

Jones, Paul A. and Bampouras, Theodoros (2010) A comparison of isokinetic and functional methods of assessing bilateral strength imbalance. *Journal of Strength and Conditioning Research*, 24 (6). pp. 1553-1558.

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Manuscript title: A comparison of isokinetic and functional methods of assessing bilateral strength imbalance.

Running Head: Bilateral strength imbalance

Laboratory: Sports Biomechanics, School of Health & Social Sciences, University of Bolton

Authors: Paul A. Jones, MSc, CSCS¹ and Theodoros M. Bampouras, MSc²

Departments:

¹ School of Health & Social Sciences

² School of Sport

Institutions:

¹ University of Bolton, United Kingdom

² University of Cumbria, United Kingdom

Corresponding author: Paul Jones, School of Health & Social Sciences, University of Bolton, Deane Road, Bolton BL3 5AB, Lancashire, United Kingdom / +44 1204 903640 / P.Jones@bolton.ac.uk

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ABSTRACT

Muscle strength imbalances have been linked with poor agility performance and higher injury risk. Isokinetic dynamometry has been used to investigate such imbalances; however this method is impractical and inaccessible for most strength and conditioning coaches. The aim of the study was to compare isokinetic dynamometry with functional field tests for assessing bilateral strength imbalance. Thirteen male athletes from various sports (mean \pm SD: age 21 ± 1.1 years, height 179.8 ± 7.0 cm, body mass 80.8 ± 9.7 kg) participated in the study. Knee flexor and extensor strength at $60 \text{ deg}\cdot\text{s}^{-1}$ was assessed for both limbs with the use of isokinetic dynamometry. Field tests involved seated unilateral leg press, horizontal hop, single leg vertical and drop jumps. Significant differences ($p < 0.01$) were found when comparing strength dominant and non-dominant limbs for all strength measures, ranging from 4.5% (hop test) to 12.4% (eccentric extension). No significant differences between the right and left limbs were found ($p > 0.05$). No significant relationships between strength dominant / non-dominant ratios of isokinetic variables and the field tests were evident ($p > 0.05$). The findings provide support for the use of field tests to detect imbalances between lower limbs, but the ultimate choice of test used should depend on the specific strength quality that predominates in the sport.

Keywords: asymmetry, field test, injury risk, isokinetic strength

INTRODUCTION

Muscular imbalance is a term frequently used in the fields of rehabilitation as well as performance sport, describing substantial deviation from normative data or muscle performance differences between limbs (11, 29). Handedness, previous injury, or specific sport demands, have been suggested as possible reasons that could result in the development of bilateral muscle strength imbalances among athletes (22, 28). Several previous studies have shown side-to-side strength imbalances to be present in well-trained athletes (10, 18, 22, 25, 28).

Previous studies have linked bilateral strength imbalance with injury. Knapik et al. (17) found that athletes had a higher injury rate with a knee flexor or hip extensor imbalance of 15% or more on either side of the body. Side-to-side strength imbalance have been suggested as a risk factor for anterior cruciate ligament injury in female athletes (7, 14, 21), while hamstring injuries were shown to be associated with low hamstring muscle side to side peak torque ratio at 60 deg·s⁻¹ (24).

In addition to the higher injury risk associated with muscular imbalances (17, 24), athletic performance may also be impaired. However, limited studies have compared the effect of bilateral muscle strength imbalance in terms of performance. Young et al. (34) investigated strength and power determinants of agility performance and found participants who turned faster to one side tended to have a reactive strength dominance in the leg responsible for the push-off action. In addition, Flanagan and Harrison (9) concluded that muscle imbalances, generated by higher leg-spring stiffness for the preferred leg, will result in different explosive

jump performances between limbs. Being equally proficient in turning quickly to either sides or using either leg to jump / push off is crucial for an athlete to enhance on-field performance, hence such imbalances are undesirable.

Perhaps one reason for this lack of information is that traditionally, bilateral strength imbalance has been investigated by isokinetic dynamometry (10, 18, 25, 26, 28, 30). However, this method is often impractical for strength and conditioning coaches and physiotherapists, due to the need for specialised equipment and the time-consuming nature of isokinetic assessment. In addition, isokinetic dynamometry excludes the holistic impact of qualities such as power, reactive strength or skill performance, which may affect the imbalance measures (6, 12). Previous research (22) has suggested that functional laboratory-based tests (bilateral and unilateral vertical jumps and bilateral squats) could all detect significant differences between dominant and non-dominant legs. In addition, it was found that a simple 5-hop field test could also potentially detect significant dominant to non-dominant imbalances.

Attempts have been made to examine a range of field tests that could help assess lower limb function (12, 22, 25, 27), in order to provide practitioners a simple and cost-effective alternative option. However, the findings from these studies present an unclear picture as some contradictions have been reported. Single-leg hop test scores have been found not to be strongly related to isokinetic assessment results (12, 25, 27), however its use was suggested (12, 27). The triple-hop was found to be a good predictor of clinical strength and power performance (25, 27) but it has been shown to have low (25) to moderate (27) correlations with isokinetic performance. Finally, other field tests (5-hop, vertical jump, one-leg rising and square-hop) were not correlated with isokinetic assessment (22, 25, 27). In addition to the

inconclusive results, Murphy and Wilson (20) stressed the importance of functional tests being able to assess changes in muscular performance following a training or rehabilitation intervention.

Given the aforementioned issues with isokinetic testing as well as the specificity of functional tests (12), the possibility of field tests being able to assess muscular imbalance warrants further investigation. Other field tests in addition to the ones above must be examined, to assist in the creation of a battery of tests. Hence, the aim of this study was twofold; firstly, to investigate whether a range of commonly used unilateral functional field tests can reveal muscle strength imbalance of the lower limbs and secondly, to investigate whether there is any relationship between the various muscle strength qualities assessed in this study. It is hypothesised that functional field tests can detect bilateral lower limb strength asymmetry as typically found by isokinetic dynamometry.

METHODS

Experimental Approach to the Problem

The present study used a cross sectional design to investigate whether a range of standard unilateral functional field tests such as leg press, horizontal hop, vertical and drop jumps can reveal muscle strength imbalances of the lower limbs similar to that found by isokinetic dynamometry. Literature has previously used either one test (12) or a combination of unilateral and bilateral tests (22, 25, 27). It is therefore important to assess the strength qualities of relevant field tests in a purely unilateral way, to examine the possibility of compiling a battery of tests. For the various tests used, the performance of each leg was

obtained for subsequent comparison between left and right and strength dominant (strongest leg) and non-dominant (weakest leg) limbs to examine the imbalance between limbs. Correlational analyses were conducted to determine relationships between imbalance ratios calculated from isokinetic dynamometry results to that calculated from the functional field tests.

Subjects

Thirteen male university sports participants (mean \pm SD: age 21 ± 1.1 years, height 179.9 ± 7.0 cm, body mass 80.8 ± 9.7 kg) took part in the study. The subjects were all experienced, competitive athletes in sports with a high contribution of anaerobic power and where unilateral lower limb neuromuscular performance was important to successful performance. All subjects were free of lower limb injuries and they were in the competitive phases of their respective annual plans. The study was approved by the Departmental Ethics Committee and all subjects provided written informed consent to participate.

Procedures

Testing took place over a two-day period with 1) seated unilateral leg press (LP) and horizontal single leg hop (HOP) for distance, 2) unilateral isokinetic concentric and eccentric knee extensor and flexor strength (CON EXT, ECC EXT, CON FLEX and ECC FLEX, respectively) and single leg vertical jump (VJ) and drop jump (DJ), performed on separate days. The test order for either limb was counterbalanced for all tests to reduce order bias. For all tests except the isokinetic assessment, two trials were performed on each limb with the best score used for subsequent analysis.

All subjects were familiarised with the procedures prior to testing. The subjects had been instructed to refrain from strenuous exercise for forty eight hours prior to testing and to avoid food and caffeine intake for two hours preceding the assessments. All subjects completed testing at the same time of day to avoid any circadian rhythm effects (2). Finally, all equipment utilised was calibrated according to manufacturers' standardised procedures.

Isoinertial strength describes the phenomenon where force is generated by a muscle or muscle group when accelerating a constant gravitational load (16). Isoinertial strength was assessed using a Concept II dynamometer (Concept II Ltd, Nottingham, UK) for LP. Initial data in our laboratory from twenty one athletic subjects (with similar characteristics to the sample of this study) who performed the leg press on two separate occasions, yielded an ICC (3,1) = 0.914. The subjects were seated with their back straight and in contact with the backrest at all times and arms grasping handles attached to the seat. The range of motion was from full knee extension to approximately 90° of knee flexion. Execution form was maintained the same for all subjects and trials. The scores obtained were in kilogrammes, as the dynamometer calculated force by monitoring the acceleration of the known-resistance flywheel.

HOP has been previously used for monitoring rehabilitation of knee-injured athletes (23) with generally high reliability reported; ICC $r = 0.96$ (1, 6), SEM = 4.56 cm (6). The test required the subjects to jump from and land on the same leg and hold the landing position for a further 2 seconds; otherwise the jump was deemed invalid. The subjects were instructed to jump for maximum distance and the distance travelled of the valid jumps was recorded to the nearest centimetre.

VJ and DJ were performed on each leg, whilst maintaining hands on hips to isolate the contribution from the leg muscles (13). The test-retest reliability of using contact mats to determine single leg vertical jump variables has previously shown to be reasonable [ICC 2,1 >0.89] (27). For the DJ's subjects were instructed to step off, rather than jump, from the raised platform to ensure a homogeneous drop distance for each DJ trial. Previous research (33) has shown that instructions on how to perform drops jumps can have implications on the actual strength quality being measured. Hence, subjects were instructed to perform a 'bounce' drop jump aiming for maximum height and minimum contact time. The height of the raised platform was 0.2 m. All measures were determined using a Newtest Power timer jump mat (Newtest Oy, Oulu, Finland).

Knee flexor and extensor muscle strength of both limbs, was assessed at $60 \text{ deg}\cdot\text{s}^{-1}$ using an isokinetic dynamometer (Contrex, Switzerland). The subjects were seated with the hip joint at 90° (supine position = 0°). The centre of rotation of the knee was aligned with the dynamometer arm rotation axis while extraneous movement was prevented by straps, positioned at the hip, shoulders and tested thigh. Measurements were corrected for gravity and peak torque was obtained from 4 repetitions for both concentric and eccentric contractions, as previously recommended (3). Peak torque was taken from 0 to 90° of knee flexion (full knee extension = 0°). The order of tests was concentric extensor, concentric flexor, eccentric extensor and eccentric flexor.

Statistical analyses

Normality of data was examined using the Kolmogorov-Smirnov test and confirmed for all variables with the exception of strength imbalance ratios for HOP and isokinetic eccentric

extensor tests. Two-tailed Student's *t*-tests were used to compare right and left leg and strength dominant and non-dominant limbs for each strength measure. Imbalance between right and left limbs was calculated for each variable by the formulae $(\text{Right leg} - \text{Left leg} / \text{Right leg} \times 100)$. Imbalance between strength dominant (D) and non-dominant (ND) limbs was calculated using $(D - ND / D \times 100)$. Pearson's product moment correlation were used to explore relationships amongst strength ratios (D:ND), while Spearman's rho was used to investigate relationships with HOP and isokinetic eccentric extensor tests. All statistical analysis was performed in SPSS v 14 (Chicago, Illinois).

RESULTS

Significant differences were found when comparing D and ND limbs for all strength measures (Table 1 to 3; $P < 0.01$) with effects sizes (eta-squared values ranging from 0.41-0.79), indicating a true effect (19). No significant differences were observed between right and left limbs (Table 1).

TABLE 1 TO TABLE 3 ABOUT HERE

Pearson correlation analysis revealed a significant relationship in D:ND ratio between LP and DJ ($r = 0.698$, $df = 11$, $p < 0.05$) However, there were no significant relationships between isokinetic variables and the functional field tests used in the study ($P > 0.05$).

DISCUSSION

The aim of the present study was to investigate the application of various unilateral field tests for the assessment of lower limb muscle strength imbalance. The study compared a range of functional field-based tests with the traditional isokinetic dynamometry method of assessing lower leg imbalance. Significant differences were found between strength dominant and non-dominant limbs for all methods of assessment, but no significant differences were observed between right and left limbs, substantiating previous research (22). The results suggest the field tests used in the present study can detect lower limb strength imbalance substantiating the hypotheses of the present study. However, no significant relationship between isokinetic and the field test variables were evident, suggesting that each strength imbalance ratio is independent of each other and it measures distinct strength imbalance ratios.

The results of the present study provide further support to previous findings (10, 18, 22, 28) of the presence of muscular imbalance in athletic individuals. In particular, Newton et al. (22) found significant differences between strength D-ND limbs in peak and average force achieved during bilateral squat, single and bilateral vertical jumps, isokinetic extension and flexion peak torque at 60 and 240 deg·s⁻¹ and a 5 hop test, but not between right and left limbs. The present study produced similar findings in that all tests found significant differences between strength dominant and non-dominant limbs. Moreover, the percentage imbalance values in Newton et al (22) ranged from 4 to 16% across the various tests, which compares favourably with the range of 4% to 12% of the current study.

The present study found no significant differences between right and left limbs for all tests, despite all subjects being right handed and preferring the right limb in throwing and kicking tasks. It is likely that, despite all subjects being 'right sided', some subjects were actually left leg strength dominant, nullifying strength differences when averaged across the groups.

Schlumberger et al. (29) suggested against comparing preferred and non-preferred limb strength, as limb dominance may not actually have sufficient external validity. Indeed, Österberg et al. (25) found no difference in strength when comparing right-left and preferred-non preferred sides in female footballers. However, weak-strong leg comparisons yielded a range of side differences between 4 and 16%.

In relation to the above point, another reason for lack of any significant differences between right and left limbs could be the low homogeneity of athletic background of the participants, despite the sample size being similar to relevant previous studies (16, 22, 30). The subjects in the present study preferred to use the right side for throwing and kicking and hence, strength asymmetry was not a result of limb preference. However, they were of various sports and therefore, the development of a strength dominant limb could be the result of the specific training effect of playing the sport on a regular basis (9, 22, 28); again, nullifying strength differences between right and left limbs and preferred and non-preferred limbs with different sports participants. Indeed, there was some variation in right to left leg strength dominance across the various tests. If the subject sample was more homogeneous, it is suggested that strength imbalance patterns may have shown a consistent trend toward preferred and non-preferred sides as has previously been found (10, 28). Future research needs to investigate potential imbalance patterns that may develop across sports.

No significant relationships between imbalance ratios were detected from isokinetic dynamometry and the field tests. Our findings largely agree with Newton et al. (22) who found that a 5 hop test imbalance ratio had a moderate, but non-significant relationship with isokinetic concentric flexion ($r = 0.573$, $r=0.381$) and extension ratios ($r = 0.365$, $r = -0.147$) at speeds of 60 and 240 $\text{deg}\cdot\text{s}^{-1}$, respectively. In addition, they reported a moderate, but non-

significant correlation between average and peak force during a single leg vertical jump and isokinetic variables.

The lack of any significant relationship between any imbalance ratio, suggests that although the field tests can detect imbalances, their magnitude can not be adequately determined. This is probably due the fact the field tests are indeed more functional involving multiple joints and antagonist co-contractions compared to isokinetic tests, where muscle groups are isolated. Furthermore the fields tests are assessing different muscle strength qualities, namely power (vertical jump and hop tests) or reactive strength (drop jumps). Hence, subjects may indeed develop strength imbalance toward a particular muscle strength quality depending on how they perform in the sport. This may have implications for screening athletes in that the choice of tests should coincide with the type of muscle strength quality used in their sports action.

Future research is needed to confirm the suggested link between bilateral strength asymmetry with injury and performance, which is as yet inconclusive (5, 31). In particular, if imbalance is proven to have negative effects on performance and injury risk, how much imbalance is deemed to be detrimental? Barber et al (4) using normal subjects and Noyes et al (23) using ACL-deficient patients (and functional tests similar to the present study), established an imbalance index of 85% (weaker leg as a % of stronger leg), answering the question with regards to the 'imbalance threshold' for injury risk, which substantiates recommendations for isokinetic testing of 15% difference between limbs (8, 17, 32). However, despite measurements of limb strength in athletic populations (10, 35) a similar index for detrimental performance has not been developed.

PRACTICAL APPLICATIONS

In summary, the results of the present study support the use of simple field test measures to detect lower limb strength asymmetry, allowing strength coaches or physiotherapists to quickly determine whether an athlete is in need of a training programme that emphasizes unilateral exercises in an effort to isolate each side to improve the bilateral imbalance. These tests maybe useful in monitoring training improvements or recovery following lower-limb injury. However, the current battery of tests did not show correlation with the results obtained from isokinetic dynamometry. Therefore, sports scientists and strength and conditioning coaches should; firstly, be aware of the need to assess lower-limb strength imbalance in the appropriate and more suitable way and secondly, if sufficient time and equipment is available consider assessing lower-limb strength imbalance by due consideration of the muscle strength qualities that predominates in the sport.

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Table 1. Jump tests scores for right, left, dominant and non-dominant limbs. Data is presented in mean \pm SD.

Variable	Right leg (cm)	Left leg (cm)	Imbalance (%)	D (cm)	ND (cm)	Imbalance (%)
HOP (cm)	167.15 \pm 17.3	161.62 \pm 15.8	3.11 \pm 5.46	168.31 \pm 17.5	160.46 \pm 15.1*	4.47 \pm 4.3
VJ (cm)	21.9 \pm 5.6	22.1 \pm 5.3	-1.89 \pm 15.84	23.2 \pm 5.3	20.8 \pm 5.4*	10.40 \pm 7.65
DJ (cm)	23.9 \pm 7.4	23.2 \pm 5.7	0.98 \pm 14.46	25.0 \pm 7.1	22.2 \pm 5.7*	10.57 \pm 8.63

Note: VJ = single leg vertical jump, DJ = single leg drop jump,

* Indicates significant difference at $p < 0.01$ when comparing the two limbs

Table 2. Seated leg press for right, left, dominant and non-dominant limbs. Data is presented in mean \pm SD.

Variable	Right (kg)	Left (kg)	Imbalance (%)	D (kg)	ND (kg)	Imbalance (%)
LP (kg)	103.8 \pm 15.8	99.2 \pm 18.3	4.42 \pm 12.72	105.6 \pm 14.1	97.4 \pm 18.9*	8.47 \pm 9.8

* Indicates significant difference at $p < 0.01$ when comparing the two limbs

Table 3. Isokinetic knee extension and flexion peak torques at 60 %s for right, left, dominant and non-dominant limbs. Data is presented in mean \pm SD.

Variable	Right (Nm)	Left (Nm)	Imbalance (%)	D (Nm)	ND (Nm)	Imbalance (%)
CON EXT (Nm)	224.5 \pm 41	213.9 \pm 46.7	4.63 \pm 14.60	230.4 \pm 36.8	208.1 \pm 47.9*	10.53 \pm 9.44
CON EXT (Nm)	164.6 \pm 25.9	159.3 \pm 19.6	1.88 \pm 13.86	170.8 \pm 21.5	153 \pm 20.8*	10.30 \pm 5.69
ECC EXT (Nm)	261.4 \pm 80.8	238.6 \pm 78.6	8.32 \pm 15.1	266.1 \pm 78.6	233.9 \pm 79*	12.43 \pm 11.37
ECC FLEX (Nm)	184.6 \pm 40.8	186.1 31.8	-2.76 \pm 13.99	194 \pm 36.1	176.8 \pm 34.8*	8.81 \pm 8.01

Note: CON = concentric, ECC = Eccentric, EXT = Extensor, FLEX = Flexor.

* Indicates significant difference at $p < 0.01$ when comparing the two limbs