± 7.7 y, stature:175.5±9.4 cm, body mass:84.2± 17.4 kg, R dominant: n=92, L dominant: n=13) who participate in multidirectional sports including soccer and netball, provided written, informed consent in the spirit of the Helsinki Declaration. Prior to testing, all participants completed an injury history questionnaire to assess previous lateral ankle injury on each leg, and leg dominance. Dominant leg was defined as the preferred leg for kicking a ball [44] and LAS history was defined as at least one episode of an ankle sprain[45]. Participants were excluded if they had a history of lower extremity surgery, any health conditions that may influence foot and ankle function, and previous history of lower extremity injury in the last six months. The participants were instructed to maintain their regular training regimens but were told not to exercise 48 hours prior to the day of testing. Ethical clearance was obtained by the institutional ethics review panel.

Procedure

DFROM measurements were obtained using the weight bearing lunge test (WBLT) where the back foot (BF) heel was raised off the floor. [46] This method has been shown to have excellent intra-rater reliability. [46] Participants were instructed to position themselves in a tandem stance position in front of a wall. The big toe and midline of the heel of both feet were maintained perpendicular to the wall and each participant was instructed to keep the BF knee straight during each test position. Their BF heel was raised off the floor so that the participant was on their toes. Participants were asked to place their hands against the wall in front so that their hands were flat, and no gripping was allowed. Measurements were taken using a tape measure (to the nearest 0.1cm) from the big toe to the wall (Fig. 1). Once participants were able to maintain the position with the knee touching the wall, the test foot was then progressed away from the wall in 1cm increments until their reach their maximum range of dorsiflexion. [38] The examiner ensured that front heel contact was made throughout the testing using manual contact alongside verbal instructions but did not control either pronation or supination of the foot during testing. The BF was maintained in the same position throughout the test. No warmup was performed prior to testing and the testing took place in the same place using the same instruments to standardize testing conditions. The WBLT was completed three times for each leg and the mean of the three measurements was used for analysis. Leg order was randomly selected prior to the testing session.

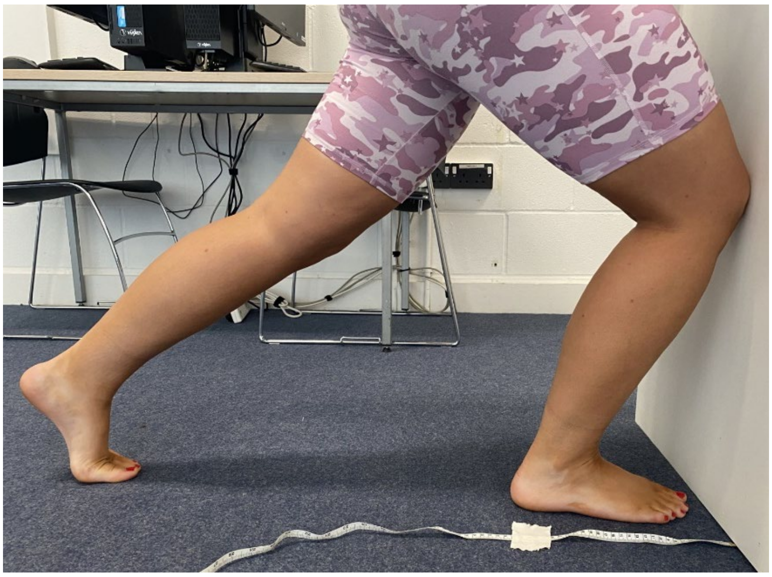

Figure. 1. WBLT with BF raised off the floor

Data Analysis

The average of three attempts were used for statistical analysis. [47] For the first study aim, a three-way mixed ANOVA (IBM SPSS, version 29) was conducted to compare the effects of two between subject variables; lateral ankle sprain history (yes, no) sex (Male or female) and a within subject's variable: leg dominance (dominant or non-dominant) on DFROM. The assumption of normality for the data was checked using the Kolmogorov-Smirnov test with normative data obtained for all DFROM measurements ($p>0.05$). There was homogeneity of variances for dominant limb ($p=0.90$) and non-dominant limb ($p=0.43$) as assessed by the Levene's test for equality of variances.

To determine interlimb asymmetry the calculation 100/(max value) x (min value) x -1 + 100 was used.[48] To determine the direction of asymmetry (which ankle has higher DFROM) an 'IF function' was added to the end of the above formula: *IF(dominant <non-dominant,1,-1). [49]

An asymmetry threshold (AT%) was calculated for DFROM all participants and this was used to determine whether a participant can be considered as having a true asymmetry. This threshold was based on the population mean + smallest worthwhile change (SWC) using the calculation AT% = magnitude of asymmetry mean% + (0.2 x SD) [50]. The SD is the standard deviation of the mean magnitude of asymmetry. High asymmetry was calculated using population mean + (1.0 x between subject SD) for all participants [50]. The assumption of normality for the data was checked for asymmetry data using the Kolmogorov Smirnov test and was not normally distributed ($P<0.05$). There was homogeneity of variances as assessed by Levene's test for equality of variances $p=0.19$). A two-way ANOVA was conducted to compare sex (male or female) and LAS history (yes or no) on magnitude of asymmetry (%). A Chi Square test of independence was conducted to determine whether there was an association between sex and direction of asymmetry.

RESULTS

The descriptive statistics for all measurements for both dominant and non-dominant limb are presented in Table.1. 92 (87.6%) participants (57 males, 35 females) reported their right leg to be their dominant leg in comparison to 13 (12.4%) participants (11 males, 2females) who reported their left leg to be the dominant leg. 70 (66.6%) of participants reported a history of LAS in comparison to 35 (33.3%) of participants who reported no history of LAS.

Table 1. Mean DFROM measurements and SD for sex, LAS history and leg dominance.

Sex	Participants (n)	LAS History (yes, no)	Mean (cm)	SD ±
Male				
Dominant	41	Yes	8.94	3.25
	27	No	10.38	3.45
Non-Dominant				
	41	Yes	9.44	3.23
	27	No	10.52	3.46
Female				
Dominant	25	Yes	9.86	3.31
	12	No	11.85	3.09
Non-Dominant	25	Yes	9.70	3.15
	12	No	12.21	2.39

Results from the three-way mixed ANOVA indicated no 3-way interaction between sex, LAS history, and leg dominance on DFROM ($F(1,101) = 0.21$, $P = 0.65$, $\eta 2 = 0.00$) and no 2-way interactions between sex and leg dominance ($p=0.82$, $\eta 2=0.00$), leg dominance and LAS history ($p=0.94$, $\eta 2= 0.00$), or sex and LAS history ($p=0.33$, $\eta 2= 0.01$). Significant main effects were found for sex ($p=0.04$, $\eta 2=0.43$) and LAS history ($p=<0.00$, $\eta 2=0.10$). No significant main effects were found for leg dominance ($P=0.66$, $\eta 2=0.00$).

Magnitude of asymmetry values (%) are shown in Table 2. The 2-way ANOVA indicated no 2-way interaction between sex and LAS history on magnitude of asymmetry $F(1, 101)= .03$, p=.88, η2=0.00) and no main effects were found for sex (p=0.25, η2=0.00) or LAS history (p=0.82, η2=0.00).

Table 2. Mean interlimb asymmetry values and SD for sex and LAS history.

Sex	Participants (n)	LAS History	Asymmetry %	SD ±
Male				
	41	Yes	13.5	18.2
	27	No	13.3	13.7
Female				
	25	Yes	10.4	11.8
	12	No	9.2	8.5
Asymmetry Threshold (AT%) 11.8%			**High Asymmetry Threshold (HAT%) 25.6%**	

26 (24.7%) males (11 males LAS history, 15 no LAS history) 10 (9.5%) females (7 LAS history, 3 no LAS history) exhibited DFROM asymmetry magnitudes above the AT%. 12 (11.4%) of males (6 LAS history, 6 no LAS history) and 3 (2.8%) females (2 LAS history, 1 no LAS history) exhibited high asymmetry.

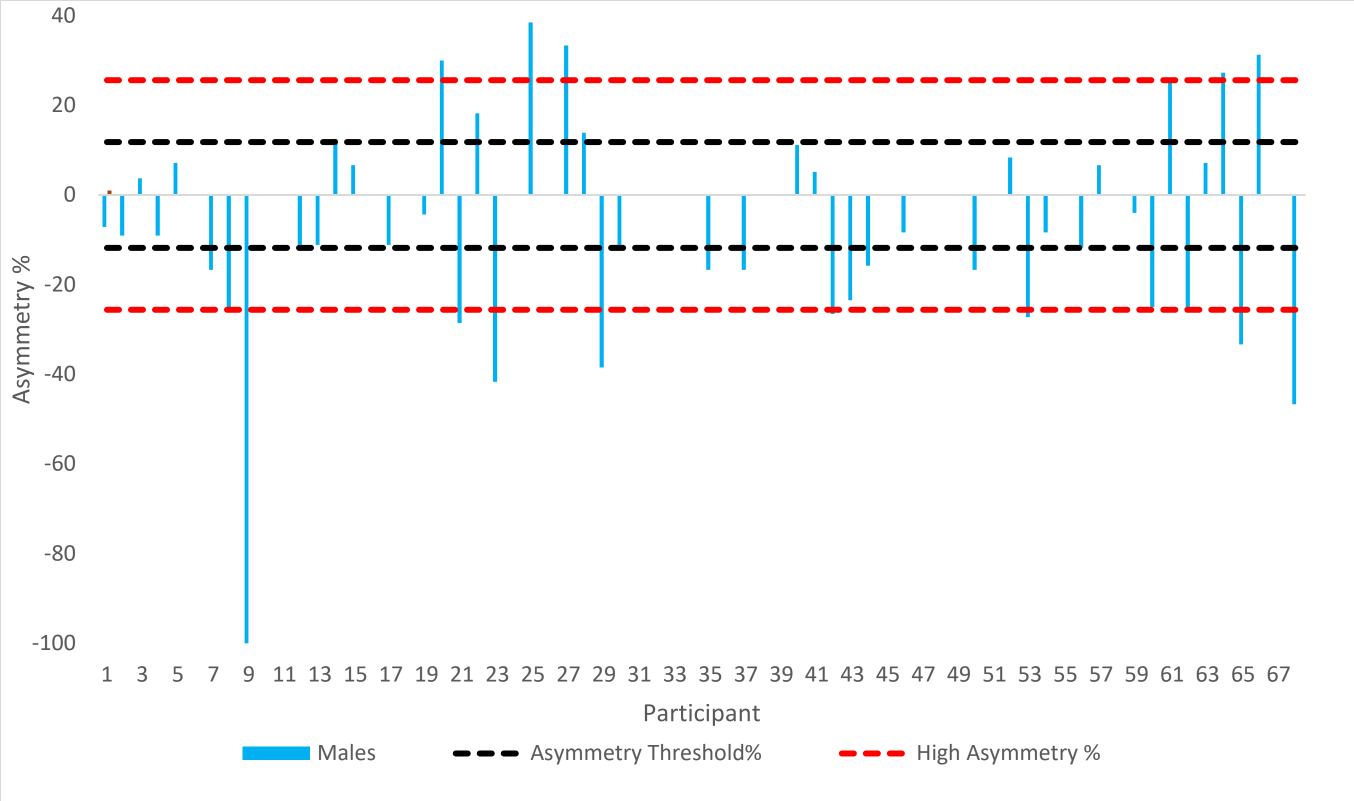

Figure 5.2. Individual DFROM asymmetry scores for males.

Above 0 indicates asymmetry favours the dominant limb and below 0 indicates that asymmetry favours the non-dominant limb.

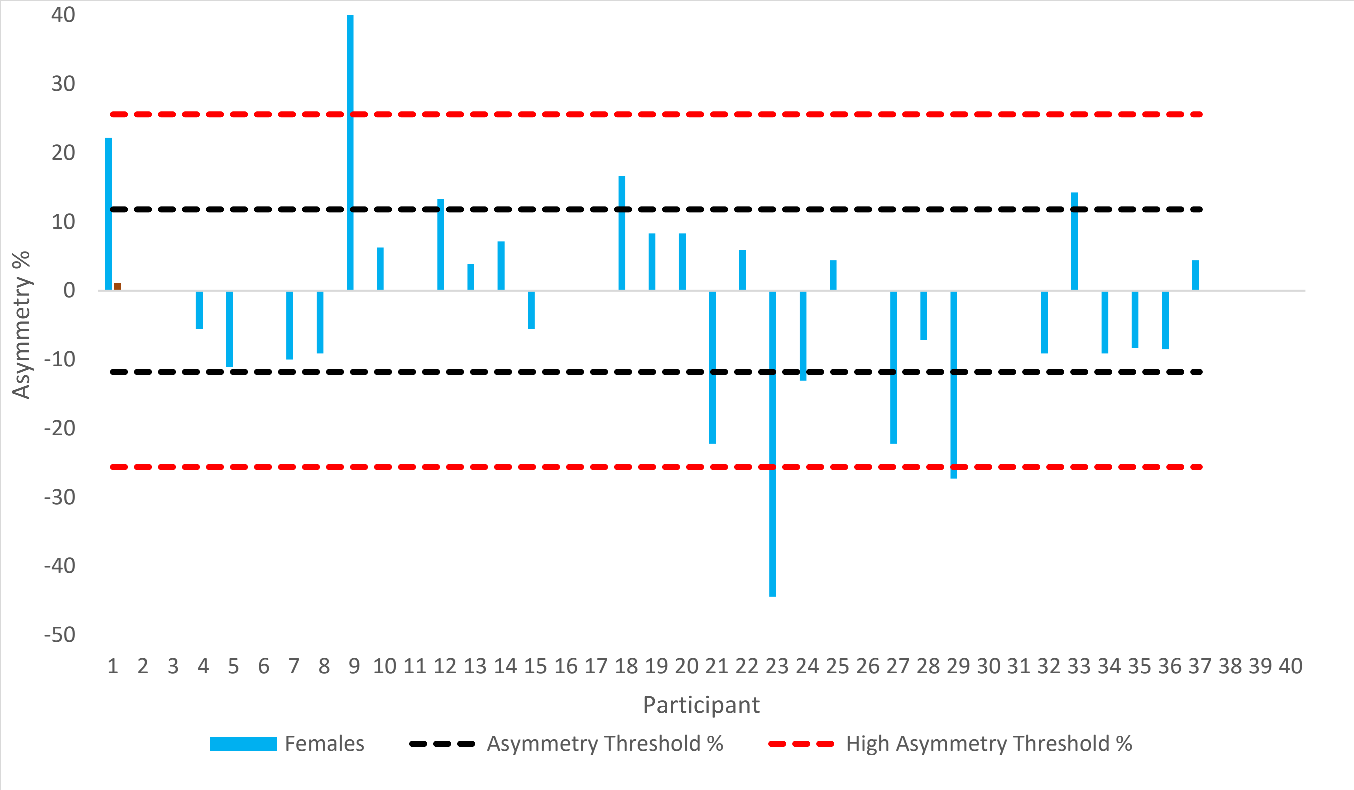

Figure 5.2. Individual DFROM asymmetry scores for females.

Above 0 indicates asymmetry favours the dominant limb and below 0 indicates that asymmetry favours the non-dominant limb.

A chi-square test for independence was conducted between sex and direction of asymmetry (positive or negative). There were statistically significant association between sex and whether asymmetry favoured the dominant or non-dominant limb ($\chi 2(1) = 11.26$, $p = .00$). 65.2% of males were shown to have higher DFROM in their non-dominant limb compared to 75% of females who were shown to have higher DFROM in their dominant limb.

DISCUSSION

This study found no statistically significant interaction between sex, leg dominance and LAS history on DFROM (F(1,202) = 0.19, P = 0.66. Furthermore, there were no significant two-way interactions found for DFROM, however, significant main effects were reported for sex (p=0.04, η2=0.43) and LAS history (p=0.00, η2=0.10) on DFROM. As this is the first known study to investigate the effect of sex, LAS history and leg dominance on DFROM using the WBLT, these results cannot be compared to any previous published findings. The significant main effect of sex suggests that males demonstrated less DFROM (9.82cm) than females (10.91cm). It has been argued that females are shown to exhibit greater ROM due to lower muscle stiffness that allows a higher tolerance of muscle stretch, [51] however, the findings from this study contradicts Miller et al [29] and Llurda-Almuzara [30] who found no significant effect of sex on DFROM in a group of elite level gymnasts and soccer players respectively. Decreased DFROM has linked to changes in lower extremity biomechanics which may increase risk of injury of non-contact ACL injuries especially in the female athlete. Although this study found that DFROM is affected by sex, males were reported to have smaller DFROM values, which suggests that males may be more at risk of developing lower extremity biomechanics that may predispose them to injury. More research on sex differences in DFROM and the effect on lower extremity biomechanics during sports specific activities is therefore needed.

This study reported a significant main effect of LAS history on DFROM with those athletes with a history of LAS demonstrating less DFROM (LAS history 9.48cm, no LAS history 11.25cm, p=0.00). This supports findings from Miller et al. [29], who reported similar findings in elite level gymnasts. However, Denegar et al [52] and Sugimoto et al [53] found no differences in DFROM in those with LAS history but this could be attributed to the measurement of DFROM as this was measured passively which is less reliable. These findings therefore suggest that those with previous LAS history have less DFROM which may predispose them injury. However, there is a need to understand what it meant by decreased DFROM and whether there is a specific ROM that may predispose an individual to adverse lower extremity biomechanics.

Magnitudes of asymmetry can be found in Table 2. The results of this study indicated that sex or LAS did not affect magnitude of asymmetry for DFROM. The mean magnitude of asymmetry ranged from 13.3%-13.5% in males and 9.2% -10.4% in females (males: LAS history: 13.6%±18.2%, No LAS history: 13.3%±13.7%; Females: LAS history: 10.4%±11.9%; No LAS history: 9.2%±8.6%). Magnitude of asymmetry values reported in this study are much higher compared to Madruga– Parera et al [54] who reported asymmetry of 5.88% ± 3.42 and Gonzalo Skok et al [25] who reported asymmetry 9.6% in fifteen youth elite male basketball players, however they are consistent with findings from Arede et al [40] and Isin [41] who reported magnitude of asymmetries over 10% in semi-professional male soccer players. The AT% for this study population was calculated as 11.8%. Of the 105 athletes tested 28 (41.17%) of males (16.17% LAS history and 22.05% no LAS history) and 13 (35.13%) females (27.02% LAS history and 8.10% no LAS history) exhibited DFROM asymmetries which exceeded the AT%. Furthermore, 12 (17.6%) males and only 3 (8.1%) females exhibited asymmetry values above HAT%. This suggested that symmetries are present in males and females and supports findings from Hoch and McKeon, [38] Rabin et al, [39] Howe et al [42] and Arede et al, [40] who all reported interlimb asymmetries in ankle DFROM in healthy populations. Therefore, clinicians should exercise caution if using bilateral comparisons during injury assessment. However, true asymmetries (above the AT% for that population) are only seen in 41.17% males and 35.13% of females and 12 (17.6%) males and 3 (8.1%) females report high asymmetry. It is important to recognise that these values are only specific to this population for this specific testing period as asymmetry has been shown to metric, population and test specific and therefore should not be used as a threshold for other studies [55]. Furthermore, it is not known whether a true asymmetry or high asymmetry may influence performance or lower extremity biomechanics as this may help practitioners in understanding whether it would be beneficial to improve DFROM, and therefore more research is needed in this area.

DFROM has been linked to changes in lower extremity biomechanics which may result in dynamic knee valgus which has been linked to several lower extremity injuries such as ACL rupture or PFP. [15-17] During 'high risk' sporting activities such as landing and cutting, asymmetries may result in adoption of different movement strategies which may affect our ability to produce or absorb forces and influence lower extremity biomechanics, but this has yet to be established within the current evidence. Furthermore, there is argument that asymmetries may occur naturally due the functional demands of the sport. Dynamic movements occurring in sport are normally performed using unilateral landing and take-off which may lead to interlimb asymmetries occurring [56] and there is no current evidence to suggested that asymmetry increased injury risk [35]At present there is no current study which investigates the effect of sex differences on the magnitude and direction of asymmetry on lower extremity biomechanics during cutting and landing which are common mechanisms of knee injuries such as ACL rupture and there exists a gap in the current evidence which would be useful to explore.

Another interesting finding from this present study is that there was a significant association of sex on direction of asymmetry ($\chi2(1) = 11.26$, $p = .00$). 65.2% of males were shown to have higher DFROM in their non-dominant limb compared to 75% of females who were more likely to have higher ROM in their dominant limb. It has been argued that athletes should have greater DFROM in their non-dominant (stance) limb as this limb needs to provide stability and balance when cutting and landing which is needed in sports requiring frequent COD [39] but this needs to be explore further. Furthermore, it is not known how direction and magnitude affects lower extremity biomechanics during specific activities as previous research has only investigated performance measures. [54] Females have been shown to favour one limb more than another (leg dominance) in sports compared to males who have been shown to have less reliance on one limb and this may predispose them to injury risk [2] and several studies have found that females are a higher risk of injury of injuring their non-dominant limb which suggests that leg dominance is a factor. [26-28] It is important to note that these findings are only specific for the participants in this study and that these results have only been taken on one test session. Several studies suggest that asymmetry is dependent on a variety of different factors which include playing history, sport(s) played, position and level of competition [57] Furthermore, asymmetry has been shown to vary considerably amongst athletes and direction of asymmetry varied amongst athletes performing the same test over different test sessions [58, 59], Therefore, it has been recommended that practitioners should test athletes over several testing sessions to ensure consistency of both magnitude and direction of asymmetry before determining asymmetry and injury risk[60]. However, current research has not investigated the effect of sex and magnitude and direction of asymmetry on lower extremity biomechanics during sports specific movements and presents a gap in the current research which could be explored.

This study is not without its limitations, although a large sample size was used for this study (n=105), the athletes used were from a variety of different sports which required changes of direction and athletes were participating at different levels. Previous research [54, 58, 59, 61] shows that asymmetry differs depending on both sport, level, task and population studied and therefore it is not known whether these sex differences would be seen if the tested on one sport and from athletes participating at the same level. Furthermore, the data from this study was collected during one single data collection point and caution must be taken when interpreting this data as both magnitude and direction has been shown to vary considerably across several testing sessions. This study also did not measure the effect of DFROM asymmetry on a specific performance variable and so it is not known how asymmetries may influence a variety of difference sports specific activities.

CONCLUSION

In conclusion, this study found no significant interaction between sex, leg dominance and LAS history on DFROM. However, females were reported to have higher DFROM values compared to males. Furthermore, those with LAS history were found to have less DFROM compared to those without. Interlimb asymmetry is common for all athletes, and this was not affected by sex or LAS history. A chi square test of independence found a difference in association of sex on direction of asymmetry as females were shown to have direction in favour of their dominant limb compared to males which is the non-dominant limb, but caution should be exercised in interpreting these results as asymmetry is metric, population and test specific. Although an interesting finding, how this may affect injury risk is unknown. Future research would be useful to determine the sex differences in magnitude and direction of asymmetry in DFROM whilst performing specific sports specific manoeuvres. DFROM has been linked to changes in lower extremity biomechanics which may be attributed to an increased risk of several lower limb injuries such as PFP and ACL rupture. Investigating sex differences in the magnitude and direction of asymmetry on lower extremity biomechanics would be help inform sex specific rehabilitation and prevention strategies.

Conflict of interest

The authors report not conflict of interest.

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