Short Communication

Isometric force production symmetry and jumping performance in collegiate athletes

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Objectives: The purpose of this study was to identify the relationship between isometric force production symmetry and jumping performance in weighted and un-weighted static and countermovement jumps (SJ and CMJ).
Design: Bivariate correlation between isometric force production symmetry and vertical jump performance variables.
Methods: Collegiate athletes were evaluated for this study (n=36). Subjects performed SJ, CMJ, and isometric mid-thigh pulls (IMTP). Jumps were analyzed for jump height (JH) and peak power (PP). IMTP was analyzed for peak force (PF) for left and right sides, and values were calculated to produce a peak force symmetry index (PF-SI) score. Correlational statistics were performed examining the relationship between PF-SI and jump variables.
Results: Moderate statistically significant negative correlations were observed between PF-SI and all jump variables, indicating that as asymmetry increases jump performance decreases. SJ correlations weakened in weighted conditions (JH r=-0.52 @ 0 kg/r=-0.39 @ 20 kg, PP r=-0.43 @ 0 kg/r=-0.34 @ 20 kg), but CMJ produced similar correlations for both conditions (JH r=-0.47 @ 0 kg/r=-0.49 @ 20 kg, PP r=-0.28 @ 0 kg/r=-0.34 @ 20 kg). Unlike the SJ, which only contains the propulsive or concentric portion of the jump, the CMJ also contains the eccentric portion and performance contributions of the stretch-shortening cycle (SSC). The addition of the SSC may play a role in the maintaining the magnitude of asymmetry in the CMJ weighted condition.
Conclusions: The results indicate that force production asymmetry may be detrimental to bilateral vertical jumping performance. The findings should be considered for further investigation on sport-specific tasks.
(*Journal of Trainology* 2013;2:1-5)

Key words: kinetic ■ ground reaction force ■ isometric mid-thigh pull

Introduction

Participation in sports can place numerous physical demands on the athletes who partake in them. Many of these sports may require the athlete to repeat the same motions countless times. Concerning a sport such as baseball or softball, a player may throw or hit with the same side of their body possibly leading to altered ranges of motion and strength asymmetries.[1-3] Other sports may require the players to utilize both sides of their body equally, but lengthy playing careers in any sport may result in changes in the range of motion, force producing capabilities, and overall symmetry of one's body.

Of increasing importance to the sport scientist is the question: is asymmetry a cause for concern or is it merely a product of increasing efficiency in a given sport task. According to Knapik et al[4], a bilateral isokinetic strength imbalance of 15% or greater is consistent with a high risk of injury when concerning knee flexion and extension. Nadler et al[5] also demonstrated contralateral strength imbalances of the hip flexors were predictors of low back pain in 163 collegiate athletes. However others have shown contrary findings. Bennell and colleagues[6] failed to establish a relationship between strength testing, symmetry, and hamstring injury. Buekeboom et al.[7] found significant strength asymmetries in 25 collegiate track sprinters and middle distance runners but also failed to link those to any injury predictability.

Potential injury is not the only concern when considering asymmetry. One must also consider if there is any detriment to performance resulting from asymmetry. To date there has been a limited amount of research investigating the relationship between force production symmetry and performance. Most of the previous research has investigated unilateral asymmetry and sought to correlate single leg jumping performance with sprinting and change of direction performance.[8-10] Considerably less research has investigated bilateral force production asymmetry and the majority examined previously injured populations.[11-12] Yoshioka et al[20] assessed bilateral strength asymmetry in a computer simulation model, and their results indicated that jump height was not affected by strength asymmetry and that the stronger leg possibly compensated for the weaker leg. If this was assessed on human subjects, the compensation of the stronger side may not be adequate to make up for the weaker side and the results may be different. To our knowledge, this has not been tested on human subjects, and there is a need for

Received February 26, 2013, accepted April 24, 2013
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Journal of Trainology **2013:2:1-5** **http://trainology.org/**

evidence-based support for practical use.

Kawamori et al[13] and Kraska et al[14] demonstrated a relationship between isometric peak force and weighted and un-weighted static and countermovement vertical jump performance (SJ and CMJ). Both studies provided data indicating that athletes who produce high forces isometrically also excel in jumping performance indicating that maximizing the force production is essential to jump performance. However, it is unclear how those forces are produced in bilateral tasks. Both mentioned studies reported how the total force production in isometric task related to superior jump performance instead of investigating the force production from left and right separately. The influence of isometric force production asymmetry to jump performance is yet unknown. There is a need for understanding how magnitude of bilateral asymmetry in isometric force production possibly influences the jump performance. Therefore the purpose of this study was to identify the relationship between isometric force production symmetry and jumping performance in both weighted and un-weighted SJ and CMJ. It was hypothesized that higher bilateral asymmetries would be related to decreases in jumping performance.

METHODS

Subjects

Thirty-six male collegiate athletes were evaluated (body mass: 84.2 ± 8.3 kg, height: 180.7 ± 5.8 cm, age: 20.3 ± 1.0 yr). All subjects participating in the current study were active members of collegiate athletic teams and testing occurred during their respective off-season. All subjects read and signed University Institutional Review Board approved informed consent documents.

Instrumentation & Data Collection Procedures

Subjects performed all testing on the same day, which included SJ and CMJ and Isometric Mid-Thigh Pull (IMTP) strength testing. The testing session began with a standardized warm-up consisting of 25 jump-jacks, a set of five repetitions of dynamic pulls from mid-thigh position with 20 kg, and three sets of five repetitions at 60 kg. Jumps were performed from a 91cm x 91cm force plate (Rice Lake, WI) and data were sampled at 1,000 Hz. Prior to all jump conditions, familiarization and warm-up trials at 50 and 75% of perceived efforts were completed. All jumps were performed while athletes held either a PVC pipe or 20 kg bar behind the neck just below the 7th cervical vertebrae in an effort to minimize any contributions from an arm swing. During the SJ, the athlete descended to a knee angle of 90˚, previously measured with a goniometer. This position was held for 3 seconds and then the command to jump was given. A jump was considered successful if the athlete gave a maximal effort and there was no visible countermovement. Following the SJ, athletes executed the CMJ. From the standing position, the athlete descended to a self-selected depth, and then jumped. Athletes performed two SJs and two CMJs for unloaded (0 kg) and loaded conditions (20 kg) for a total of four jumps. Similarly to the procedure by Kraska et al. (2009), the weight of the PVC pipe was considered negligible and served as the 0 kg condition, while 20 kg bar served as the loaded condition (See Figure 1 below). The loaded conditions were included in order to simulate a situation of fatigue and to examine how subjects respond to an external load in jumping performance. Rest between jumps was approximately 1 minute. Averages of each jump variable were determined to better indicate the athlete's typical performance level.[15] Jump height (JH) was derived from flight time using the equation:

$$JH = (9.81\ m/s \cdot s) \cdot (ft \cdot ft)/8$$

where flight time is abbreviated as ft. Peak power (PP) was deemed the highest instantaneous power in the range of concentric movement. Test-retest reliability for all jump variables has been determined previously in our laboratory (ICCα≥0.90, n>200).

IMTPs were completed in a custom designed power rack, using a dual force plate set up (2 separate 45.5 cm x 91 cm) (RoughDeck HP; Rice Lake, WI) and data were sampled at 1,000 Hz. The apparatus and standard positioning were established based on previously published data from Haff et

Figure 1 Photograph of a loaded condition (20 kg) of a static jump.

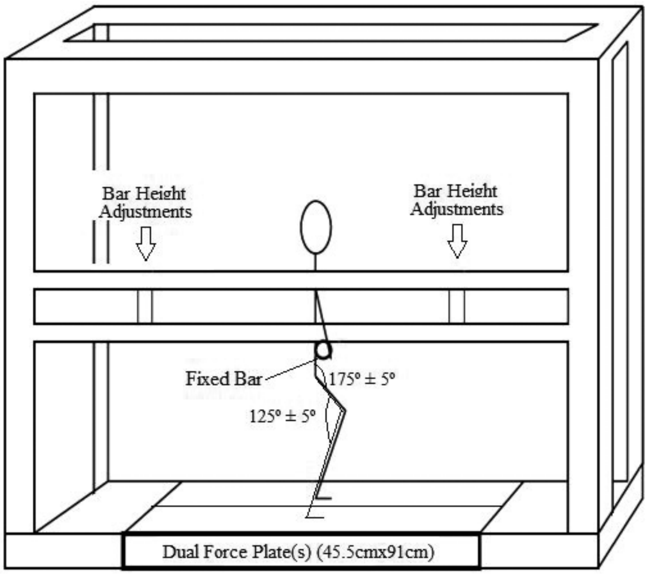

Figure 2 Isometric mid-thigh pull positioning on dual force plates with a knee angle of 125˚ ± 5˚ and a hip angle of 175˚ ± 5˚.

al[16] and Kraska et al.[14] Bar heights were set specific to the individual, corresponding to a knee angle of 125˚ ± 5˚ and a hip angle of 175˚ ± 5˚ (see Figures 2 and 3). Athletes' hands were fixed to the bar using weightlifting straps and athletic tape to prevent their hand movement and to ensure a maximum effort could be given without the limitation of hand grip strength.

Each athlete performed two warm up trials at 50 and 75% effort, followed by two maximal voluntary isometric contractions with 1 minute rest between each pull. The athlete was verbally instructed to "pull as fast and as hard as possible". For the purposes of this study, isometric peak force (PF) was analyzed. Pulls were counted as successful if there was no visible countermovement. If trials were unsuccessful, they were repeated. Previous testing in our laboratory (n>200) has consistently produced a test-retest reliability of PF ICCα≥0.98. Two synchronized force plates were utilized during the IMTP testing to calculate force production symmetry. Subjects were carefully positioned with each foot centered on an individual force plate.

Data and Statistical Analysis

The level of symmetry was determined from the subsequent equation, which results in a percentage.

$$SI = (\text{larger value} - \text{smaller value}) / \text{total value} \times 100$$

The resultant percentage is termed the symmetry index (SI) and a PF symmetry index (PF-SI) score of 0% indicates perfect symmetry.[17-18] Data were processed using LabView 10.0 software (National Instruments Co., Austin, TX) and analyzed with PASW software (SPSS version 19.0: An IBM company, New York, NY). Pearson correlation coefficients were determined to assess the level of relationship between variables. Criteria for establishing strength of relationships were as follows: greater than 0.5 is considered large, 0.3-0.5 is moderate, 0.1-0.3 is small, and less than 0.1 is trivial.[19] Variables considered for correlations were PF-SI score from IMTP, JH, and PP from weighted and un-weight SJ and CMJ. Statistical significance was set at $p \leq 0.05$.

Figure 3 Photograph of isometric mid-thigh pull positioning on dual force plates.

RESULTS

The average PF-SI was 6.6 % (±5.1). Table 1 shows the descriptive results of jump variables (mean ± standard deviation). Table 2 shows correlations between PF-SI and jump variables along with the slope and y intercepts of each line. All PF-SI data are negatively correlated with jump variables, indicating the level of asymmetry increases, the jump performance described from JH and PP decrease. Furthermore the correlation values were statistically significant but actual values were within the moderate range with the exception of the PP of the 0 kg CMJ (-.28). Figure 4 illustrates the relationship between PF-SI and unloaded static jump height in a scatterplot.

Table 1 Results of jump variables displayed as means with standard deviations.

Results Mean ± Standard Deviation

Variable	SJ	CMJ
Jump Height 0 kg (m)	0.35±0.04	0.40±0.07
Peak Power 0 kg (w)	4796.62±793.96	5927.09±1365.91
Jump Height 20 kg (m)	0.28±0.05	0.32±0.06
Peak Power 20 kg (w)	4573.86±842.09	5421.19±1678.45

Table 2 Correlation r values, slopes and y intercepts between isometric peak force symmetry index (%) and jump variables.

	SJ			CMJ		
Variable	r value	Slope	y intercept	r value	Slope	y intercept
Jump Height (0 kg)	-0.52**	-0.0049	0.3887	-0.47**	-0.0063	0.4442
Jump Height (20 kg)	-0.39**	-0.0044	0.3127	-0.49**	-0.0061	0.3652
Peak Power (0 kg)	-0.43**	-60.283	5196.7	-0.28*	-74.913	6424.3
Peak Power (20 kg)	-0.34*	-54.73	4937.1	-0.34*	-111.94	6164.1

* Correlation was statistically significant to the 0.05 level, ** correlation was statistically significant to the 0.01 level.

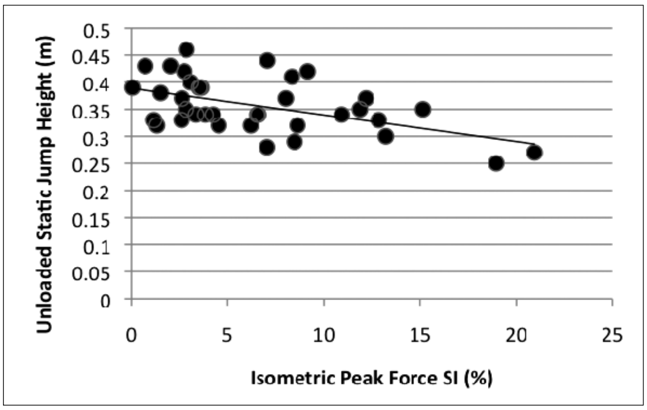

Figure 4 Scatter plot illustrating relationship between isometric peak force symmetry index (%) and unloaded static jump height (m) (r=-0.52, y=-0.0049x + 0.3887).

DISCUSSION

The primary finding of this study was the statistically significant negative relationship between PF-SI score and jump performance. This is illustrated by the negative moderate correlation and negative line slopes. This finding supports our hypothesis to some extent. PF-SI values ranged from 0.04% to a 20.95%, indicating that some subjects are nearly perfect in PF-SI score and some possess excessive asymmetry. The presence of an asymmetry is consistent with previous findings.[5-7] Yoshioka and colleagues [20] determined that a 10% bilateral strength asymmetry would not affect jump performance, however the presence of a relationship in the current investigation may suggest otherwise. Unlike the simulation study, the stronger leg may not have adequately compensated for the weaker leg, consequently detrimentally affecting the jumping performance. This brings up the question on the level of PF-SI scores necessary to compromise athletic performance. The strongest correlations were observed between PF-SI and JH. Specifically considering the SJ an r value of -0.52 was observed with the 0 kg condition which dropped to -0.43 with the 20 kg condition. Similarly the PP produced a 0 kg r value of -0.39 and a -0.34 for the 20 kg condition in SJ. Although the statistical significance was maintained, decreases in the r value are intriguing. One possible explanation is that the weighted condition reinforced athletes to attain strength symmetry in order to overcome the external resistance. In other words the 20 kg SJ may require a greater level of symmetrical force production, especially from the weaker side to overcome the resistance. Future investigation is necessary to understand the changes in PF-SI with various external resistances. Similarly to the SJ, the CMJ produced the highest correlation values with PF-SI and JH; while the PF-SI and PP correlation values were lower, but remained statistically significant. Unlike the SJ condition, the relationship did not weaken under the weighted condition for either variable. The SJ only contains the propulsive or concentric portion of the jump, while the CMJ also contains the eccentric portion and performance contributions of the stretch-shortening cycle (SSC). The level of asymmetry was maintained from the un-weighted to the weighted condition in the CMJ. This indicates that the addition of the SSC may be a factor in maintaining the magnitude of asymmetry during the CMJ weighted condition. However, the role of the SSC in maintaining the magnitude of asymmetry is not fully understood, and further research seems justified to determine the specific contributions by the SSC and its association with bilateral strength asymmetry. This may also have some implications for other dynamic sporting performances that involve the SSC and bilateral force production.[17]

While it is conceivable that large asymmetry values may have influenced the correlation strength, this may also be indicative of the threshold required to produce detriment. Future studies with larger sample sizes may be able to contribute to this area. It is a possible limitation that the relatively high level of variation in PF-SI may be due to training age, injury history or previous training volumes, but neither variable was assessed in the current study. Another possible limitation of the current study could be that there was no instantaneous symmetry information relayed to the subject during setup. Thus, a subject could start with an unequal weight distribution which may carry over to IMTP and jump performance. Weight distribution asymmetry has been shown to have some carry over in squatting performance;[17] however, attempts were made to control for this limitation by encouraging subjects to stand centered in the middle of the force plates. In the current study, investigators focused on actual jump height to emphasize the practicality of how PF-SI would influence the jump performance. Other dependent variables such as rate of force development and impulse could further support the current findings.

CONCLUSION

Although it is not known with certainty if a force production asymmetry is a risk factor for injury,[6-7] the athletes in the present study completed the season injury free. The current study does indicate that force production asymmetry may be a detriment to bilateral vertical jumping performance. Furthermore, coaching professionals should keep in mind that the current findings produced only moderate correlations, thus only providing a partial view of the relationship between force production symmetry and jumping performance. Further research investigating the relationship between strength asymmetry and sport specific performance variables as well as the contributing factors associated with bilateral strength asymmetry appears to be justified.

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