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Contralateral Leg Deficits in Kinetic and Kinematic Variables During Running in Australian Rules Football Players With Previous Hamstring Injuries

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Abstract

Brughelli, M, Cronin, J, Mendiguchia, J, Kinsella, D, and Nosaka, K. Contralateral leg deficits in kinetic and kinematic variables during running in Australian rules football players with previous hamstring injuries. *J Strength Cond Res* 24(9): 2539–2544, 2010—Contralateral leg deficits between lower limbs during athletic movements are thought to increase the risk of injury and compromise performance. The purpose of this study was to quantify the magnitude of leg deficits during running in noninjured and previously injured Australian Rules football (ARF) players. The players included a group of noninjured ARF players ($n = 11$) and a group of previously injured ARF players ($n = 11$; hamstring injuries only). The players in the injured group (IG) had at least 1 acute hamstring injury in the previous 2 years. The legs of the noninjured players (NIG) were classified as right and left, whereas the legs of the injured players were classified as injured or noninjured. The players ran on a nonmotorized force treadmill at approximately 80% of their maximum velocity (Vmax). For the NIG, there were no significant differences between right and left legs for any of the variables. For the IG, the only variable that was significantly ($p < 0.001$) different between the injured and noninjured leg was horizontal force (175 ± 30 vs. 326 ± 44 N). Furthermore, horizontal force was significantly greater in the noninjured leg (IG) in comparison with either legs in the NIG (19.2% and 20.5%) and significantly less in the injured leg (IG) in comparison with either legs of the NIG (31.5% and 32.7%). In the present study, athletes with previous hamstring injuries had contralateral leg deficits in horizontal but not vertical force during running at submaximal velocities.

Key Words muscle strains, horizontal force, transfer of power, bi-articulate muscles, limb imbalances

Introduction

Contralateral leg deficits usually refer to the relative difference in strength or power between the lower limbs. The assessment of contralateral leg deficits has been widely used in the literature to quantify functional deficits in maximum strength (1,8,19,31). Such deficits are thought to increase the risk of injury and possibly affect athletic performance (9,25). However, the threshold at which a deficit becomes problematic is the subject of conjecture. Contralateral isokinetic strength deficits of greater than 15% are thought to increase the risk of future hamstring muscle strains by up to 2.6 times (4,19). However, the findings from cross-sectional studies have been inconclusive because both significant and nonsignificant contralateral leg deficits have been reported during isokinetic flexion and extension of the hip and knee joints (1,8,9,13,19,25,31). With such contradictions in the literature, it is important to gain more knowledge about contralateral leg deficits in both healthy and injured athletic populations.

As evident from the preceding paragraph, isokinetic dynamometry is the most common form of assessing contralateral leg deficits; however, it is expensive and thought nonspecific to most sport movements (i.e., typically uniarticular, open-chain, and constant velocity muscular contractions). In an attempt to avoid these limitations during assessment, functional tests have been developed that utilize closed chain movements, high, velocities and stretch-shortening cycle (SSC)–type movements (2,24). Tests such as unilateral jumping, hopping, landing, and change of direction have been used to quantify the differences between legs in regard to jump height, jump distance, force production, power production, vertical stiffness, joint movements,

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and flight times (12,15,16,23). Some of these studies have reported significant differences between contralateral legs during functional tests, such as landing and jumping (12,16,23,26). However, these leg deficits were very small in magnitude in regard to between-leg percent differences (i.e., <5.0%) and effect sizes (ES) typically less than 0.50. It has also been suggested that leg deficits of up to 15% are acceptable during jumping, hopping, and landing tasks to progress an athlete through the late stages of a return-to-sport rehabilitation program for anterior cruciate ligament (ACL) injuries (11,14,21). It may be speculated that, although leg deficits may be statistically significant, such differences may not be clinically meaningful or relevant for practitioners.

Contralateral leg deficits have also been reported during human running (3,10) in recreational and endurance-trained athletes. Nonsignificant leg deficits have been reported for center of mass (CM) displacement, contact time, leg stiffness, negative work, and resonance frequency (3,9,30). Conversely, significant leg deficits have been reported for positive work and various ankle-joint kinematic variables (i.e., frontal plane joint angles during landing and take-off and joint-angle displacements) (30). However, no studies have investigated leg deficits in vertical or horizontal force during running in noninjured athletes. Similarly, with regard to the injured athlete, no research has investigated the effects of previous hamstring injuries on leg deficits during running. Thus, the purpose of this paper was to investigate if leg deficits exist in vertical and horizontal force in noninjured and injured Australian Rules football (ARF) players during running at 80% Vmax (maximum velocity). Given that most assessments of deficits measure acyclic movements in the vertical plane, it is of interest whether a dynamic cyclic analysis separating the vertical and horizontal components of force is of diagnostic value to the strength and conditioning practitioner or clinician.

Methods

Experimental Approach to the Problem

To assess leg deficits during running at submaximal velocities in healthy and previously injured (i.e., hamstring injuries) ARF players, the players were asked to run at 80% of their maximal velocity on a nonmotorized treadmill. Comparisons were made between right and left and injured and noninjured legs, within and between players. Leg deficits were measured for the following variables: horizontal force, vertical force, vertical stiffness, leg stiffness, contact times, impulse, resonance frequency, positive work, and vertical CM displacement.

Subjects

Twenty-two ARF players from the Western Australian Football League participated in this study. All athletes had at least 3 years of previous experience in club ARF. Players were screened for previous hamstring injuries and placed in 1 of 2 groups: previously injured and noninjured. The inclusion for the noninjured group (NIG) included players who had not experienced hamstring or any other lower-limb injuries in the previous 2 years. The inclusion criteria for the previously injured group (IG) included: (a) an injury history of 1 or multiple hamstring injuries to 1 leg only; (b) the injury caused the athlete to miss at least 1 week of training; and (c) the injury occurred less than 2 years prior to the testing. The muscle strains ranged from grade 1 to grade 3. The previously injured group included 11 semi-professional Australian Football players (age = 22.4 years; height = 183.0 cm; weight = 84.1 kg), and the NIG included 11 semi-professional Australian Football players (age = 21.9 years; height = 183.5 cm; weight = 84.0 kg). All players provided written, informed consent within the guidelines of the Ethics Committee of Edith Cowan University.

Experimental Protocol

The players ran on a nonmotorized force treadmill (Force Treadmill Dynamometer, Woodway 3.0, Waukesha, Wisconsin, USA). The players wore a harness around their waists, which was connected to a nonelastic tether. The tether was connected to a horizontal load cell, which measured horizontal force, with a "Y"-jointed steel wire. The horizontal load cell was attached to a metal vertical pillar with a sliding gauge. The sliding gauge allowed the horizontal load cell to be adjusted vertically in accordance with the subject's height so that the tether was approximately horizontal to the player's CM during the running bouts. The horizontal load cell was calibrated before and after each testing session using a range of known weights. Treadmill belt velocity was monitored by 2 optical speed photomicrosensors, collected by a tachometer (XPV7 PCB), and analyzed with Force 3.0 software (Innervations Solutions, Joondalup, Australia). Vertical force was measured by 4 individual vertical load cells that were mounted under the running surface. The vertical load cells were calibrated before and after each testing session using a range of known weights. Vertical and horizontal force was collected at a sampling rate of 200 Hz.

All players ran at approximately 80% of their Vmax. The noninjured subjects were used to determine the Vmax. It was felt that asking athletes with previous hamstring injuries to run higher than 80% of their Vmax would be dangerous. Thus, 80% Vmax was chosen as the running velocity for this study as it is commonly used in the literature and has been used in previous studies for previously injured athletes with ACL injuries (14,21). The players were asked to progress to 80% Vmax over a 3-second period and then to maintain their velocity for another 8 seconds. Vertical and horizontal forces were measured during the 8-second period. During the running bouts 12 total steps were recorded and analyzed (Figure 1). In the IG, the previously injured and noninjured legs were analyzed separately (i.e., 6 steps for noninjured and 6 steps for previously injured). The legs were classified as right and left legs for the NIG. For both groups, the 6 peak values were averaged for a final value, and the coefficient of variance (CV) of each variable was calculated as the ratio of the standard deviation (*SD*) to the mean value. The average CVs for vertical and horizontal force production were 2.2% and 4.6%, respectively, for both groups and legs.

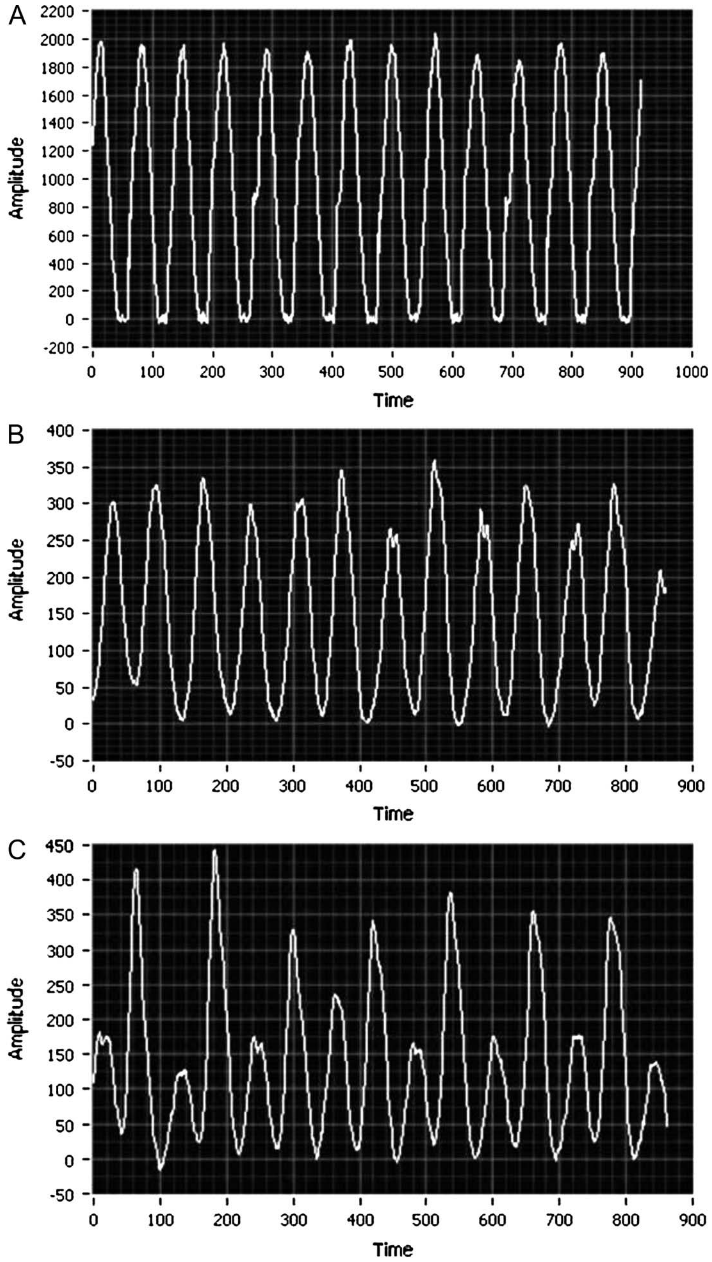

Figure 1. A, Schematic representation of vertical force during running in both groups (i.e., injured group [IG] and noninjured group [NIG]) with no significant leg contralateral leg deficits. B, Schematic representation of horizontal force during running in the NIG with no significant contralateral leg deficits. C, Schematic representation of horizontal force during running in the IG with significant contralateral leg deficits of ~45%.

Data Analysis

The spring-mass model (5,20) was used to investigate the mechanical stiffness parameters of the lower limbs during running. *Vertical stiffness* (k_{vert}) in kN/m was calculated as: $k_{vert} = F_{max}/\Delta y_c$ with F_{max} the maximal ground reaction force during contact (in kN) and Δy_c the vertical displacement of the CM when it attained its lowest point (meters). Vertical displacement was determined by double integration of the vertical acceleration over time (20,22). *Leg stiffness* (k_{leg}) in kN/m was calculated as $k_{leg} = F_{max}/\Delta L$ where F_{max} = maximum vertical force. The change in initial leg length (ΔL) was calculated as: $\Delta L = \Delta y_c + L(1 - \cos\theta)$, where the leg landing angle (θ) was calculated as: $\theta = \sin^{-1}(vCt/2L)$, where v = forward running velocity and L = initial leg length (measured as the distance from the great trochanter to the ground in a standing position). *Contact time (Ct)* was determined from the time (in seconds) the force applied to the treadmill exceeded 0 Newtons and when the force signal returned to 0 Newtons. *Aerial time (At)* was determined from the time between the end of the ground contact period of 1 foot to the beginning of the ground contact period of the contralateral foot. *Effective contact time* (Ct_e) was determined from the time that the vertical force was greater than body weight, and *effective aerial time* (At_e) was determined from the time that vertical force was below body weight.

Statistics

The data were analyzed using SPSS statistical software (SPSS 12, Chicago, Illinois, U.S.A.). Means and standard deviations were used as measures of centrality and spread of data. The percent difference (%) between the right and left leg and between the noninjured and injured leg were determined using the following formula: (high value – low value)/low value × 100 = %. Independent sample *t*-tests were used to determine if significant differences existed between the 2 groups (injured and healthy groups) in terms of age, height, and weight. A 2 × 2 factorial analysis of variance (ANOVA) was used to determine if significant

TABLE 1. Mean (± *SD*) for leg asymmetries in Australian Rules football players during running at 80% Vmax.

	Injured group (IG)		Imbalance (%)	Noninjured Group (NIG)		Imbalance (%)
	Injured leg	Noninjured leg		Right leg	Left leg	
Vertical force (N)	1905 ± 253	1,887 ± 153	1.0	1,905 ± 314	1,892 ± 329	1.6
Horizontal force (N)	175 ± 30*†‡	324 ± 44†‡	45.9	261 ± 43	252 ± 51	4.9
Vertical stiffness (kN/m)	48.8 ± 11.9	45.1 ± 10.9	7.6	50.3 ± 9.7	47.2 ± 10.4	6.5
Leg stiffness (kN/m)	7.2 ± 1.0	7.6 ± 0.9	5.3	8.0 ± 0.9	7.2 ± 0.9	4.2
CM displacement (cm)	3.9 ± 0.9	4.18 ± 0.8	6.7	3.8 ± 0.7	4.0 ± 0.8	5.0
Contact time (s)	0.211 ± 0.03	0.214 ± 0.03	1.9	0.226 ± 0.02	0.214 ± 0.03	3.5
Impulse (J)	222 ± 2.1	217 ± 2.1	4.0	230 ± 2.1	222 ± 1.9	4.2
Positive work (J)	260 ± 2.3	245 ± 2.3	6.9	281 ± 1.9	255 ± 2.7	10.7

*Significantly different ($p < 0.01$) from noninjured leg (Injured Group).
†Significantly different ($p < 0.05$) from dominant leg (Noninjured Group).
‡Significantly different ($p < 0.05$) from nondominant leg (Noninjured Group).

differences existed between groups and legs. Significance was set at $p < 0.05$ with significant interactions further examined using Bonferroni post hoc analysis.

RESULTS

No significant differences were seen between the IG and the NIG for age, height, or weight. For the NIG, there were no significant differences between right and left legs for any of the variables (Table 1). For the IG, the only variable that was significantly different between the injured and noninjured leg was horizontal force (45.9%). Horizontal force was significantly less in the injured leg (175 ± 30 N) as compared to the noninjured leg (326 ± 44 N). When comparing the 2 groups (i.e., IG and NIG), the only variable that was significantly different was horizontal force. Horizontal force was significantly greater in the noninjured leg (IG) in comparison with the right and left legs in the NIG (19.2% and 20.5%). In addition, horizontal force was significantly less in the injured leg (IG) in comparison with the right and left legs of the NIG (31.5% and 32.7%). It should be noted that some of the subjects in the NIG (i.e., 3 athletes) had greater vertical force values in 1 leg and greater horizontal force values in the contralateral leg. Thus, right and left legs were compared in the NIG, as opposed to dominant and nondominant legs.

DISCUSSION

The purpose of this study was to quantify the magnitude of leg deficits during running in noninjured and previously injured ARF players. No significant differences were found for any variable between right and left legs in the NIG. In the IG, the only variable that was significantly different between the legs was horizontal force.

With regard to the expected deficits between contralateral legs in noninjured athletes, it was thought that leg deficits might exist during human running because Cavanagh et al. (7) proposed that o1 leg behaves like a spring (i.e., greater positive work, CM displacement, and knee flexion) and the other leg acts like a stick (i.e., greater leg stiffness) during running. However, researchers have reported no significant leg deficits for CM displacement, negative work, resonance frequency, leg stiffness, or contact times during running at submaximal velocities in endurance-trained athletes (3,10,30).

The only variables that have been reported to be significantly different between legs in noninjured athletes were positive work and various ankle-joint kinematic variables (10,30). Dalleau et al. (10), reported that the spring leg produced significantly greater positive work than the stick leg in recreationally trained athletes running at 90% of their maximum aerobic capacity. These findings could be explained by the fact that positive work was calculated with both vertical and horizontal velocity and displacement of the CM. It is conceivable that the horizontal contribution on the CM had a greater effect on the leg deficits because previous research (3,10) has shown that vertical CM displacement is not significantly different between legs during running. This research was the only study to our knowledge that has assessed (a) leg deficits in vertical or horizontal force production during running and (b) leg deficits during running in field-sport athletes, who perform a mixture of training methods (i.e., explosive training and endurance training). Although the contralateral leg differences of the noninjured players ranged between 3.0 to 11.0% in the variables of interest in this study, none of these variables were found to differ significantly.

Some authors have recommended that injured athletes (e.g., ACL injuries) must reduce leg deficits to less than 15% to return to sport or progress through rehabilitation programs during quantifiable tests such as jumping for distance (single and multiple jumps), crossover jumps, timed jumps more than 6 meters, vertical force during dropping, modified agility T-test (MAT), and power during vertical jumping for athletes to progress through a return-to-sport rehabilitation program (11,14,21). However, it is unclear as to how threshold values such as 15% are derived and whether all injuries have the same threshold. The percent difference for various tests and the ability to use quantifiable tests (as opposed to subjective/qualitative tests) would be useful for practitioners working with injured or at-risk athletes. There are few objective/quantifiable tests that are used for progressing athletes with hamstring injuries through a rehabilitation program or identifying athletes at risk for future hamstring injuries. Thus, finding variables that are not significantly different during human running is just as important as identifying variables that are significantly different. It seems that contralateral leg deficits of ≤11% are acceptable for the variables investigated in this research.

For the injured athlete, previous research has reported that isokinetic torque during knee flexion does not decrease after hamstring injuries (6,9). It has also been shown that the ratio of quadriceps torque and hamstring torque was not significantly altered after hamstring injuries (6). Conversely, prospective studies have suggested that contralateral leg deficits of greater than 15% during isokinetic knee flexion increase the risk of hamstring injury (4,19). No previous studies, to our knowledge, have assessed leg deficits during running after hamstring injuries. The present study found that Australian Football players with previous hamstring injuries had significant deficits in horizontal force (45.9%) (Figures 1B and 1C). No other significantly different leg deficits were seen for any other variable measured. Furthermore, horizontal force was significantly less for the injured leg in comparison with the right and left legs in the NIG. The noninjured leg appeared to compensate with significantly greater horizontal force than the right and left legs in the NIG. Thus, the NIG had leg deficits of less than 5.0% in horizontal force, and IG had leg deficits of 45.9% when running at 80% Vmax.

We feel it is important to mention a few limitations of the present study. First, most hamstring injuries occur during the late swing phase of Vmax running. Thus, assessing leg asymmetry during Vmax running, as opposed to submaximal running velocities, would appear to be more valid. However, because previous hamstring injury is a major risk factor for future injury, we felt that running should be performed at submaximum velocities to reduce the risk of injury during testing. Second, the present study did not measure leg deficits before the hamstring injuries occurred in the injured group. Thus, it is impossible to determine if the leg asymmetries are the result of hamstring injury or vice versa.

Practical Applications

It is concluded that for this sample of noninjured ARF players, significant leg deficits in the variables of interest were not observed during running at 80% Vmax. The only variable that was significantly different between legs during running was horizontal force production in the hamstring-injured group of ARF players. Furthermore, there may be an increase in horizontal force capability in the noninjured leg as a possible compensatory adaptation to the hamstring injury. In terms of injury prevention and diagnosis, it may be of great value for practitioners and clinicians to assess horizontal force production during running. This type of assessment may be used to identify potential injury incidence in athletes and to monitor the effects of a return-to-sport rehabilitation program and/or specific training interventions. Whether a unilateral horizontal jump may provide similar insight into deficits and injury potential may be worth exploring.

Future research should investigate the effects of previous hamstring injuries on the lumbo–pelvic–hip complex (i.e., anterior pelvic rotation and hip extension range of motion) using 3-dimensional videography in combination with kinetic information on leg deficits (i.e., vertical and horizontal force production) during running. Although much is known about the influence of rotating joints on the vertical and horizontal translation of the center of mass during running, little is known about how injury affects these mechanics (17,18,22). Schache and colleagues (27–29) have suggested that altered lumbo–pelvic–hip motion could lead to muscle strain injury. Longitudinal prospective studies are also needed to determine if leg deficits in horizontal force increase the risk of hamstring injuries. Future research should also investigate the magnitude of leg deficits in injuries other than hamstrings, using a similar methodology to this study. Such an approach may result in greater insight as to those variables that are of greatest diagnostic benefit and also the magnitude of interlimb differences that are of practical relevance.

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