



## Original research

## Kinetic asymmetries during running in male youth



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## ABSTRACT

**Objectives:** A possible injury risk factor is limb asymmetry, which may differ across maturation given the adult growth spurt. The aim of this study is to quantify the magnitude of asymmetry in a number of kinetic variables during a running task in male youth of different maturity status.

**Design:** Quantitative observational laboratory study.

**Setting:** Sports performance laboratory.

**Participants:** Non-injured youth athletes in pre-, mid-, and post-pubescent status.

**Main outcome measures:** Inter-limb leg asymmetries whilst sprinting on a non-motorized treadmill.

Percent asymmetry was defined as:  $(\text{Left leg} - \text{right leg}) / \text{right leg} * 100 = \% \text{asymmetry}$ .

**Results:** Horizontal force presented limb asymmetries of 15.4, 14.8 and 14.7% for the pre-, mid- and post-PHV group respectively. Values for vertical force were higher (18.1, 20.2 and 20.8% respectively). Power asymmetries were 14.9, 15.8, and 15.5% respectively and work asymmetries were significant higher in pre-PHV participants (26.4%) compared to mid- (14.7%) and post-PHV (17.3%) participants.

**Conclusions:** As the population in this study was characterized as non-injured, asymmetries of 15–20% appeared typical during a running task in developmental athletes.

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## 1. Introduction

With every training session and competitive event, athletes are at risk of injury. To decrease the likelihood of athlete injury, coaching staff implement various types of screens to identify possible risk factors. One possible risk factor identified in the literature is lower limb asymmetry, which has been proven to impact the incidence of injuries (Croisier, Forthomme, Namurois, Vanderthommen, & Crielaard, 2002; Knapik, Bauman, Jones, Harris, & Vaughn, 1991; Orchard, Marsden, Lord, & Garlick, 1997; Yamamoto, 1993).

Testing for leg asymmetry can be performed utilizing acyclic and cyclic methods. Acyclic asymmetries are usually quantified via a

unilateral jumping task such as a vertical or horizontal jump (Flanagan & Harrison, 2007; Hoffman, Ratamess, Klatt, Faigenbaum, & Kang, 2007; Impellizzeri, Rampinini, Maffiuletti, & Marcora, 2007; Newton et al., 2006) or dynamometers (Croisier et al., 2002; Impellizzeri et al., 2007; Newton et al., 2006; Orchard et al., 1997; Rahnama, Lees, & Bambaecichi, 2005). Cyclic assessments used to determine the magnitude of asymmetry have included: consecutive jumping (Flanagan & Harrison, 2007) and running assessments (Bachman, Heise, & Bressel, 1999; Belli, Lacour, Komi, Candau, & Denis, 1995; Brughelli, Cronin, Mendiguchia, Kinsella, & Nosaka, 2010; Dalleau, Belli, Bourdin, & Lacour, 1998; Vagenas & Hoshizaki, 1992) performed on motorized and non-motorized treadmills and force plates.

With regards to cyclic assessments, the asymmetry associated with a variety of variables whilst jumping and running has been reported. Differences of 1.3–4.2% for flight time, reactive strength index, vertical stiffness and peak vertical force have been reported for consecutive jumping (Flanagan & Harrison, 2007). Leg asymmetries of 3.5% for contact time (Brughelli et al., 2010), 4.2–16.7% for leg stiffness (Bachman et al., 1999; Brughelli et al., 2010; Dalleau

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et al., 1998), 6.5–12.6% for vertical stiffness (Bachman et al., 1999; Brughelli et al., 2010), 0.9% for negative work (Dalleau et al., 1998), 10.7% for positive work (Brughelli et al., 2010), 1.1–3.7% for step time (Belli et al., 1995), 3.7–11.6% for displacement (Belli et al., 1995; Brughelli et al., 2010; Vagenas & Hoshizaki, 1992), and 46.3% (Brughelli et al., 2010) have been reported whilst running.

All the research discussed thus far has quantified the magnitude of asymmetry in adult participants. With the increase in elite sports academies in schools and many clubs identifying and developing talent at an early age, it would seem logical to screen developing athletes for leg asymmetries as well. The testing should preferably involve the main activity of the sports, such as running for football or field-hockey or jumping for volleyball, netball or basketball. However, studies quantifying asymmetry in children and/or youth athletes (Chin, So, Yuan, Li, & Wong, 1994; Teixeira, Silva, & Carvalho, 2003; Teixeira & Teixeira, 2008) are rare, and no researchers to the author's knowledge have quantified asymmetry whilst running in youths. Certainly asymmetry has not been investigated with regard to youth athletes of different maturity status. This would seem important given the rise of hormone levels (testosterone and growth hormones) associated with puberty (Forbes, Bullers, Lovell, McNaughton, Polman, & Siegler, 2009; Fraiser, Gafford, & Horton, 1969; Kraemer, 1988; Ramos, Frontera, Llopart, & Feliciano, 1998; Round, Jones, Honour, & Nevill, 1999) around peak height velocity (PHV) and the large improvements in strength (Mero, Kauhanen, Peltola, Vuorimaa, & Komi, 1990), and consequently power output (Armstrong, Welsman, & Chia, 2001; Armstrong, Welsman, Williams, & Kirby, 2000; Forbes et al., 2009; Ioakimidis, Gerodimos, Kellis, Alexandris, & Kellis, 2004; Mero et al., 1990). In addition and inherent with those changes in physical performance, it is thought that muscle and ligaments cannot keep pace with bone growth especially around the athlete's growth spurt, causing decreased flexibility and muscle imbalances (d'Hemecourt, Zurakowski, Kriemler, & Micheli, 2002; Purcell & Micheli, 2009), which in turn can increase incidence of injury, as evidenced in youth soccer players (Le Gall, Carling, & Reilly, 2007). Given this information it is hypothesized that the magnitude of asymmetry will be greater in more mature athletes, the purpose of this study therefore to quantify the magnitude of asymmetry in a number of kinetic variables during a running task in male youth of different maturity status.

## 2. Methods

### 2.1. Participants

Two invitation letters for participation in this investigation were sent to a) the national sport school and b) a high school that has a specific focus on excellence in sport. The principals discussed the possible participation with the sport directors and thereafter provided suitable participants. One hundred and twenty-two male athletes between 8 and 16 years of age volunteered to participate in this study. All participants were physically active, trained a minimum of two times per week for their sport, represented their club and/or school at a regional and/or national level and were involved in sports (soccer, field hockey, sprinting, distance running) where running/sprinting was an important component of their performance. The participants were further divided into three maturational groups (Rumpf, Cronin, Pinder, Oliver, & Hughes, 2012). The first group consisted of the pre-pubescent ( $\leq 12$  years of age = pre-peak height velocity PHV), the second of the mid-pubescent (13–15 years of age = mid-PHV) and the last of the post-pubescent ( $\geq 16$  years of age = post-PHV) athletes. Participant characteristics can be observed in Table 1. All participants and their legal guardians were informed of the risks and benefits of

**Table 1**

Participant characteristics according to their maturation status.

	Age (years)	Maturation offset (years)	Height (cm)	Mass (kg)	BMI (kg/m <sup>2</sup> )
	Mean $\pm$ Std	Mean $\pm$ Std	Mean $\pm$ Std	Mean $\pm$ Std	Mean $\pm$ Std
Pre-PHV (N = 41)	10.5 $\pm$ 1.37	−2.95 $\pm$ 0.92	141 $\pm$ 7.85	36.2 $\pm$ 10.2	17.9 $\pm$ 3.48
Mid-PHV (N = 30)	14.5 $\pm$ 0.93	0.36 $\pm$ 0.52	166 $\pm$ 6.93	55.2 $\pm$ 6.59	19.4 $\pm$ 4.19
Post-PHV (N = 51)	15.4 $\pm$ 0.74	1.79 $\pm$ 0.56	178 $\pm$ 8.22	70.4 $\pm$ 13.3	22.3 $\pm$ 3.55

participation and both legal guardians and participants provided written informed consent and assent to participate in this study. Procedures were approved by the Ethics Committee of the AUT-University.

### 2.2. Equipment

Running performance was assessed using a non-motorized force treadmill (Woodway, Weil am Rhein, Germany) in conjunction with the Pacer Performance Software (Fittech, Australia). The participants wore a harness around their waist, which was connected to a non-elastic tether. The tether was connected to a horizontal load cell (Model BS-500 Class III, Transcell Technology Inc, Buffalo Grove, USA), which measured horizontal force. The height of the load cell was adjusted accordingly to the subject's height, so that the tether was horizontal during testing. Vertical force was measured by four individual vertical load cells that were mounted under the running surface. The entire system was calibrated using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz with a cut-off frequency of 4 Hz. Treadmill belt velocity was monitored by two optical speed photomicrosensors, collected by a tachometer XPV7 PCB (Fitness Technology, Adelaide, Australia), and analyzed with the Pacer Performance software (Fitness Technology, Australia).

### 2.3. Procedures

Data collection sessions were standardized around mode of training and daily structure. Before physical testing, anthropometric measurements were taken. The height (cm), sitting height (cm), mass (kg) were measured and the body mass index (BMI) calculated. To calculate the maturity status of participants, a maturity index (i.e. timing of maturation) was calculated using the equation of Mirwald, Baxter-Jones, Bailey, and Beunen (2002): Maturity Offset =  $-9.236 + (0.0002708 \times \text{leg length} \times \text{sitting height}) + (-0.001663 \times \text{age} \times \text{leg length}) + (0.007216 \times \text{age} \times \text{sitting height}) + (0.02292 \times \text{weight by height ratio})$ . This assessment is a non-invasive and practical method of predicting years from PHV as a measure of maturity offset using anthropometric variables. The standard error of estimate for PHV was 0.49 years for boys (Mirwald et al., 2002).

Participants then received a familiarization session on the non-motorized treadmill, which consisted of standing, walking and running at a self-chosen speed. The familiarization was also used as a warm-up phase ( $\sim 10$  min). If the participants were unable to run freely, without holding on to the frame of the treadmill, the data collection was postponed and further familiarization took place. Otherwise, a series of warm-up sprints on the treadmill i.e.  $3 \times 5$  s preceded the data collection. The fastest two from three sprints over a 30 m distance from a standing split start were then collected and used for data analysis. A four minute rest was scheduled after each trial.

## 2.4. Data analysis

While vertical and horizontal forces were measured directly, average leg asymmetries (average power and average work) were calculated. Power was calculated by multiplying the instantaneous horizontal force by the instantaneous velocity. Work was calculated by horizontal force multiplied with displacement for each sample. Values were calculated for all steps during the 30 m sprint and then averaged for each leg. Percent asymmetry was defined as:

$$(\text{Left leg} - \text{right leg}) / \text{right leg} * 100 = \% \text{ asymmetry}$$

## 2.5. Statistical analysis

Means and standard deviation for all mentioned variables were calculated and used as measures of centrality and spread of data. Data was checked for outliers and normality using the Kolmogorov–Smirnov statistic. A one way analysis of variance (ANOVA) as well as Tukey post hoc contrasts was used to detect statistical difference in the variables of interest across the three maturational groups. Ninety five percent confidence levels or an alpha level of 0.05 were used where appropriate.

## 3. Results

The values for the variables of interest in this study can be observed in Table 2. All variables increased in magnitude with maturation, the largest increases noted in work (205%) and power (252%).

The cyclic asymmetries observed during the 30 m sprint on the Woodway treadmill ranged from 14.7% to 26.4% as can be observed in Table 2. When averaged across maturation, asymmetries in horizontal force (15.0%) were found to be significantly ( $p < 0.05$ ) smaller than vertical force (19.7%) and work (19.5%). Furthermore, asymmetries in vertical force were significantly greater than in power (15.4%).

In terms of the between group comparisons for each of the dependent variables, the only variable found to differ significantly between maturation levels was work, the observed asymmetries in the pre-PHV group were substantially greater ( $26.4\% \pm 19.9$ ) than the other two maturation groups ( $14.7 \pm 10.7$  and  $17.3 \pm 16.1$ ).

## 4. Discussion

Inter-limb differences in non-injured youth ranged from 14.7 to 26.4% in the variables of interest whilst running on a non-motorized treadmill. These differences seem high compared to the only other study that has measured asymmetry whilst running on a non-motorized treadmill. Brughelli et al. (2010) reported imbalances of 1.6, 4.9, and 10.7% for vertical forces, horizontal forces, and work in non-injured AFL players measured at 80% of maximum speed respectively. It is difficult to make direct comparisons between these studies as the running protocols used to determine asymmetry differ, however, it seems that there is substantially greater asymmetry in youths. This may be attributed to the greater movement variability and/or the physiological/physical differences associated with maturation (Armstrong et al., 2001, 2000; Forbes et al., 2009; Ioakimidis et al., 2004; Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004). However, this contention is somewhat speculative and research is needed that compares the youth and mature athlete utilizing the same equipment and protocols.

Substantial increases in hormone levels (Forbes et al., 2009; Fraiser et al., 1969; Kraemer, 1988; Ramos et al., 1998; Round et al., 1999) and anthropometric factors (height, weight, muscle mass, etc.) are associated with puberty, and consequently large improvements in strength (Mero et al., 1990), and consequently power output (Armstrong et al., 2001, 2000; Forbes et al., 2009; Ioakimidis et al., 2004; Mero et al., 1990) are known to occur and therefore may challenge coordinated force production and sprint capability, and may in turn affect asymmetry of athletes of different maturity status. The inter-group comparisons for the most part revealed no significant differences between maturation groups in the variables of interest with the exception of work where pre-PHV participants were found to differ ( $p < 0.05$ ) to the mid and post-PHV participants.

Another finding was that the asymmetries varied significantly according to the variable used. That is, when averaged across maturation groups vertical force (19.7%) and work (19.5%) were significantly greater than horizontal force asymmetry (15.0%). Thus asymmetry seems to be directional and variable specific, our findings supporting those of Hewitt, Cronin, and Hume (2012) who found asymmetries to differ significantly ( $p = 0.02$ ) for vertical force (3.1%) as compared to power (9.2%) for an acyclic jumping task.

**Table 2**  
Mean, SD and percent difference between legs for subjects of different maturation status.

	Pre-PHV		Mid-PHV		Post-PHV	
	Mean $\pm$ SD	LCI–UCI	Mean $\pm$ SD	LCI–UCI	Mean $\pm$ SD	LCI–UCI
Horizontal force left (N)	91.6 $\pm$ 17.4	86.1–97.1	127 $\pm$ 17.3	120–134	150 $\pm$ 24.9	143–157
Horizontal force right (N)	88.3 $\pm$ 18.6	82.4–94.1	131 $\pm$ 20.1	124–139	152 $\pm$ 24.0	145–159
%difference	15.4 $\pm$ 14.2	10.9–19.9	14.8 $\pm$ 10.9	10.7–18.9	14.7 $\pm$ 14.3	10.7–18.8
Vertical force left (N)	395 $\pm$ 124	356–434	547 $\pm$ 113	505–590	657 $\pm$ 135	619–695
Vertical force right (N)	360 $\pm$ 131	319–401	507 $\pm$ 94.0	472–542	693 $\pm$ 145	653–735
%difference	18.1 $\pm$ 15.6	18.1–15.6	20.2 $\pm$ 16.8	14.0–26.5	20.8 $\pm$ 15.8	16.4–25.3
Power left (W)	274 $\pm$ 69.5	241–308	504 $\pm$ 92.6	463–545	666 $\pm$ 143	618–715
Power right (W)	264 $\pm$ 79.6	226–303	529 $\pm$ 106	481–576	691 $\pm$ 143	642–739
%difference	14.9 $\pm$ 14.6	10.3–19.5	15.8 $\pm$ 10.9	11.7–19.8	15.5 $\pm$ 14.7	11.4–19.6
Work left (J)	69.1 $\pm$ 20.7	62.6–75.6	114 $\pm$ 25.1	105–124	140 $\pm$ 28.8	132–148
Work right (J)	68.9 $\pm$ 24.9	61.1–76.8	116 $\pm$ 29.3	105–127	145 $\pm$ 32.4	136–154
%difference	*26.4 $\pm$ 19.9	20.1–32.7	14.7 $\pm$ 10.7	10.7–18.7	17.3 $\pm$ 16.1	12.7–21.8

Key: LCI = lower confidence interval, UPI = upper confidence interval, \*significant different from mid- and post-PHV ( $p < 0.05$ ).

It needs to be acknowledged that there are limitations to this study. First, our participants were characterized as athletic or trained and therefore do not necessarily mirror a general population. Second, to calculate true running asymmetry, athletes should have performed over-ground running, their foot strikes recorded by a number of force plates laid in series. However, this methodology is impractical for most laboratories due to the financial outlay required to lay a series of in-ground force plates. It would seem therefore that a non-motorized treadmill provides a relative inexpensive and practical alternative to measure the kinetics and asymmetries whilst running/sprinting. We represented asymmetry over 30 m, however it may be that these asymmetries differ during different phases of the sprint (acceleration, maximum velocity, and/or deceleration) or at steady state running e.g. 80% of maximum velocity. Finally, the analysis of the kinetics was limited by the manufacturer's software and documenting asymmetry in other variables such as leg or vertical stiffness might have been of interest also.

## 5. Conclusion

Only the asymmetry of one variable (work) was found to differ significantly between groups and interestingly the greatest asymmetry was found in the pre-PHV and not the mid- (and/or post-) PHV group as hypothesized. With regards to the magnitude of asymmetry expected when using a NMT with a youth population, on average asymmetries of 17% (95%CI 13.2 lower bound and 21.6% upper bound) are not unusual in non-injured youth athletes whilst performing a running task. However the reader needs to be cognizant that individual player asymmetry is masked when data is presented in such a manner. Therefore, data should remain individualized when assessing athlete strengths and weaknesses for diagnostic and prognostic purposes.

Future research needs to determine if cyclic and acyclic asymmetries are similar in magnitude. If this is true leg asymmetry may be dependent upon the movement task being performed and then functional movement assessments as well as training programs must address movements that are specific to the athletic task of interest. If in doubt, it may be best to develop an acyclic single-leg multi-directional leg power and asymmetry profile as well as a cyclic running profile, which would provide information that drives the individualization of programming.

## Conflict of interest

None declared.

## Ethical statement

The AUT University Ethics Committee approved this study. The reference numbers are 09/291 and 11/149.

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