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ASSESSING MUSCLE STRENGTH ASYMMETRY VIA A UNILATERAL STANCE ISOMETRIC MID-THIGH PULL

Original Investigation

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Abstract

Purpose: The purpose of this study was to investigate the within-session reliability of bilateral and unilateral stance isometric mid-thigh pull (IMTP) force-time characteristics including peak force (PF), relative PF and impulse at time bands (0-100, 0-200, 0-250 and 0-300 ms); and to compare isometric force-time characteristics between right and left and dominant (D) and non–dominant (ND) limbs. **Methods:** Professional male Rugby league and multi-sport collegiate male athletes (n=54, age 23.4 ± 4.2 years, height 1.80 ± 0.05 m, mass: 88.9 ± 12.9 kg) performed 3 bilateral IMTP trials, and 3 unilateral stance IMTP trials per leg on a force plate sampling at 600 Hz. **Results**: Intraclass correlation coefficients (ICC) and coefficients of variation (CV) demonstrated high-within session reliability for bilateral and unilateral IMTP PF (ICC =.94, CV = 4.7–5.5%). Lower reliability measures and greater variability were observed for bilateral and unilateral IMTP impulse at time bands (ICC =.81-.88, CV =7.7-11.8%). Paired sample t-tests and Cohen's *d* effect sizes revealed no significant differences for all isometric force-time characteristics between right and left limbs in collegiate male athletes (p >.05, *d* ≤0.32) and professional rugby league players (p >.05, *d* ≤0.11), however significant differences were found between D and ND limbs in male collegiate athletes (p <.001, *d* = 0.43–0.91) and professional rugby league players (p < .001, *d* = 0.27–0.46). **Conclusion:** This study demonstrated high within-session reliability for unilateral stance IMTP PF; revealing significant differences in isometric force-time characteristics between D and ND limbs in male athletes.

Keywords: peak force, impulse, imbalance, reliability

Introduction

Muscle strength asymmetry (MSA) refers to the relative strength differences and deficits between limbs,[1] with a strength discrepancy of 10-15% or more between two sides considered to represent a potentially problematic asymmetry.[2] Higher MSA indexes have been suggested to place athletes at a greater risk of injury,[3 4, 5] conversely researchers have demonstrated no connection between MSA and injury.[6, 7] However, there is no specific value in the literature that represents the threshold between injured and non-injured athletes, or values that definitively identify an increased injury risk in athletes.[8] It should be noted that asymmetries may be a positive adaptation of the sport, developed by specific sporting demands.[9] In terms of athletic performance previous studies have also shown MSA can negatively impact performance during change of direction,[10] vertical jumping,[11, 12] and kicking.[13] However, asymmetry index values for athletic performance measures have yet to be established.[14]

Muscle strength asymmetry has typically been assessed in athletes via isokinetic dynamometry,[3, 14] vertical jump,[12] and multidirectional jump and hop tasks;[15] with research suggesting that the magnitude of MSA are task dependant.[14, 15] More recently researchers have investigated isometric bilateral asymmetries through isometric squat[13, 16] and isometric mid-thigh pull (IMTP)[11, 17-19] assessments via a dual force plate system. Interestingly, isometric asymmetrical differences have been observed between dominant (D) and non-dominant (ND) limbs for peak force,[11, 17-19] and time-specific force values,[18, 19] with researchers reporting larger asymmetries in weaker athletes[16-18] and female athletes[18, 19] in comparison to stronger athletes. Moreover, larger asymmetries have been associated with lower jump heights and lower peak power in loaded and unloaded jumps.[11] However, block periodised strength training has been shown to reduce bilateral asymmetries in weaker athletes.[16] Therefore, the assessment of lower limb MSA allows scientists and practitioners to monitor and identify higher imbalanced athletes to subsequently design effective training programs to reduce strength imbalances. This could potentially reduce risk of injury and improve athletic performance.

Jumping, sprinting and change of direction (COD) movements are unilateral, requiring unilateral propulsive force production. Researchers have investigated unilateral force production through unilateral jump assessments in relation to athletic performance tasks [10, 20] and to investigate imbalances between lower limbs.[15, 21] To our knowledge, previous investigations have only assessed unilateral isometric force-time characteristics via an unilateral isometric squat[13, 22, 23] demonstrating high reliability measures. However, as IMTP assessments are becoming more common in testing batteries in various athletic populations,[18, 24] and yield high reliability and low measurement error in force-time variables;[24, 25] it is somewhat surprising that a unilateral stance IMTP has yet to be investigated for assessing MSA.

As previously stated bilateral asymmetries have been established during bilateral IMTP assessments via a dual force plate system, [11, 18, 19] however a unilateral stance IMTP would allow direct comparisons between left and right limbs to establish any MSA indexes and the identification of D and ND limbs. Furthermore, given the unilateral force production requirements of sprinting, jumping and COD movements, arguably a unilateral stance IMTP would be more specific to these dynamic sporting movements. Although the relationship of MSA and injury risk remains inconclusive, from a performance perspective it would be advantageous being equally proficient at producing force in both lower limbs,[14] given the unpredictable nature of multidirectional sports where athletes must change direction, jump and land off either limb in response to stimuli.

The aims of this study were firstly to assess the within-session reliability of bilateral and unilateral IMTP force-time characteristics (Peak force [PF], relative PF, impulse at time bands 0-100, 0-200, 0-250, 0-300 ms). Secondly, to compare left and right and D and ND limbs to determine if any significant differences and imbalances were present between limbs. Thirdly, to establish normative MSA ranges for male collegiate athletes and professional male rugby league players. It was hypothesized that the unilateral IMTP would demonstrate high reliability, similar to the bilateral IMTP. Further, it was hypothesized that no significant differences will be found in isometric force-time characteristic between left and right limbs, but that significant differences would be observed between D and ND limbs.

Methods

Subjects

54 male athletes consisting of 35 professional male rugby league players (age 24.2 ± 4.8 years, height 1.81 ± 0.06 m, mass 94.5 ± 11.2 kg) and 19 collegiate male athletes (soccer n=7, rugby n=2, boxing n=2, weightlifting n=2, water polo n=1, cricket n=1, judo n=2, American football n=2) (age 21.7 ± 2.3 years, height 1.80 ± 0.05 m, mass 78.4 ± 7.9 kg) provided informed consent to participate in this study which was approved by the institutional review board. All subjects were familiar with the IMTP and possessed >2 years resistance training experience. At the time of testing, the rugby athletes were at the end of pre-season and collegiate athletes were currently in season.

Design

A within subjects design was used to determine any significant differences in isometric force-time characteristics (PF, relative PF, impulse at time bands 0-100, 0-200, 0-250, 0-300 ms) between left and right and D and ND limbs during the unilateral IMTP; and to determine MSA indexes between limbs. Subjects performed three maximal bilateral IMTPs, and 3 unilateral stance IMTP trials per leg on a force plate sampling at 600 Hz. Within-session reliability was assessed for all isometric force-time characteristics for both bilateral and unilateral IMTPs.

Procedures

Pre-isometric warm up

All subjects performed a standardized warm-up outlined in previous research,[26] comprising of 5 minutes of dynamic stretching before advancing to dynamic mid-thigh clean pulls. One set of 5 repetitions was performed with an empty barbell (Werksan Olympic Bar, Werksan, Moorsetown, NJ, USA) followed by 3 bilateral isometric efforts at perceived intensities of 50%, 70%, and 90% of maximum effort, interspersed with 1-minute recoveries.

Bilateral and unilateral isometric mid-thigh pull protocol

Bilateral IMTP testing followed similar protocols used in previous research.[27] The IMTP testing was performed on a portable force plate sampling at 600 Hz (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia) using a portable IMTP rack (Fitness Technology, Adelaide, Australia). Sampling as low as 500 Hz has been shown to produce high reliability measures for isometric force-time variables.[26] The force plate was interfaced with computer software [Ballistic Measurement System (BMS)] which allowed direct measurement of force-time characteristics.

For the bilateral stance IMTP testing, a collarless steel bar was positioned to correspond to the athlete's second-pull power clean position[24] just below the crease of the hip. The bar height could be adjusted (3 cm increments) at various heights above the force plate to accommodate different sized athletes. Athletes were strapped to the bar in accordance to previous research[28] and positioned in their self-selected mid-thigh clean position established in the familiarization trials whereby feet were shoulder width apart, knees were flexed over the toes, shoulders were just behind the bar, and torso was upright.[26] Researchers have demonstrated that differences in knee and hip joint angles during the IMTP do not influence kinetic variables[25] justifying the self-selected preferred mid-thigh position. All subjects received standardized instructions to pull as fast and as hard as possible and push their feet into the force plate until being told to stop, as these instructions have been shown to be optimal in producing maximum PF and RFD results.[28] Once the body was stabilised (verified by watching the subject and force trace) the IMTP was initiated with the countdown "3, 2, 1 pull," with subjects ensuring that maximal effort was applied for 5 seconds based on previous protocols;[24, 28] data was collected for a duration of 8 seconds. Minimal pre-tension was allowed to ensure there is no slack in the body prior to initiation of pull. Verbal encouragement was given for all trials and subjects. Subjects performed a total of 3 bilateral maximal effort trials and interspersed with 2-minute recoveries.

Unilateral stance IMTP testing followed the same procedures outlined for bilateral IMTP testing however was only performed with one foot on the force platform with the other limb flexed 90° at the knee. Subjects were positioned at the same hip and knee joint angle established during bilateral testing. Subjects were instructed to maintain balance and pull as fast and as hard as possible and pushing their single foot into the force plate. Subjects performed a total of six unilateral maximum effort trials (3 with left and right limbs each) in an alternating order, interspersed with 2-minute recoveries. Any trials whereby subjects lost balance were excluded, and further trials were performed after a further 2-minute rest period.

Isometric Force-Time Curve Assessment

Isometric force-time data was analysed via BMS software. The maximum force recorded during the 5-second bilateral and unilateral IMTP trials was reported as PF. Relative PF was calculated PF / body mass. Impulse at 100 (IP 100), 200 (IP 200), 250 (IP 250) and 300 (IP 300) ms were also calculated (area under the force-time curve for each window) from onset of contraction (40 N threshold) and have demonstrated high reliability measures. [25, 27]

Statistical Analyses

Statistical analysis was performed using SPSS software version 22 (SPSS, Chicago, Ill, USA) and a custom reliability spreadsheet.[29] Normality was confirmed for all variables using a Shapiro Wilks-test. Within-session reliability was assessed via intraclass correlation coefficients (ICC), 95% confidence intervals (CI), coefficient of variation (CV), typical error of measurement (TE) expressed as CV between the three trials for each dependant variable using a custom spreadsheet[29] and percentage change in mean. The CV was calculated based on the mean square error term of logarithmically transformed data.[29] Minimum acceptable reliability was determined with an ICC > 0.7 and CV < 10%.[30, 31] Mean ± SD were calculated for all dependent variables.

Asymmetry index (imbalance between right and left limbs) was calculated by the formulae (right leg – left leg/ right leg × 100) for unilateral IMTP variables.[9] Asymmetry index for D and ND limbs was calculated by the formulae (dominant leg – non dominant leg/ dominant leg x 100) for unilateral IMTP variables, in accordance to previous research.[9] Limb dominance was defined as the limb that produced the highest isometric force-time value. To assess the magnitude of differences in force-time characteristics between limbs in male collegiate and professional rugby league players, paired sample t-tests and Cohen's *d* effect sizes were implemented. Effect sizes were calculated by the formula Cohen's $d = M - M2/\sigma$ pooled[32] and interpreted as trivial (<0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), and very large (2.0–4.0).[33] The criterion for significance was set at $p \leq 0.05$.

Results

Intraclass correlation coefficients and CV demonstrated high within-session reliability for bilateral and unilateral IMTP PF (ICC = .94, CV = 4.7 – 5.5%) (Table 1). Lower reliability measures and greater variability were observed for bilateral and unilateral IMTP impulse at time bands (ICC = .81 - .88, CV = 7.7 - 11.8%) (Table 1). Unilateral IMTP left and right IP 100 met minimum acceptable reliability criteria (ICC = .83 - .87, CV = 9.3 – 9.5%); however IP 200, IP 250 and IP 300 demonstrated a greater level of variance than has previously been recommended (ICC= .82 - .88, CV = 10.3 – 11.6%).[32] Descriptive statistics for bilateral and unilateral IMTP force-time characteristics are presented in Tables 2 and 3. Unilateral IMTP descriptive statistics, MSA indexes and ESs are presented in Tables 2 and 3.

Insert Table 1 around here

Professional Male Rugby League Players

No significant differences ($p > .05$, $d \leq 0.11$) between right and left limbs were observed for all isometric force-time characteristics; with trivial differences between limbs (Table 2).

Conversely, small significant differences ($p < .001$, $d = 0.27 – 0.46$) were found between D and ND limbs for all isometric force-time characteristics (Table 3).

Collegiate Male Athletes

No significant differences ($p > .05$, $d \leq 0.32$) between right and left limbs were observed for all isometric force-time characteristics; with trivial to small differences between limbs (Table 2). Conversely, small to moderate significant differences ($p < .001$, $d = 0.43 – 0.91$) were found between D and ND limbs for all isometric force-time characteristics (Table 3).

Insert Table 2 around here

Insert Table 3 around here

Discussion

The aims of this study were to assess the within-session reliability of bilateral and unilateral stance IMTP force-time characteristics and to determine if significant differences in isometric strength were present between lower limbs in male collegiate and male professional rugby league athletes. The results from this study demonstrated high-within session reliability for bilateral and unilateral stance IMTP PF meeting minimum acceptable reliability criteria. Lower reliability measures and greater variability were observed for unilateral IMTP IP 100, however still met minimum acceptable reliability criteria. Conversely, unilateral IMTP IP 200, IP 250 and IP 300 demonstrated a greater level of variance than has previously been recommended (Table 1).[32] Trivial to small non-significant differences were observed between force-time characteristics for right and left limbs in collegiate and professional rugby league players (Table 2). However, small to moderate significant differences were revealed between D and ND limbs in male collegiate athletes and small significant differences between D and ND in professional rugby league players (Table 3). These findings are in agreement with our hypotheses.

The bilateral IMTP has been reported to be highly reliable with a low measurement error.[24, 25, 27] Traditionally, IMTP assessments have been performed bilaterally, with asymmetries having only been established with the use of dual force platforms during bilateral IMTPs.[11, 17, 18] To our knowledge, this study is the first to investigate a unilateral stance IMTP for the assessment of MSA indexes, demonstrating high reliability measures for isometric PF and lower reliability measures for impulse at time bands (Table 1). Further, significant differences were also observed between D and ND limbs (Table 3) for all isometric force-time characteristics. Therefore, this study revealed high within-session reliability for the assessment of unilateral stance IMTP PF and significant differences in force-time characteristics between D and ND limbs in male athletes (Table 3). However, a limitation of the present study is only the within-session reliability of the unilateral stance IMTP force-time characteristics was assessed, therefore, further research is required assessing between session test-retest reliability of the unilateral stance IMTP.

As previously stated limited studies have inspected unilateral multi-joint isometric strength through unilateral isometric squat assessments.[13, 22, 23] Hart et al[22] reported very high reliability measures of unilateral squat isometric PF (ICC = .96 – .98, CV = 3.6 - 4.7%) in 11 male athletes. Spiteri et al[23] demonstrated similar reliability measures for unilateral isometric squat PF (ICC = .95, CV = 5.5 – 7%) in 12 male and 12 female athletes. Specifically, the present study demonstrated comparable reliability measures for unilateral IMTP PF (ICC = .94, CV = 4.7 – 5.0%) to the above-mentioned studies in a large male sample (n = 54). Moreover, athletes may experience less discomfort when performing a unilateral IMTP in comparison to a unilateral isometric squat, due to pulling an immovable bar in comparison to pushing against an immovable bar positioned on the upper back (mid trapezius) during isometric squats. Consequently, the unilateral stance IMTP demonstrates high within-session reliability for PF assessments, with further research required into the between session reliability of unilateral PF.

This study is the first to inspect impulse at time bands (0-100, 0-200, 0-250, 0-300 ms) during unilateral stance IMTP assessments, demonstrating lower within-session reliability (ICC = .82 – .88, CV = 9.3 - 11.6%) and greater variability in contrast to PF reliability measures. Excluding IP 100, all unilateral stance impulse at time bands demonstrated a greater level of variance than has previously been recommended.[32] Dynamic tasks such as sprinting, jumping and changing direction are heavily dependent on an athlete's capability to rapidly apply unilateral force over short time intervals;[23, 27] therefore the ability to assess an athlete's unilateral force and impulse production capabilities via the unilateral stance IMTP may allow practitioners and scientists to identify any deficiencies in force production in specific limbs and also monitor the effectiveness of training interventions. Although it should be acknowledged that isometric and dynamic tasks are different. Our results indicate that the unilateral IP 100 demonstrates acceptable reliability, although practitioners should be aware greater variability may be observed when assessing impulse at alternative time bands (Table 1).

No significant differences were observed between left and right limbs for isometric force-time characteristics in collegiate male athletes ($p > .05$, $d \leq 0.32$) and professional rugby league players ($p > .05$, $d \leq 0.11$). However, significant differences were observed when comparing D and ND limbs in male collegiate athletes ($p < 0.001$, $d = 0.43 – 0.91$) and professional rugby league players ($p < .001$, $d = 0.27 – 0.46$); highlighting that isometric strength deficits between lower limbs are present in male athletes. Future research is required establishing isometric MSA indexes in female athletes.

Insert Figure 1 around here
Insert Figure 2 around here

The magnitudes of asymmetry in collegiate male athletes (6.2 ± 4.8 to 11.5 ± 9.5%) and professional rugby league players (5.1 ± 3.8 to 9.6 ± 8.6%) are presented in Table 3; individual PF imbalances are also illustrated in Figures 1 and 2. It should be noted that the that larger asymmetry values observed in the collegiate male athletes could be attributed to a heterogonous mixed sporting sample that contained athletes from sports where there are specific asymmetrical movement demands for example soccer, boxing and cricket which may result in the development of strength asymmetries.[34, 35] For example, Figure 2 illustrates the individual PF imbalance between D and ND limbs in collegiate male athletes, showing the boxers in this cohort demonstrated higher asymmetries in contrast to the other athletes from different which elevates the mean imbalance of this cohort. It should also be acknowledged the results of this present study are only applicable and representative of the athletes at the specific time of the season they were tested; and are therefore likely to change over a competitive season. Researchers have shown seasonal changes in fitness and strength characteristics throughout a season[36, 37] and the specific training phase has also shown to influence jump performance.[38] However, to our knowledge no literature exists investigating isometric strength asymmetries throughout a competitive season. Therefore, a future direction of research is to investigate seasonal variations in MSA as measured by the IMTP.

A strength discrepancy of 10-15% between limbs is considered to represent a potentially problematic asymmetry.[2] Although, no literature is available to substantiate this claim,[8] it is likely that the typical magnitude of MSA may vary between different muscle strength qualities for example concentric, eccentric, isometric and dynamic strength,[14, 15] and between different athlete populations.[35] Our findings provide normative MSA data for unilateral IMTP kinetics in different populations (Table 3). Athletes who demonstrate MSA greater than the values in Table 3 could therefore be considered asymmetrical.

Asymmetries during IMTP have only been established bilaterally with each foot on a separate force plate, with researchers observing asymmetries in isometric force time-characteristics in male and female athletes.[11, 17-19] Further, research suggests that weaker athletes display greater asymmetries in isometric force-time characteristics in comparison to stronger athletes during bilateral IMTPs[17, 18] and bilateral isometric squats[16] which may have a detrimental impact on vertical jumping performance.[11] Block periodised bilateral strength training has been reported to reduce bilateral asymmetries in weaker athletes;[16] highlighting the importance of maximising athletes bilateral strength to reduce the magnitude of bilateral MSA. It is unknown if this would be the case for unilateral IMTP MSA, thus future investigations are required determining the impact of strength training on unilateral IMTP MSA.

It should be noted that above-mentioned studies have inspected asymmetries during bilateral isometric squats and IMTPs and is therefore not a direct assessment of an isolated limb's force production capabilities. Consequently, a unilateral stance IMTP would allow the direct assessment of multi-joint isometric force production of a specific limb replicating unilateral stance of sprint, jumps and COD supported by the high reliability shown in the current findings. This will also help scientists and practitioners assess strength deficits between limbs and identify normative MSA values for athletic populations to benchmark standards in monitoring and strength assessments. Further, from a rehabilitation perspective a unilateral stance IMTP could be implemented to assess an athlete's isometric strength pre- and post-injury to determine the effectiveness training interventions and establish return to play criteria.

The impact of MSA on injury risk in athletes remains inconclusive;[8] however from a performance perspective it would be advantageous to be equally proficient in force production between limbs,[14] due to the unilateral requirements of sprinting, jumping, landing and change of directions. Previous studies have shown strength deficits between limbs can negatively impact performance during change of direction,[10] vertical jumping,[11, 12] and kicking.[13] Our results revealed significant differences in unilateral IMTP force-time characteristics between D and ND limbs in male athletes. However the implications of unilateral IMTP MSA on dynamic performance such as jumping and COD is unknown, thus is an area of further research.

Practical Applications

Overall, this study confirmed that the unilateral stance IMTP produces high within-session reliability for PF and IP 100 also met minimum reliability criteria. Furthermore, small to moderate significant differences were observed between D and ND limbs for all isometric force-time characteristics with greater magnitudes of asymmetry of MSA in male collegiate athletes in comparison to professional rugby players. Male athletes with isometric force-time characteristics asymmetries greater than the mean plus the SD of the normative MSA indexes presented in Table 3 maybe considered asymmetrical. Practitioners and scientists should therefore consider assessing athlete's unilateral isometric force production capabilities via a unilateral stance IMTP. This would permit the direct assessment of multi-joint isometric force production of the lower limbs replicating the unilateral stance of sprinting, jumping and COD; allowing practitioners to identify strength deficits between limbs so subsequent training programmes can be implemented to reduce the deficit which may reduce the likelihood of injury and improve athletic performance. From a rehabilitation perspective a unilateral stance IMTP would allow comparisons of lower limb strength and pre- and post-injury and also monitor the effectiveness of training interventions.

Conclusion

Bilateral and unilateral stance IMTP assessments demonstrated high within-session reliability for PF and lower although acceptable reliability measures for IP 100. Impulse at time bands (0-200, 0-250 and 0-300 ms) demonstrated a greater level of variance than has previously been recommended. No significant differences were observed between left and right limbs during unilateral stance IMTP for male collegiate and rugby league players however significant differences were revealed for all isometric force-time characteristics between D and ND limbs. Future research should focus on the effect of strength training on the magnitude of unilateral stance IMTP asymmetry and effect of isometric MSA on athletic performance.

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Table 1. Bilateral and Unilateral Isometric Mid-Thigh Pull Within-Session Reliability Measures

	Bilateral				Right				Left			
Variable	**ICC (95% CI)**	**CV (95% CI)**	**TE**	**Change in mean (%)**	**ICC (95% CI)**	**CV (95% CI)**	**TE**	**Change in mean (%)**	**ICC (95% CI)**	**CV (95% CI)**	**TE**	**Change in mean (%)**
PF (N)	.94 (.91-.96)	5.5 (4.8-6.6)	166.64	0.87	.94 (.89-.96)	5.0 (4.3-5.9)	137.27	0.23	.94 (.91-.96)	4.7 (4.1-5.6)	129.03	0.87
Rel PF ($N.Kg^{-1}$)	.82 (.73-.89)	5.5 (4.8-6.6)	2.91	0.87	.86 (.77-.91)	5.0 (4.3-5.9)	1.49	0.23	.90 (.84-.94)	4.7 (4.1-5.6)	1.42	0.87
IP 100 (N•s)	.88 (.81-.93)	7.7 (6.7-9.2)	7.75	2.29	.87 (.79-.92)	9.5 (8.3-11.4)	8.87	2.79	.83 (.74-.90)	9.3 (8.0-11.1)	9.14	2.05
IP 200 (N•s)	.86 (.78-.92)	9.3 (8.1-11.2)	22.69	0.48	.86 (.79-.91)	10.8 (9.3-12.9)	21.47	2.70	.82 (.72-.89)	10.3 (8.9-12.4)	23.03	1.74
IP 250 (N•s)	.81 (.72-.88)	11.0 (9.5-13.2)	35.49	0.71	.87 (.80-.92)	10.6 (9.2-12.7)	28.04	2.32	.82 (.72-.90)	10.9 (9.4-13.1)	32.55	1.46
IP 300 (N•s)	.81 (.71-.88)	11.8 (10.2-14.2)	47.37	1.26	.88 (.81-.92)	10.5 (9.1-12.6)	35.64	1.62	.82 (.71-.89)	11.6 (10.0-13.9)	43.57	1.17

Key: PF = Peak Force; Re l = Relative; IP 100 = Impulse at 100 ms; IP 200 = Impulse at 200 ms; IP 250 = Impulse at 250 ms; IP 300= Impulse at 300 ms; ICC = Intraclass Correlation Coefficients; CV = Coefficient of Variation; CI = Confidence Intervals; TE = Typical Error of Measurement; IMTP = Isometric Mid-Thigh Pull

Table 2. Isometric force time characteristics and muscle strength asymmetry indexes between left and right limbs

	Professional rugby league players (n = 35)					Collegiate male athletes (n = 19)				
Variable	**Bilateral**	**Right**	**Left**	**R vs L imbalance (%)**	***d***	**Bilateral**	**Right**	**Left**	**R vs L imbalance (%)**	***d***
PF (N)	3238± 725	2851 ± 514	2880 ± 544	-1.1 ± 6.8	-0.05	3180 ± 542	2529 ± 404	2589 ± 392	-2.8 ± 8.1	-0.15
Rel PF (N.Kg^{-1})	33.8 ± 5.4	30.1 ± 3.2	30.4 ± 3.8	-1.1 ± 6.8	-0.09	40.6 ± 5.6	32.3 ± 4.2	33.1 ± 4.5	-2.8 ± 8.1	-0.19
IP 100 (N•s)	104.0 ± 21.9	102.6 ± 26.4	101.2 ± 23.9	0.6 ± 8.7	0.06	105.3 ± 19.5	103.7 ± 14.3	104.1 ± 13.4	-1.4 ± 14.5	-0.03
IP 200 (N•s)	229.1 ± 48.7	220.3 ± 58.9	223.5 ± 52.7	-2.7 ± 11.8	0.06	262.6 ± 56.5	245.2 ± 38.9	255.1 ± 33.8	-6.0 ± 19.7	-0.27
IP 250 (N•s)	308.5 ± 67.8	290.2 ± 79.3	297.1 ± 72.1	-3.7 ±14.2	-0.09	365.3 ± 75.9	330.8 ± 54.2	346.9 ± 45.4	-7.2 ± 21.3	-0.32
IP 300 (N•s)	400.0 ± 91.1	368.4 ± 102.3	379.4 ± 95.2	-4.4 ± 15.9	-0.11	477.8 ± 95.5	425.3 ± 69.7	445.6 ± 57.0	-7.2 ± 22.0	-0.32

Key: R = Right; L = Left; PF = Peak Force; Rel= Relative; IP 100 = Impulse at 100 ms; IP 200 = Impulse at 200 ms; IP 250 = Impulse at 250 ms; IP 300= Impulse at 300 ms; *d* = Cohen's *d*

Table 3. Isometric force time characteristics and muscle strength asymmetry indexes between dominant and non-dominant limbs

	Professional rugby league players (n = 35)				Collegiate male athletes (n = 19)			
Variable	**D**	**ND**	**D vs ND imbalance (%)**	***d***	**D**	**ND**	**D vs ND imbalance (%)**	***d***
PF (N)	2941 ± 533	2791 ± 516*	5.1 ± 3.8	0.29	2643 ± 405	2476 ± 375*	6.2 ± 4.8	0.43
Rel PF ($N.Kg^{-1}$)	31.0 ± 3.5	29.4 ± 3.4*	5.1 ± 3.8	0.46	33.8 ± 4.3	31.6 ± 4.2*	6.2 ± 4.8	0.5
IP 100 (N•s)	105.3 ± 26.1	98.5 ± 23.7*	6.2 ± 5.6	0.27	109.3 ± 11.5	98.5 ± 13.8*	10.0 ± 7.1	0.86
IP 200 (N•s)	231.4 ± 57.4	212.4 ± 52.6*	7.9 ± 7.1	0.34	265.1 ± 27.4	235.2 ± 38.5*	11.5 ± 9.5	0.91
IP 250 (N•s)	307.8 ± 77.8	279.5 ± 71.0*	8.8 ± 8.1	0.38	358.3 ± 36.8	319.4 ± 54.6*	11.1 ± 10.4	0.85
IP 300 (N•s)	393.9 ± 101.8	354.0 ± 91.7*	9.6 ± 8.6	0.41	458.2 ± 46.4	412.7 ± 71.2*	10.2 ± 10.9	0.77

Key: D = Dominant; ND = Non- Dominant; PF = Peak Force; Rel= Relative; IP 100 = Impulse at 100 ms; IP 200 = Impulse at 200 ms; IP 250 = Impulse at 250 ms; IP 300= Impulse at 300 ms; d = Cohen's d; Significant differences between D and ND limb * p<.001

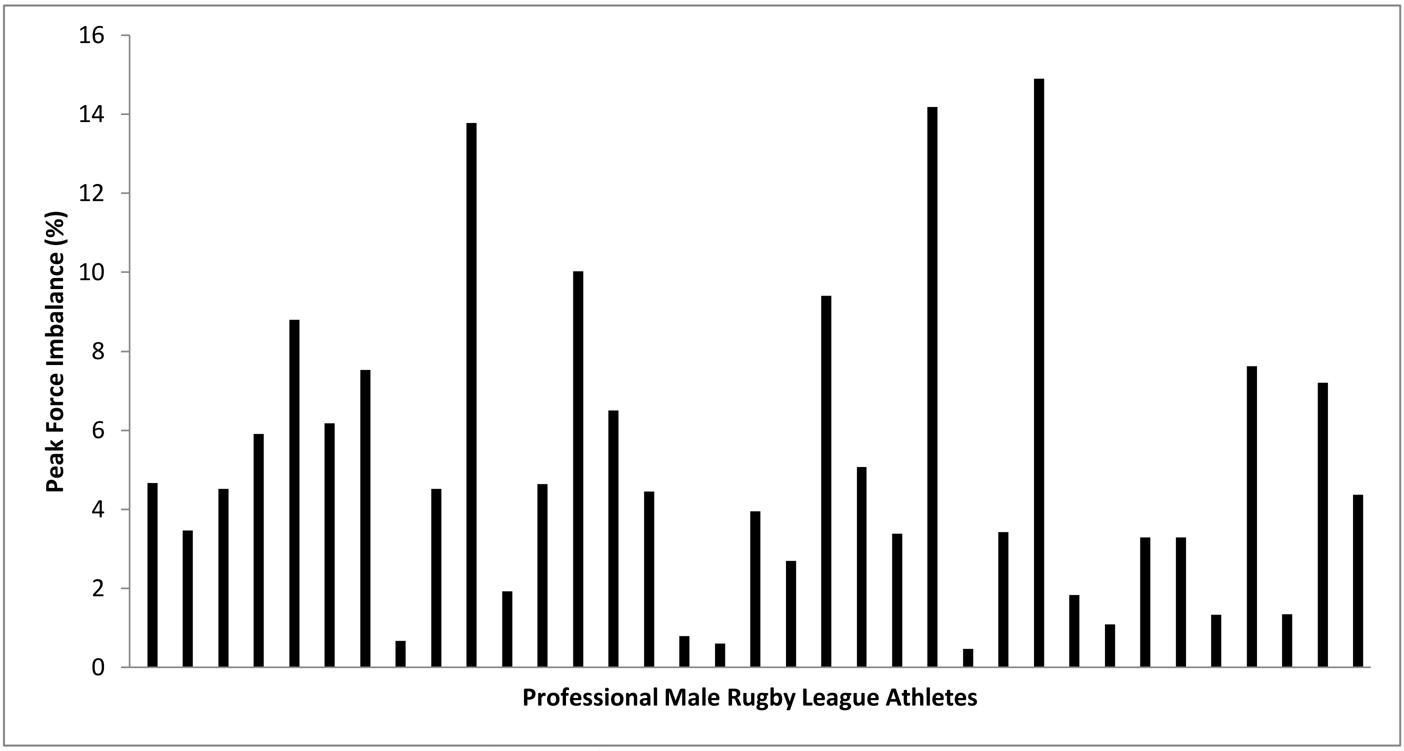

Figure 1 - Individual professional male rugby league unilateral isometric mid-thigh pull peak force imbalance between dominant and non-dominant limbs

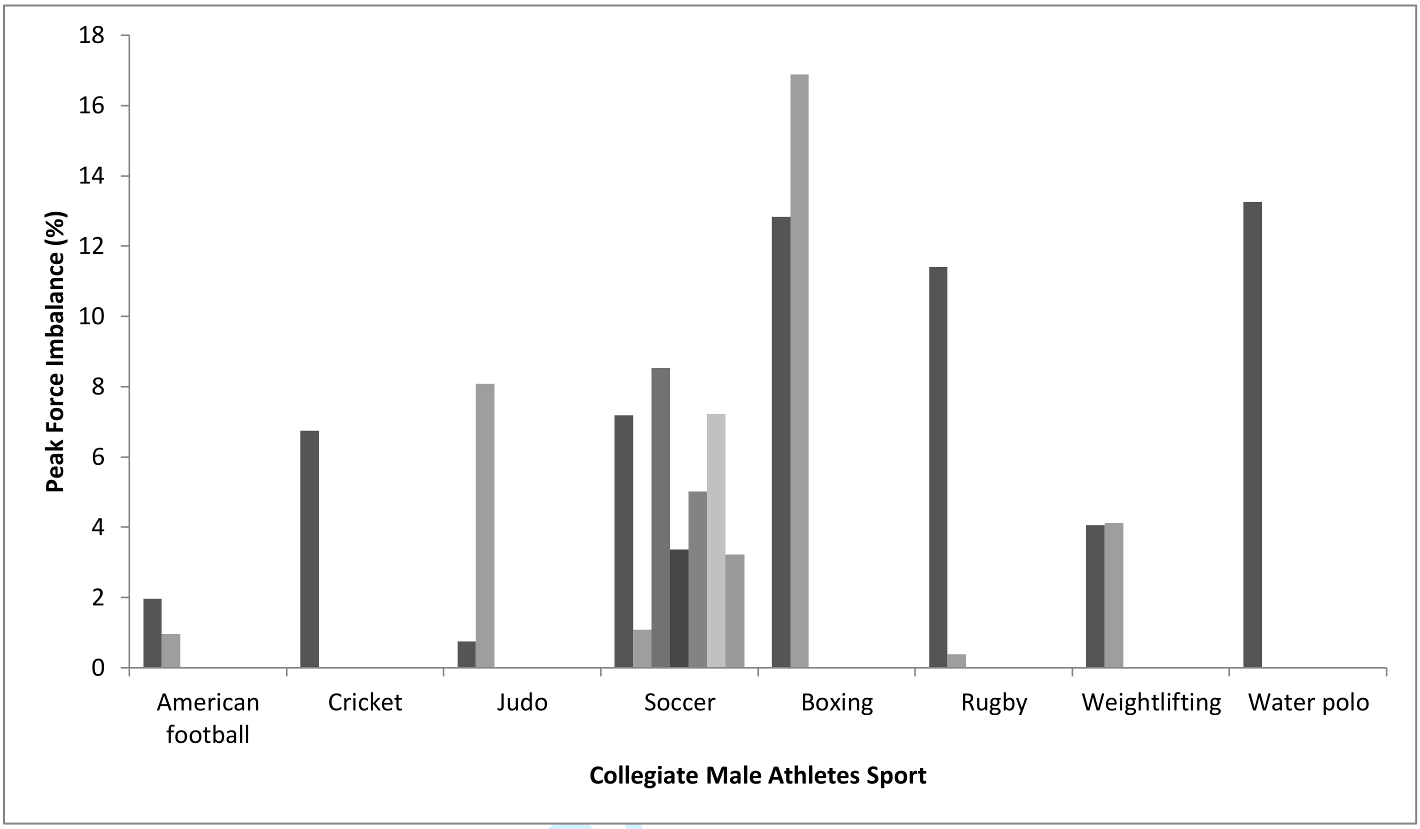

Figure 2 – Individual collegiate male athletes unilateral isometric mid-thigh pull peak force imbalance between dominant and non-dominant limbs