COMPARISON OF STATIC, COUNTERMOVEMENT, AND DROP JUMPS OF THE UPPER AND LOWER EXTREMITIES IN U.S. JUNIOR NATIONAL TEAM MALE GYMNASTS

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Abstract

This study examined and compared static, countermovement, and rebound-type drop jumps from the upper and lower extremities among USA Junior National Team male gymnasts. Twenty-one gymnasts performed two repetitions each of upper (UE) and lower extremity (LE) static (SJ), countermovement (CMJ), and drop (DJ) jumps on a force platform. Average measures of maximum jump height (MXHT), peak force (PF), rate of force development (RFD), and peak power (PP) were calculated for analysis. In addition, sample-specific allometric scaling was used to scale PF and PP. Four 2x3 repeated measures ANOVAs were calculated for analyses. Statistically significant main effects were observed for UE vs LE for MXHT, PF, RFD, and PP (all $p < 0.001$). Statistically significant main effects for jump-type were also observed: MXHT, PF, RFD, and PP (all $p < 0.001$). Finally, statistically significant extremities x jump-type interaction effects were obtained for MXHT, PF, RFD, and PP (all $p < 0.001$). These gymnasts showed better performances in CJs relative to SJs, but performances were unexpectedly poorer in the DJs. Despite using rebound-type jumps in tumbling and vaulting with UE and LE, the DJs did not appear to capture the athletes' stretch-shortening cycle skill or may reflect poor stretch-shortening cycle skill.

Keywords: *stretch-shortening cycle, vertical jump, force analysis, gymnastics.*

INTRODUCTION

Gymnastics is an unusual sport in that primacy is placed on extreme levels of strength, power, and flexibility combined with small body size (Sands et al., 1994). Gymnastics-type jumps are performed regularly and systematically with both upper (UE) and lower extremities (LE) (Knoll, 2002; Li, Sun, & Ja, 2000). The floor exercise, tumbling, and vaulting events involve LE explosive jumps. Floor exercise, vaulting, pommel horse, and parallel bars incorporate UE jumping skills. As such, gymnasts, particularly male gymnasts, are an ideal group for the study of jump characteristics relationships between UE and LE combined with different types of jumps.

Jumping activities and tests, as a fitness measure, have long formed a key component in both the training and assessment of athletes in many sports at all levels. Jumps, whether from UE or LE, are often classified as a static jump (SJ), countermovement jump (CJ), or drop jump (DJ). A SJ is performed from a relatively low position (i.e. flexed elbows (UE) or flexed knees (LE)) that is held for a few moments in an effort to reduce or eliminate any stretch-shortening cycle (SSC) mechanism prior to an explosive push from the hands (UE) or feet (LE) to raise the body and reach a maximum height flight phase. A CJ begins in an upright raised position (i.e. extended elbows (UE) and knees (LE)) from which the athlete lowers quickly to a self-selected position of elbow (UE) and knee and ankle flexion (LE) followed immediately by explosive extensions of these joints to raise the body from the ground to a maximum height flight phase. Depending on the jumper's skill, the CJ uses an intermediate level of SSC. A DJ is usually performed from a raised surface or position where the athlete falls (i.e. drops) due to gravity to land on the hands or feet. The athlete then performs a rapid absorptive flexion followed by an explosive extension in the UE or LE joints, countering the impact load, and leading to a rise and maximum flight phase (Bobbert, Huijing, & Van Ingen Schenau, 1987a, 1987b). The three types of jumps described above embody different physiological and mechanical capacities of the athlete. The SSC is largely absent from a SJ, present but modest in a CJ, and dominant in a DJ (Bobbert, Gerritsen, Litjens, & Van Soest, 1996). Research and training approaches have emerged postulating that these types of jumps may allow specific diagnoses of explosive strength capacities in athletes (McNeal, Sands, & Shultz, 2007; Sands, McNeal, & Shultz, 1999).

Characterizing the potential differences in UE and LE jumping activities may assist practitioners in the intelligent prescription of training loads and evaluation methods of athletes who require UE and/or LE strength and power abilities. The extant literature on jumping is tilted heavily toward LE investigations, as literature reviews show (Baker, 1996; Hedrick & Anderson, 1996; Wathen, 1993). However, research on UE jumping is increasing rapidly (Freeman, Karpowicz, Gray, & McGill, 2006; Garcia-Masso et al., 2011; Koch, Riemann, & Davies, 2012; Mangine, Ratamess, Hoffman, Faigenbaum, Kang, & Chilakos 2008; Moore, Tankovich, Riemann, & Davies, 2012), and at least one study involving both UE and LE jumps has been conducted (Mangine, et al., 2008). A similar study of jump-types, as proposed here, was also performed on world level divers (Sands, McNeal, & Shultz, 1999).

Male gymnasts are an unusual population because of their reliance on UE and LE strength and power in training and performance. The purpose of this exploratory study was to characterize and compare UE and LE jump characteristics in three types of vertical jumps. The performance profiles created from this study, and the derivative information from jump-types, may provide information on the comparative capacities of UEs and LEs, and the relative use of SSC mechanisms by young highly trained male gymnasts. We hypothesized that statistical differences would be observed between the UE and LE, and that jump capabilities would show increased values in the order of static, countermovement, and drop jumps – mirroring the effective presence of the SSC.

METHODS

Twenty-one young male gymnasts (age: 15.1 ± 1.7 years, height: 159.7 ± 9.6 cm, body mass: 54.3 ± 11.0 kg) who participated in extensive gymnastics training (5 d/wk and 3-4 h/d) agreed to participate in this study. Every subject was a member of the U.S.A. Junior National Gymnastics Team. Testing occurred at the United States Olympic Training Center in Colorado Springs, CO during a national team training camp. Each athlete and their parents or guardians provided their written informed assent or consent, respectively, prior to participation. This study was conducted under the requirements of the United States Olympic Committee with additional approval from the Institutional Review Board of East Tennessee State University.

A repeated measures design was used to test our hypotheses and determine the differences between UE and LE jumping and static, countermovement, and drop jumping conditions. Each participant completed a single testing session in which they performed two, single repetitions of both UE and LE static, countermovement, and drop jumps on a force platform.

A custom built force platform (61.0 cm x 61.0 cm x 11.2 cm) (Major, Sands, McNeal, Paine, & Kipp, 1998) sampling at 1,000 Hz was used to record the ground reaction forces produced during each LE and UE static, countermovement, and drop jump. The raw data from the force platform were stored in a computer and analyzed using custom software. No additional filtering or signal conditioning was used. The raw force-time data were then analyzed to calculate the variables of interest using previously established methods (Harman, 1995; Harman, Rosentstein, Frykman, Rosenstein, & Kraemer, 1991; Hatze, 1998; Semenick, 1990). Thirty-centimeter plyometric platforms (Power Systems, Inc., Knoxville, TN, USA) were used during the drop conditions for both LE and UE jumps. One box was used during the LE drop jump exercise, whereas two boxes were used during the UE drop jump exercise, one for each hand. During the drop conditions, the base of each box was positioned at the same height as the surface of the force platform.

Each athlete first completed their standard national team warm-up that consisted of various calisthenic exercises, walking, jogging, stretching, and basic tumbling skills. At the conclusion of their warm-up, athletes rotated in groups to each gymnastics event. The testing station was included in the event rotations. Upon reaching the testing station, athletes performed a self-selected number of practice repetitions for the SJ, CJ, and DJ tests to become familiar with each condition. The athletes were required to perform at least two practice repetitions of each test condition prior to testing. The lower extremity static jump (LSJ) required the athletes to squat to a knee angle of 90 degrees, remain in a static position, and without performing any extra countermovement, jump as high as possible. The lower extremity countermovement jump (LCJ) required the athletes to perform a countermovement to a self-selected knee, hip, and ankle flexion angle and then jump as high as possible. The lower extremity drop jump (LDJ) required the athletes to step off of a 30 cm plyometric box onto the force platform and immediately jump as high as possible, mimicking a gymnastics tumbling and vaulting takeoff. Each type of LE jump required the athletes to keep their hands on their hips at all times. If this posture was not maintained, the trial was repeated. Following the practice repetitions, each athlete performed two, single repetitions of the LSJ, followed by two, single repetitions of the LCJ and two, single repetitions of the LDJ. Athletes were given 1-2 min rest in between each repetition.

Upon completion of the LE jump conditions, athletes' body weights were measured with their hands on the force platform in a push-up position with the elbows extended. The athletes' effective UE mass in the push-up position was used within the scaling equations for the UE jumps. Next, the athletes performed practice repetitions of the UE static jump (USJ), countermovement jump (UCJ), and drop jump (UDJ). Like the LE jump conditions, athletes performed a self-selected number of practice repetitions, but were required to perform at least two practice repetitions for each variation. For each UE jump, the subject's feet were placed on a wood platform such that the feet were at the level of the force platform top-surface while their hands were placed on the force platform in a push-up position. The only exception of hand placement came during the UDJ, where the athletes started with one hand each on 30 cm plyometric boxes. The USJ required the athlete to start in a lowered push-up position with the chest in contact with the force platform. From this position, athletes maximally pushed off the force platform to rise as high as possible achieving flight from the hands. Similar to the LSJ, the athlete received a countdown once they achieved the starting position, and then pushed off the platform as high as possible. The UCJ was performed starting in a standard push-up start position. Athletes then rapidly lowered themselves and then maximally pushed off the force platform achieving flight from the hands. The UDJ required the athletes to start with the arms horizontally abducted and one hand on each of the 30 cm plyometric boxes, adduct their arms to drop onto the force platform, and then maximally push off the force platform achieving flight from the hands. Following the practice repetitions, each athlete performed two, single repetitions of the USJ, followed by two, single repetitions of the UCJ, and two, single repetitions of the UDJ. Athletes again were provided with 1-2 min rest between each repetition. Figures 1-3 show examples of the force-time curves for a SJ, CJ, and DJ.

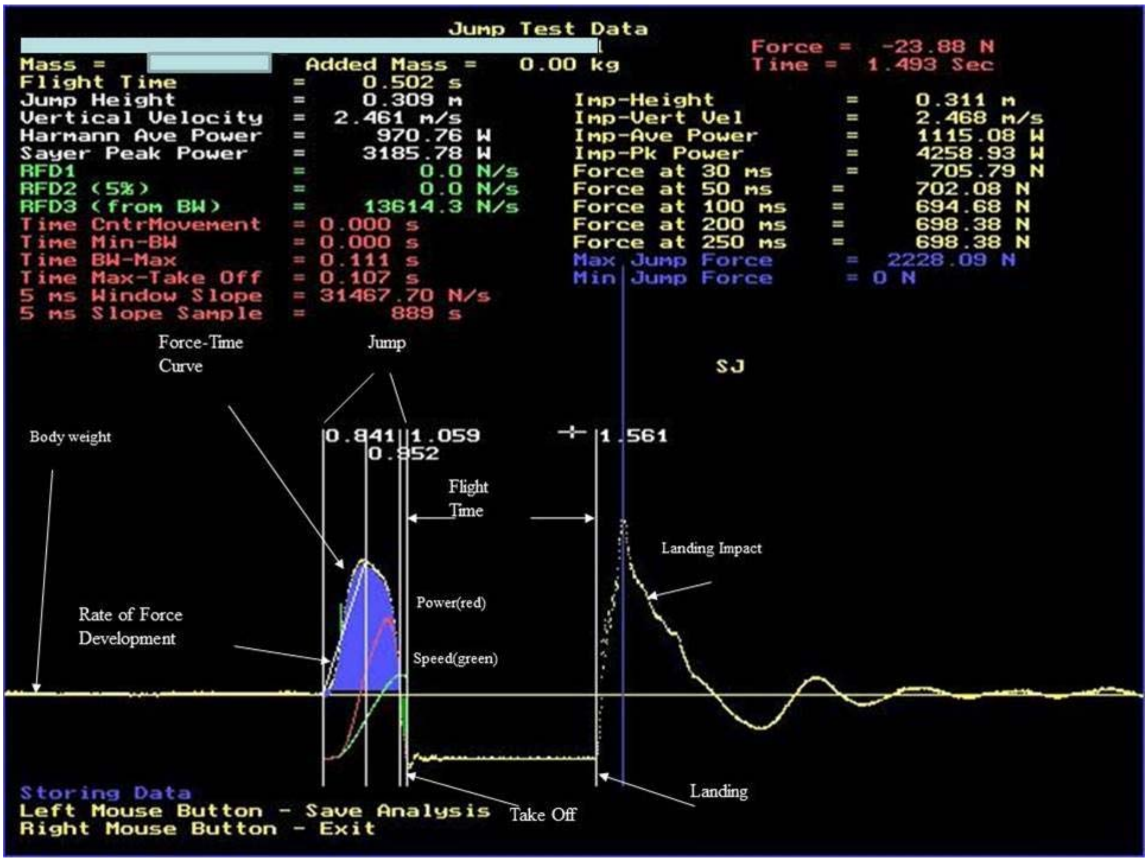

Figure 1. Force-time curve example of a static jump.

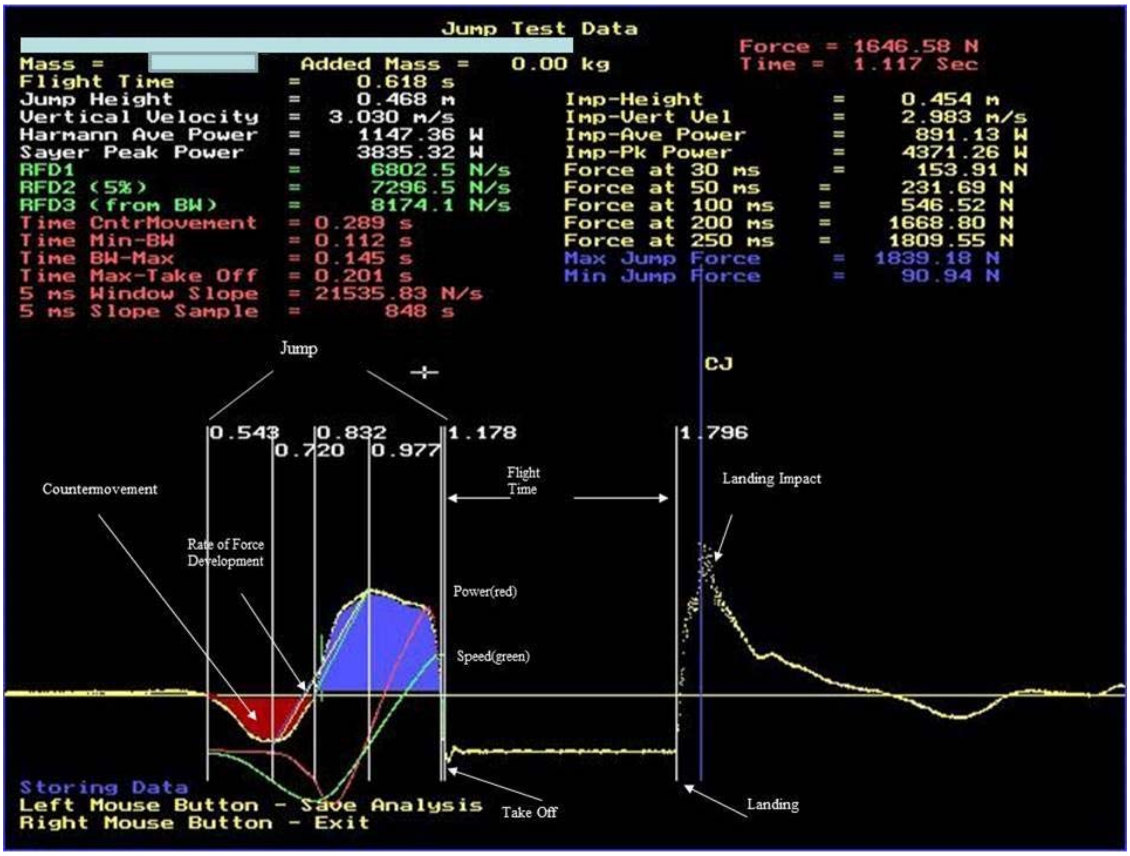

Figure 2. Force-time curve example of a countermovement jump.

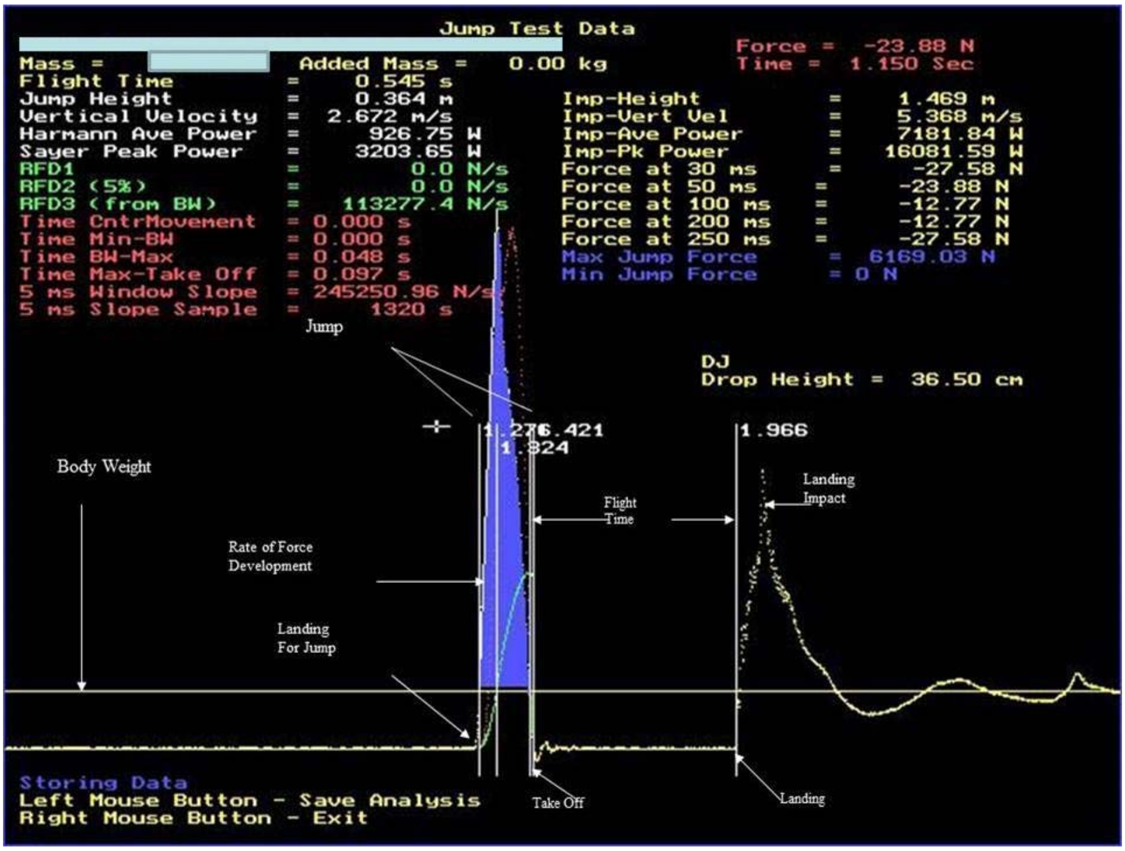

Figure 3. Force-time curve example of a drop jump.

The average of two trials for MXHT, RFD, and PF were used for further data analyses. The average of two trials of PP was used for further analyses for all jumps except the DJs. The lack of kinematics to confirm the transition from downward impact to upward jump on the UDJ and LDJ efforts did not permit power assessment. The goal of the LDJ technique was a ‘bounce drop jump’ that does not result in an identifiable countermovement from the force-time data alone. The UDJ instructions tried to achieve a ‘near’ bounce DJ, within safety limits, such as the type of UE impacts observed in tumbling and vaulting (McNeal, et al., 2007; Sands, 2014; Sands, Alumbaugh, McNeal, Murray, & Stone, 2014). All measured variables were compared between the jump and push-up movements (Henry, 1967).

Maximum jump heights were calculated from flight times produced during each jump type. Peak force and PP data were allometrically scaled using methods described by Auerbach et al. (2011) and Gayon (2000). Specific sample allometric scaling was adopted because of the youth and diminutive stature of young male gymnasts. We were concerned that the typical adult-based methods of allometric scaling would bias our results. Specifically, the natural logarithms for body mass, peak force, and peak power were calculated. Next, using regression equations, the slopes between body mass and peak force and body mass and peak power were calculated. Finally, the raw values of peak force and peak power were divided by the body mass of the subject raised to the slope found for each relationship. Using this approach, each variable includes a body mass that is raised to its own unique exponent, thus allometrically scaling each variable using its own unique relationship with either PF or PP. For the UE, the effective mass of the subject was measured while the subject was positioned in a standard push-up position with their hands on the force platform. For LE data, the entire body mass of the subject was used for allometric scaling.

A series of 2 (UE or LE) x 3 (SJ, CJ, DJ) repeated measures ANOVAs were used to analyze the data within this study. If the sphericity assumption was violated, Greenhouse-Geisser adjusted values were used. Pearson zero order product-moment correlation coefficients were used to examine the relationships between the relative gains or losses in output parameters between the upper and lower extremities. All statistical analyses were completed using SPSS 21 (IBM, New York, NY) and statistical significance was set at $p \leq 0.05$. Intraclass correlation coefficients, standard error of the measurement, minimum differences to be considered real, and paired-samples t-tests were calculated to assess the test-retest reliability of each variable using previously discussed methods (Weir, 2005) and are displayed in Table 1. Effect sizes (η^2_p) and statistical powers were calculated. Ninety-five percent confidence intervals were used for *post hoc* analyses.

RESULTS

Allometry

Calculation of the slope values for the relationships of the UE effective mass or entire body mass to each variable, as described above, showed that all values exceeded 1.0 (Table 2).

Upper versus Lower Extremities

Descriptive data for UE and LE performance measures are shown in Table 3. Statistical differences were found for all calculated variables: MXHT ($F_{1,20} = 235.36$, $p < 0.001$, $\eta^2_p = 0.92$), RFD ($F_{1,20} = 48.16$, $p < 0.001$, $\eta^2_p = 0.71$), PF ($F_{1,20} = 307.33$, $p < 0.001$, $\eta^2_p = 0.94$), PP ($F_{1,20} = 1551.43$, $p < 0.001$, $\eta^2_p = 0.99$).

No statistically significant relationships existed between the relative change in MXHT between the jump types of the upper and lower extremities for SJ-CJ ($p = 0.089$, r = 0.380), SJ-DJ ($p = 0.290$, r = 0.242), or CJ-DJ ($p = 0.839$, r = -0.047). Statistically significant relationships existed between the relative changes in RFD between jump types of the upper and lower extremities for

SJ-DJ ($p < 0.001$, r = 0.799) and for CJ-DJ ($p = 0.013$, r = 0.533), but not for SJ-CJ ($p = 0.992$, r = -0.002). There was statistically significant relationship between the relative change in PF between the upper and lower extremities for SJ-DJ ($p = 0.014$, r = 0.530), but not for SJ-CJ ($p = 0.465$, r = -0.169) or CJ-DJ ($p = 0.117$, r = 0.353). Finally, no statistically significant relationships existed between the relative change in PP between the jump types of the upper and lower extremities for SJ-CJ ($p = 0.324$, r = 0.226), SJ-DJ ($p = 0.808$, r = -0.056), or CJ-DJ ($p = 0.414$, r = -0.188).

Jump Types and Interactions

All calculated variables for jump-types and jump-type by UE and LE interactions were statistically different. Main effects for jump type were statistically different: MXHT ($F_{1,20} = 18.72$, $p < 0.001$, $\eta^2_p = 0.48$), RFD ($F_{1.01,20.09} = 46.73$, $p < 0.001$, $\eta^2_p = 0.70$), PF ($F_{1.15,22.97} = 308.71$, $p < 0.001$, $\eta^2_p = 0.94$), and PP ($F_{1.08,21.50} = 895.11$, $p < 0.001$, $\eta^2_p = 0.98$). Interaction effects (UE and LE by jump type) were found for MXHT ($F_{2,40} = 26.21$, $p < 0.001$, $\eta^2_p = 0.57$), RFD ($F_{1.01,20.14} = 45.75$, $p < 0.001$, $\eta^2_p = 0.70$), PF ($F_{1.27,25.44} = 17.76$, $p < 0.001$, $\eta^2_p = 0.47$), and PP ($F_{1.09,21.77} = 413.44$, $p < 0.001$, $\eta^2_p = 0.95$).

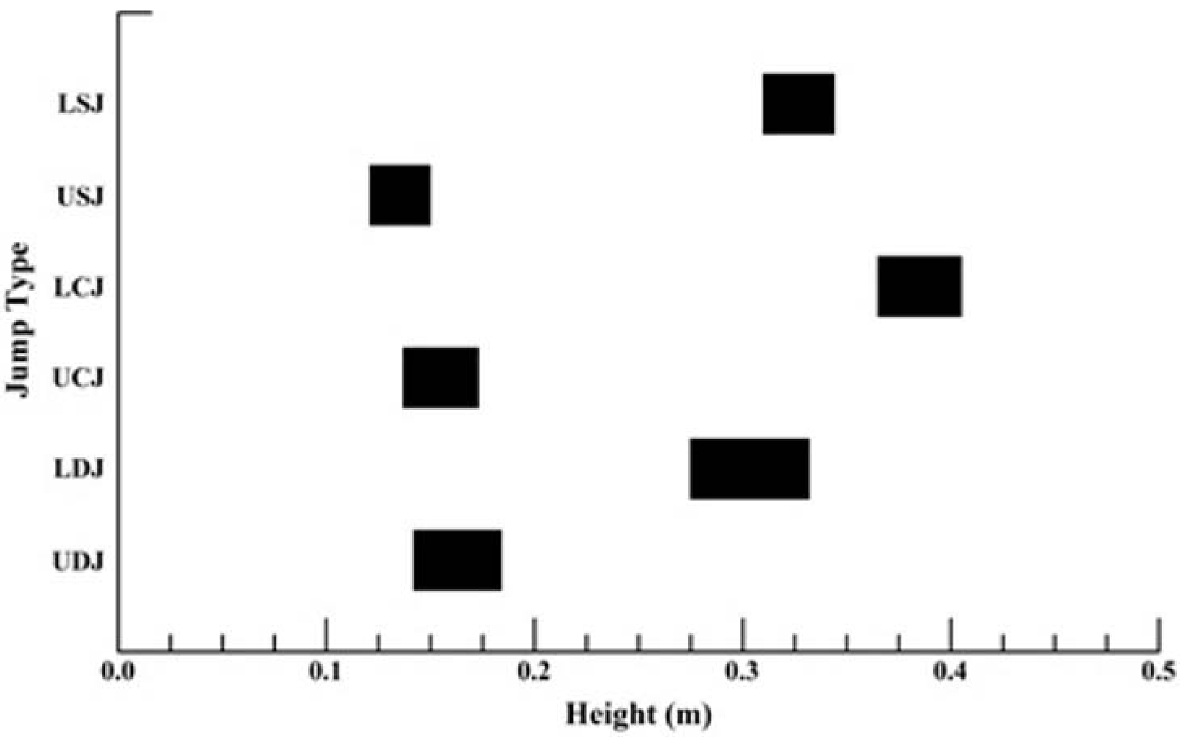

Figure 4. 95% confidence intervals for maximum jump height. USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump.

Table
Test-retest reliability statistics for maximum jump height, rate of force development, peak force, and peak power.

Exercise	Max Heigh ICC	SEM	MD	*p*
USJ	0.85	0.01	0.03	0.132
UCJ	0.86	0.01	0.04	0.001
UDJ	0.92	0.01	0.04	0.031
LSJ	0.83	0.02	0.05	0.062
LCJ	0.95	0.01	0.03	0.177
LDJ	0.96	0.01	0.03	0.019
	Rate of Force	Development		
	ICC	SEM	MD	*p*
USJ	0.93	498.10	1380.67	0.439
UCJ	0.91	532.51	1476.03	0.305
UDJ	0.82	449.00	1244.57	0.308
LSJ	0.91	1248.92	3461.83	0.660
LCJ	0.89	939.07	2602.97	0.424
LDJ	0.85	25903.12	71799.79	0.202
	Peak Force			
	ICC	SEM	MD	*p*
USJ	0.99	0.08	0.22	0.905
UCJ	0.99	0.17	0.47	0.195
UDJ	0.91	1.11	3.08	0.285
LSJ	0.98	0.27	0.74	0.250
LCJ	0.99	0.26	0.72	0.722
LDJ	0.94	1.89	5.23	0.617
	Peak Power			
	ICC	SEM	MD	*p*
USJ	0.97	0.08	0.24	0.172
UCJ	0.99	0.17	0.47	0.134
UDJ	0.99	0.64	1.76	0.127
LSJ	0.83	1.78	4.93	0.516
LCJ	0.99	0.24	0.67	0.154
LDJ	0.99	1.51	4.18	0.469

Notes: USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump; ICC = intraclass correlation coefficient; SEM = standard error of the measurement; MD = minimum difference to be considered real; *p* = paired-samples t-test p-value between each trial

Table 2
Slopes used for allometric scaling of peak force and peak power.

Exercise	Allometric Scaling Slope	
	Peak Force ($N/kg^{a\ or\ c}$)	Peak Power ($W/kg^{b\ or\ d}$)
USJ	1.307[a]	1.774[b]
UCJ	1.233[a]	1.492[b]
UDJ	1.062[a]	1.291[b]
LSJ	1.128[c]	1.091[d]
LCJ	1.049[c]	1.150[d]
LDJ	1.187[c]	1.152[d]

Notes: USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump

Table 3
Upper and lower extremity performance measures for static, countermovement, and drop jumps (Mean ± SD): n = 21.

Exercise	Max Height (m)	RFD (N/s)	Peak Force ($N/kg^{a\ or\ c}$)	Peak Power ($W/kg^{b\ or\ d}$)
USJ	0.14 ± 0.03	2632.22 ± 1882.65	6.4 ± 0.8[a]	1.82 ± 0.49[b]
UCJ	0.16 ± 0.04	3636.00 ± 1775.02	11.9 ± 1.7[a]	5.68 ± 1.70[b]
UDJ	0.16 ± 0.05	3636.95 ± 1058.31	23.5 ± 3.7[a]	22.96 ± 6.36[b]
LSJ	0.33 ± 0.04	6551.42 ± 4163.07	16.5 ± 1.9[c]	39.53 ± 4.31[d]
LCJ	0.38 ± 0.05	4255.02 ± 2831.40	20.4 ± 2.6[c]	29.55 ± 2.43[d]
LDJ	0.30 ± 0.06	103053.53 ± 66881.57	39.8 ± 7.7[c]	121.17 ± 15.07[d]

Notes: USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump; RFD = rate of force development; a = upper extremity peak force scaling factor from Table 2; b = upper extremity peak power scaling factor from Table 2; c = lower extremity peak force scaling factor from Table 2; d = lower extremity peak power scaling factor from Table 2.

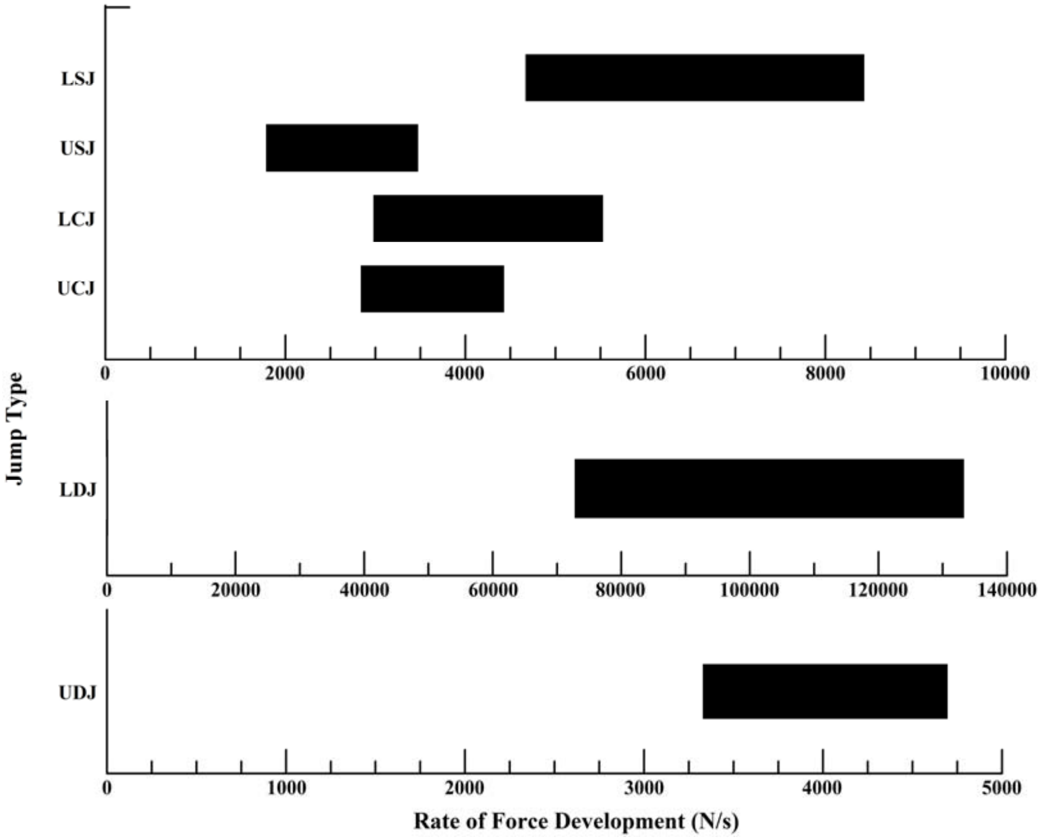

Figure 5. 95% confidence intervals for rate of force development. Note that the drop jump confidence intervals require a different scale and are shown separately at the bottom of the figure. USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump.

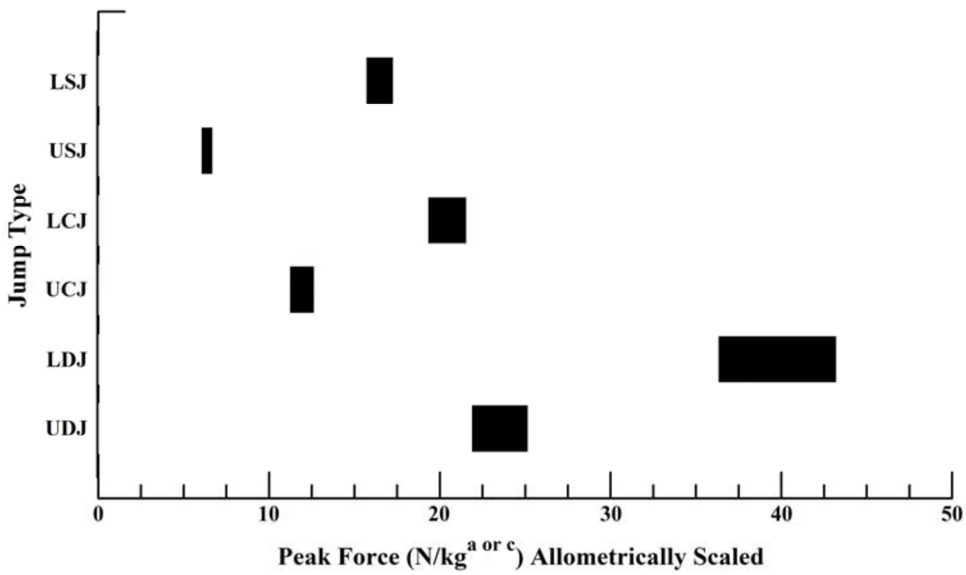

Figure 6. 95% confidence intervals for peak force allometrically scaled. USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; UDJ = upper extremity drop jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; LDJ = lower extremity drop jump; a or c = upper or lower extremity peak force scaling factor from Table 2, respectively.

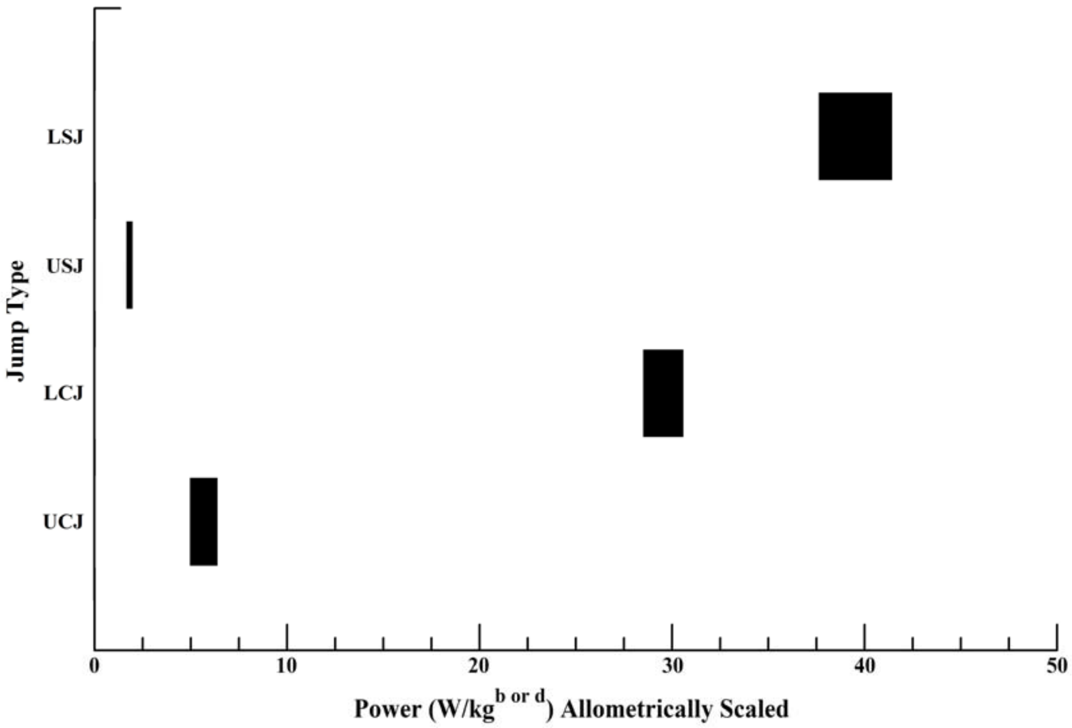

Figure 7. 95% confidence intervals for peak power allometrically scaled. Note that peak power was not calculated for the drop jumps. USJ = upper extremity static jump; UCJ = upper extremity countermovement jump; LSJ = lower extremity static jump; LCJ = lower extremity countermovement jump; b or d = upper or lower extremity peak power scaling factor from Table 2, respectively.

DISCUSSION

The reliability values displayed in Table 1 indicated that the trials data were stable. Table 2 shows the slopes or scaling exponent values for allometric scaling. Unique scaling exponent values were used because of the athletes' youth and the potential for mistaken assumptions using traditional scaling exponents such as 0.67 (Auerbach & Sylvester, 2011; Batterham, Tolfrey, & George, 1997). Table 2 shows that the scaling exponents were positive and greater than 1.0 for all variables. The scaling exponent values indicate that the variable increases more rapidly than body size, as defined by mass in these athletes. This information appears reasonable given the youth, selection to a high performance level national team, specific fitness, competitive success, and diminutive size of young male gymnasts (Carter, Ross, Aubry, Hebbelinck, & Borms, 1982; Dotan, Goldbout, & Bar-Or, 1980).

Our hypothesis that UE and LE jump variable values would differ was supported. Jump heights, PF, and PP all indicated a difference between UE and LE. However, RFD values showed little difference between the UCJ and the LCJ and were comparatively close to the USJ and LSJ, although the LSJ RFD reached greater magnitudes. The UDJ RFD values were close to both the UE and LE RFD values for SJs and CJs. Lower extremity efforts showed greater magnitudes in all variables except RFD in which the LCJ was similar to the UCJ. The relationships observed in comparisons of UE and LE variables may indicate that the UEs of these athletes had reached a performance ceiling in terms of RFD, while the LEs have a greater range of ability and/or adaptability regarding RFD. Of course, the LEs have considerably more muscle and larger joints to apply to rapid force production.

The allometrically scaled PF trended upward across the USJ, UCJ, and UDJ and the LSJ, LCJ, and LDJ. Interestingly, the only relationship between the upper and lower extremities that indicated a similar change in performance between jump types was the difference between the SJ and DJ. Allometrically scaled PP was not calculated for the UDJ and LDJ because of an inability to determine the transition from a downward direction of the impact to the upward direction of the jump. The USJ and UCJ followed our hypothesized trend of increasing performance while the LSJ and LCJ did not. The young gymnasts produced more power in the LSJ than the LCJ. The trends of these results indicate that the young gymnasts, while strong and explosive, do not appear to be well skilled in the use of the SSC. A comparable study using the same equipment and software with world and Olympic level divers (Sands, et al., 1999) showed some mixed results when comparing lower extremity SJ with CJ variables; however, the divers showed markedly improved performances in LDJ variables. Moreover, the divers generally performed in congruence with our stated hypotheses of performance magnitudes increasing from SJ to CJ to DJ. Gymnasts also differ from divers in the gymnast's general reticence to use weight training for conditioning, preferring to rely on body weight and repeated performance of gymnastics skills in a circuit-type format (Jemni, Sands, & Friemel, 2002; Sands, 2000).

In our study, the 95% confidence intervals showed that jump height of the LCJ was greater than the LSJ, but the LDJ was similar to the LSJ. Jump heights trended upward from USJ to UDJ, but did not demonstrate large differences. Additional analysis of the relationships between the relative gains or losses in MXHT revealed that the changes in performance between jump types were not similar between the upper and lower extremities. This may be due to several reasons including familiarity with the tasks, joint sequencing of each movement, and the amount of contributing musculature within the upper and lower extremities. Future research may consider performing an in-depth analysis that examines the differences between SJ-, CJ-, and DJ-type jumps between the upper and lower extremities.

The apparent inability of the young gymnasts to maximize their SSC actions, as demonstrated here, is paradoxical considering the powerful take-offs these athletes perform in tumbling and vaulting. The primary source of this paradox may be the reliance of gymnasts on jumping performances using soft mats and/or sprung surfaces (Arampatzis, 2002; Arampatzis, Bruggemann, & Klapsing, 2001). Jumping actions that involve landing on a steel plate may not share enough similarity with the specific jumping actions observed in gymnastics (Sands, 2014; Sands, et al., 2014), regardless of the extremities involved. Gymnasts jump and land using their LEs in LSJ, LCJ, and LDJ manners when tumbling and vaulting. The SJ variables were expected to be lower than the CJ variables. Countermovement jump variables were expected to be lower than DJ variables. The reasoning behind these assumptions was that gymnasts regularly and systematically train all types of jumps, but rely particularly heavily on the DJ-type of take-off for tumbling and vaulting. Common take-off foot contact durations in tumbling range from approximately 120 ms to 275 ms (Sands, 1984; Sands et al., 2013). As such, these take-off contact durations are somewhat longer than those desired by most SSC exercises and are performed on elastic spring surfaces such as the floor exercise spring floor and vault board. The longer durations of take-off foot contacts and systematic training on elastic surfaces may explain why these gymnasts were not as effective in DJs and the associated rapid SSC in this test context (Bobbert & van Zandwijk, 1999; Schmidtbleicher, 2002).

Gymnasts jump and land using their hands in USJ, UCJ, and UDJ manners when tumbling, vaulting, and during releases and re-grasps of the apparatuses. Gymnasts use a stretch-shortening-like action from the hands particularly in tumbling and vaulting (Ferkolj, 2010; Penitente, Sands, McNeal, Smith, & Kimmel, 2010). Gymnasts' UEs suffer from similar injuries as seen in the LEs, both related to impact loading (Burt, Ducher, Naughton, Courteix, & Greene, 2013). However, there is no doubt that UE SSC actions are qualitatively and quantitatively different from the LE (Koch, et al., 2012; Li, et al., 2000; Mangine, et al., 2008). The results from this study showed that the UEs were less explosive than the LEs with the exception of DJs.

Children performing SSC exercise may exhibit modified and age/maturity-related muscle stiffness properties (Lloyd, Oliver, Hughes, & Williams, 2011b). Movement variability relative to the types of jumps has been shown in youngsters with vertical jump assessments involving SJs, CJs, and DJs (Meylan, Cronin, Oliver, Hughes, & McMaster, 2012). As children mature, the neuromuscular management of the SSC activities may shift to greater reliance on supra-spinal feed-forward mechanisms (Lloyd, Oliver, Hughes, & Williams, 2012). Others have postulated that young males may have similar SJs and CJs that follow adult-like patterns while SSC activities follow an alternative pattern (Lloyd, Oliver, Hughes, & Williams, 2011a). Stretch-shortening cycle behavior in CJs with an arm swing versus without showed that children exhibit about twice the movement variability of adults without an arm swing, but that athletes trained in jumping, such as basketball, do not exhibit the same movement variability (Gerodimos et al., 2008). This study prevented arm swing actions to ensure that the jumper's LE jump techniques were more reflective of LE actions. Athletes typically find static-type jump actions to be awkward. The role of maturation, training, jumping technique context, and other factors may contribute to the young gymnast's ability or inability to capitalize on the SSC during CJs and DJs.

CONCLUSIONS

Allometric scaling exponents greater than 1.0 existed for the junior male gymnast subjects within this study, indicating that variables increased more rapidly than body size. The allometric scaling approach used in the current study indicated that the exponent used for scaling was unique for each body portion and jump condition. This information is the first we have found showing this phenomenon. Coaches may need to increase their vigilance and understanding regarding determination of physical maturation via peak height velocity or other measures by including measures of strength and power fitness.

Young male gymnasts follow the premise partially that jumping ability should proceed from low to high via static-, countermovement-, and drop-types of UE and LE jumps by using progressively greater SSC skills and abilities. However, these gymnasts were unusual in that their ability to use the SSC may be attenuated due to physical maturation, use of softer take-off and landing surfaces, and lack of emphasis or access to weight training. The addition of a periodized resistance training program may benefit young male gymnasts in developing the necessary musculature needed to improve their UE and LE jumping ability and use of the SSC (Baker, 1996). It is suggested that the resistance training program should place an emphasis on developing general strength, especially with a younger population, before transitioning to more explosive type movements. The training stimulus (i.e. tumbling, vaulting, etc.) received by young gymnasts may be sufficient in training SSC movements and therefore additional plyometric volume may be unnecessary.

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