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Original Article

Association and predictive abilityof vertical countermovement jump performance on unilateral agility in recreationally trained individuals

MARTIN S. DIETZE-HERMOSA[1], SAMUEL MONTALVO[2], NICHOLASR. CUBILLOS[3], MATTHEW P. GONZALEZ[4], SANDOR DORGO[5]
[1,2,3,4,5,]Fitness Research Facility, Department of Kinesiology, The University of Texas at El Paso, El Paso, TX, UNITED STATES OF AMERICA

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Abstract
Introduction: Many sporting activities require both vertical jumping in combination with agility. Yet, both vertical jumping and agility can be executed either bilaterally or unilaterally.**Problem Statement and Approach:**There exist no literature exploring the association between unilateral agility with vertical jump performance variables.Thus, the purpose of this study was todetermine associationsand predictive ability between performance measures during unilateral and bilateral vertical countermovement jumpswith unilateral agility measures.**Material and Method:** Thirty recreationally active adults participated in two non-consecutive sessions. During the first session,participants completed three trials of right-sideunilateral countermovement jumps, left-side unilateral countermovement jumps, and bilateral countermovement jumpsin a randomized order. All jumps were performed akimbo, on force platforms, withthirty seconds of rest between trials. During the second session,participantscompleted two distinct unilateral agilitymaneuvers:single leg up three-back one and single leg cross hops, and were given two trials for each maneuver with thirty seconds rest between trials. The average of all completed trials for all countermovement jumps and agility maneuvers were used for statistical analysis. Spearman's*R* correlation were used to find significant associations between completion time for the agility maneuvers and jump height, peak force, relative force, peak power, relative peak power, and landing force for all countermovement jumpconditions. **Results:**There were significant correlations between the cross hop and up three-back one agility maneuver completion time with countermovement jump height, peak force, peak power, relative peak power, and landing force during both unilateral and bilateral jumps. **Conclusions:**There appears to be an association between certain performance measures during bilateral and unilateral countermovement jumpsand unilateral agility. Peak power and landing force assist in predicting unilateral agility completion time. Therefore, coaches may desire to implement unilateral jumping with individuals necessitating single leg agility to complete their desired exercise or sport activity.
Key Words: **single leg; rate of force development; coordination; hopping; quickness; change of direction**

Introduction

Agility is described as any quick combination of braking, changing direction, and accelerating while maintaining motor control, in either a vertical or horizontal direction, in response to a stimulus (Y. Hachana et al., 2014; Reilly, Bangsbo, & Franks, 2000; Sheppard, Young, Doyle, Sheppard, & Newton, 2006). Agility is important in athletic events such as soccer, basketball, football, and hockey where emphasis is placed on the ability to change directions quickly(Warren Young & Farrow, 2013). In fact, the literature supports agility as an important predictor of overall sports performance (Garcia-Gil et al., 2018; Harman, Rosenstein, Frykman, & Rosenstein, 1990). Due to the direct application of agility in sports performance, the desire to increase agility and performance measures related to agility has become of great interest to strength and conditioning professionals.

Lower body rate of force development, as measured by the countermovement jump (CMJ), has been shown to have a relationship with agility (Henry, Dawson, Lay, & Young, 2016; Meylan et al., 2009). Consequently, training aimed at increasing CMJ performance is frequently implemented in strength and conditioning programs, particularly if the sport or physical activity demands jumping in addition to agility. However, lower body movements, such as jumping and agility, can be bilateral (jumping off of two legs) or unilateral (jumping off one leg) dependent on the task.Various jumps and propulsive forces are also generated unilaterally (Meylan et al., 2009). Thus, assessing unilateral jumping and agility performance may present advantageous benefits such as determining any asymmetry between limbs, which may indicate increased risk for injury (Meylan et al., 2009). Previous literatureimplementingsingle leg change of direction, agility, and hopping maneuvers have indicated direct relevance for athletic activities as well as assessing return to play (Booher,

Corresponding Author: SANDOR DORGO, E-mail: sdorgo@utep.edu

Hench, Worrell, & Stikeleather, 1993; Millikan, Grooms, Hoffman, & Simon, 2019). Consequently, unilateral training in addition to bilateral training is often implemented in exercise programs.

One study exploring unilateral and bilateral vertical jump training concluded that unilateral training reduced jump asymmetry between limbs and led to greater enhancements in actions that required applying force unilaterally in basketball players (Gonzalo-Skok et al., 2017). Another study suggests that both bilateral and unilateral training may be equally suited to improve lower body strength, 40-m speed, and change of direction in rugby players (Speirs, Bennett, Finn, & Turner, 2016). More recently, a study concluded that unilateral plyometric training was more effective at increasing both single- and double-leg jumping performance, isometric leg press force, and rate of force development compared with bilateral training (Bogdanis et al., 2019).

Yet, these studies have not examined the association between CMJ performance and unilateral agility,withvery little research exploring single leg agility. While many sports are mostly dependent on bilateral agility performance, such as running based agility sports including soccer, basketball, and football, some other sports display situations where an athlete must demonstrate advanced unilateral agility skills for high quality sports performance. Examples can include single-leg supported movements seen in skating sports (ice hockey, figure skating), in combat sports (wrestling, judo, MMA, taekwondo, karate), or game specific scenarios in ground-based team sports (basketball layup, avoiding tackles in American football).Various studies exploring unilateral training and its impact on agility have primarily used bilateral agility assessmentssuch as the pro-agility, Illinois agility, or T-tests (Fisher & Wallin, 2014; Speirs et al., 2016). This gives rise to a pertinent question in the field of strength and conditioning regarding the relationship between unilateral jumping and agility.

Thus, the purpose of this study was to determineassociations between unilateral and bilateral CMJ performance and unilateral agility performance in recreationally trained adults.Additionally, significant predictors of unilateral agility were explored.It was hypothesized that there would be an association between measures of CMJ performance and completion time during the agility tests with certain CMJ performance variables displaying significant predictive ability.

Material & methods

Participants

A cross-sectional study design was adopted with outcome variables measured during two separate sessions. During session one, anthropometrics (height, weight, leg length, and shoe size) were obtained. Additionally, participants performedthree jumps under three different jumping conditions (three jumps per condition; nine total jumps). The second session required participants to complete two unilateral agility maneuvers (two trials per unilateral agility maneuver; four total agility maneuvers; eight total trials).To ensure full recovery, sessions were completed on non-consecutive days with 48-72 hours in between sessions. Thirty healthy recreationally trained participants (n = 30: 14 males and 16 females) completed this study. For inclusion in the study, participants were between 18 and 30 years of age and were injury free for the lastthree months. Furthermore, participants were currently involved in regular exercise and/or recreational sports. Participants were recruited from the university's Kinesiology Departmentand all participants signed an informed consent prior to data collection.The study protocols conformed to the Deceleration of Helsinki and was approved by the university's IRB committee. An *apriori* power analysis was conducted using G*Power(version 3.1, Universität Kiel, Germany); a total of twenty participants were needed to find a correlation of (r= 0.59) with power (1 - β) set at 0.80 and α = 0.05 with correlation size obtained from the association between CMJ height and T-test agility completion time (Alemdaroğlu, 2012).

Measures

<u>Anthropometrics</u>

Participants' body weight and height were measured using a Detecto scale and stadiometer, respectively. During the height and weight measurements, participants were instructed to remove their shoes and stand with their back straight and head in neutral position. Height was measured to the nearest centimeter.Leg length was assessed with a metric tape measure (Gulick, M-22 CII, Michigan, USA) and recorded in centimeters (cm). Participants were asked to stand erect with their feet flat on the floor. Lengthwas measured as the distancefrom the anterior superior iliac spine and the medial malleolus.The tape measure was placed on both landmarks ensuring the tape measure ran along the body smoothly. The leg length was measured to the nearest 0.1 cm.Descriptives are presented in Table 1.

Table 1. Anthropometric Measures

	n	Height (cm)	Mass (kg)	Age (years)	Left Leg Length (cm)	Right Leg Length (cm)
Males	14	178.56 ± 9.83	92.45 ± 18.14	24.31 ± 2.92	98.00 ± 7.56	98.39 ± 7.20
Females	16	161.61 ± 5.67	64.46 ± 14.24	22.94 ± 1.43	89.59 ± 4.45	89.50 ± 4.53

Note: Values are presented as mean ± standard deviation

Vertical Jump Performance Testing

Prior to jump testing, participants performed a warm-up consisting of jogging at a self-selected pace on a treadmill for five minutes and a series of dynamic drills (walking knees to chest, lunge walks, high knee, butt kicks, and body weight squats) similar to previous jumping research (Meylan et al., 2009).

Participants then completedthree distinct CMJ conditions (bilateral vertical jump; unilateral-left vertical jump; unilateral-right vertical jump) in a randomized order. For each jumping condition, three trials were collected.Participants were instructed to "keep their hands on their hips" during all jumps, similar to previous research (Carlock et al., 2004; Lake et al., 2018).Adouble-leg landing was implemented for unilateral jumps to reduce injury and increase participant safety(Wang, 2011). Participants were required to decent and achieve a 90-degree angle at the knee for all jumps which was visually enforced by a member of the research team. Additionally, subjects were instructed not to pause between the eccentric and concentric phases of the movement. A thirty second rest period was provided between each jumptrial as well as between jump conditions. The variables of interest for the CMJ were jump height (JH), peak force (PF), relative peak force (RPF), peak power (PP), relative peak power (RPP), and landing force (LF). Jump height was calculated as: $\frac{Take-Off\ Velocity\ ^\wedge 2}{2*Gravity(9.81m/s)}$.Relative peak force was calculated as: $\frac{Peak\ Force\ (N)}{Participants\ Mass\ (kg)}$. Peak power was calculated as: $Maximum\ value\ (force*velocity)prior\ to\ take\ off$.Relative peak power was calculated as: $\frac{Peak\ Power\ \ (W)}{Participants\ Mass\ (kg)}$ (Chavda et al., 2017).

Jumps were performed with participantscommencing on theforce platforms to ensure accuracy and reliability. Tape markers were placed on the forceplatforms indicating the appropriate landing position of the feet. If feet were not fully in contact with the force platform during the landing or if hands were removed from the hips during the jump, the jump trial was repeated.Kinetic data were obtained with two force platforms (1,000 Hz; Advanced Mechanical Technology, Inc., Watertown, MA, USA) and extracted through Vicon Nexus (Vicon Motion Systems, Ltd., Oxford, UK)then imported into Matlab(The MathWorks, Natick, MA, USA) for data filtering. Kinetic data were filtered using a fourth order low pass Butterworth filter and smoothed at 50Hz (Harry et al., 2020). The smoothed data were then imported into a Microsoft Excel sheet and utilized to obtain outcome measures during the vertical jump(Chavda et al., 2017).

Agility Maneuvers

All agility maneuvers were completed on a synthetic grass sports field.After a five to eight-minute warm-up consisting of a light jog, followed by dynamic stretching exercises, participants completedtwo trials of two unilateral agility maneuversin a randomized order: 1)Single Leg Up Three-Back One,and2) Single Leg Cross Hops (see Figure 1). Participants were given thirty seconds rest between each agility trial to ensure proper recovery, following a rest protocol comparable to prior research (Munro & Herrington, 2011; Reid, Birmingham, Stratford, Alcock, & Giffin, 2007). An agility ladder was used with a fixed distance for the agility maneuvers to be completed. Agility performance was defined as the time it took for participants to complete the designated distance for the two agility maneuvers. Timing gates(Brower Timing System, Draper, UT, USA)wereutilized to accurately capture completion time which is the variable of interest(Younes Hachana et al., 2013; Sekulic, Spasic, Mirkov, Cavar, & Sattler, 2013). The placement of the timing gates and the dimensions of the agility ladder were consistent across all trials for both agility maneuvers.

The agility-speed ladder was custom made following typical dimension of ladders used in sport and exercise (see Figure 1). Specifically, the ladder was created with white athletic tape which adhered to the synthetic field and could be easily seen by participants. The agility-speed ladder was 4.57 m long, 50.80 cm wide, dividing tape "rungs" were parallel and placed 45.70 cm apart, which resulted in ten total agility boxes (see Figure 1). Timing gates were placed 2.03 m apart at both the first and last rung. The same agility-speed ladder dimensions were used for all participants and trials to ensure reliability.

The Single Leg Up Three-Back One maneuverwas adopted from Hewett et al. (2006). In brief, participants start the maneuver balancing on one foot, then hop through an agility-speed ladder utilizing the same leg up three boxes, back one, and repeat this cycle until the ladder is completed.In total, the participant completed 19 total foot contacts per trial and a total of 4.5 total cycles to complete the agility ladder. The Single Leg Cross Hops maneuverinvolves commencing on one leg and hopping in a diagonal pattern through the agility-speed ladder from side to side in a cyclical motion until the end of the agility ladder is reached.The participants completed 21 foot contacts per trial requiring a total of 5.5 cycles to complete the agility ladder. The Single Leg CrossHop maneuver, although in the present study adapted using the speed-agility ladder, has been utilized in prior research (Munro & Herrington, 2011; Ross, Langford, & Whelan, 2002).The agility ladder dimensions and course completion time are similar to those used in sports performance and previous literature(Haff, 2016; Hess, Joyce, Arnold, & Gansneder, 2001; Ng, Cheung, & Raymond, 2017). Thus, the duration of the agility maneuver is not suspected to interfere with performance by causing excessive fatigue yet able to provide a sensitive measure of single leg agility.

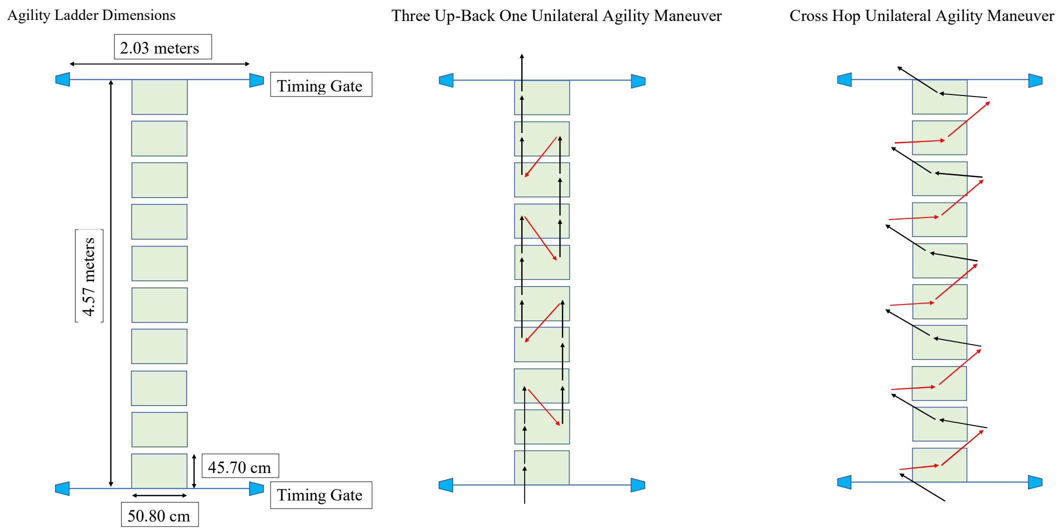

Figure 1. Illustration of both agility maneuvers implemented and dimensions of custom speed-agility ladder
Note: Left: Dimensions;Middle: Up Three-Back One; Right: Cross Hop. Color change denotes a change in direction

Trials were repeated if the participant deviated from the pattern, lost balance and the opposite foot came in contact with the ground, or the participant stepped on the athletic tape. The same researcher supervised all sessions ensuring the quality of recorded data and monitored that all testing trials were completed with appropriate technique. Data was then transferred into aMicrosoft Excel spread sheet and data accuracy was verified.

Table 2. Counter Movement Jump and Agility Measurements

	Minimum	**Maximum**	**Mean (SD)**
Cross Hop Left (s)	6.65	13.8	8.09 (1.30)
Cross Hop Right (s)	6.3	14.95	8.20 (1.53)
Up Three, Back One Left (s)	6.39	13.71	8.30 (1.32)
Up Three, Back One Right (s)	6.1	13.78	8.37 (1.44)
SL CMJ Left Jump Height (cm)	4.5	26.0	11.88 (5.23)
SL CMJ Left Peak Force (N)	320.0	1022.0	610.73 (190.39)
SL CMJ Left Relative Force (N/kg)	4.48	12.88	8.13 (2.10)
SL CMJ Left Peak Power (W)	895.0	3862.0	1976.9 (758.21)
SL CMJ Left Relative Power (W/kg)	15.83	39.83	25.66 (5.69)
SL CMJ Left Landing Force (N)	1260	4106.5	2517.03 (706.53)
SL CMJ Right Jump Height (cm)	1.0	17.5	9.5 (4.0)
SL CMJ Right Peak Force (N)	229.0	863.0	496.41 (139.37)
SL CMJ Right Relative Force (N/kg)	2.0	13.35	7.21 (2.55)
SL CMJ Right Peak Power (W)	693.0	2460.5	1609.38 (419.13)
SL CMJ Right Relative Power (W/kg)	6.2	30.55	22.56 (5.61)
SL CMJ Right Landing Force (N)	1210.0	4620.0	2522.80 (809.76)
DL CMJ Jump Height (cm)	12.0	37.5	25.52 (6.96)
DL CMJ Peak Force (N)	472.0	1743.5	888.17 (300.33)
DL CMJ Relative Force (N/kg)	7.4	17.94	11.70 (2.47)
DL CMJ Peak Power (W)	1596.5	5520.5	3239.02 (1176.11)
DL CMJ Relative Power (W/kg)	26.59	55.47	41.93 (7.67)
DL CMJ Landing Force (N)	1538.5	4311.5	3003.32 (673.63)

Note: Values are presented as mean (standard deviation). SL = Single Leg; DL = Double Leg; CMJ = Countermovement Jump

Statistical Analysis

Reliability of trial performance for each jump condition and agility maneuver were calculated. Jump conditions displayed high agreement (DL CMJ ICC = 0.98; Left CMJ ICC = 0.89; Right CMJ ICC = 0.88). A high agreement was also found for agility trials (Left Cross Hop ICC = 0.86; Right Cross Hop ICC = 0.89; Left Three Up Back One ICC = 0.86; Right Three Up Back One ICC = 0.86). Thus,the average values from the three trials of each jumping condition and the two unilateral agility trials were utilized for this analysis. A Shapiro-Wilk normality test was conducted to ensure data normality. The time to completion for all agility tests were not normally distributed, therefore non-parametric statistics were used to determine the association between jumping performance and agility. Spearman's Rho (nonparametric test) correlations between each jumping variable (JH, PF, RPF, PP, RPP, and LF of all CMJs) and the agility variable (completion time) were conducted.Correlations were interpreted according to Hopkins (Hopkins, 2009)who has suggested that a correlation coefficient of 0.11–0.30 is considered small, 0.31–0.5 moderate, 0.51–0.7 large, 0.71–0.9 very large, and 0.9–0.99 nearly perfect. Mann-WhitneyU tests were conducted to see if completion time during agility maneuversdiffered between limbs; Independent T-tests were used for measures of unilateral CMJ performance.Additionally, PP and LF consistently displayed the strongest associations with unilateral Cross Hop agility across both unilateral and bilateral CMJs. Therefore, a linear regression analysis was conducted to explore whether PP and LF could predict unilateral Cross Hop agility performance. Three models were conducted for both the right and left Cross Hop maneuver. Model 1 included PP of the ipsilateral limb. Model 2 included PP and LF of the ipsilateral limb. Finally, model three included PP and LF of the ipsilateral limb and combined limbs. All statistical analyses were performed in SPSS 26 (Version 26.0. Armonk, NY: IBM Corp) at alpha level of 0.05.

Results

Unilateral Differences

There were no significant differences in completion time between the left and right Cross Hop (p=0.75) or Up Three-Back One agility maneuvers (p=0.82). However, there were significant differences in JH (p=0.04), PF (p=0.01), PP (p=0.02), and RPP (p=0.04) between single leg right and left CMJ. Relative Peak Force (p=0.13), and LF (p=0.97) did not differ between limbs. Table 3 displays the associations between unilateral agility maneuver completion times and JH, PF, RPF, PP, RPP, and LFduring unilateral and bilateral CMJs.

Cross Hops

There were moderateto very large associations between time to completion during the left Cross Hop andJH, PF, RPP, PP, and LF during left single leg CMJ.Jump Height, PF, PP, RPP, and LFduring bilateral CMJ were also associated with left Cross Hop completion time (see Table 3). Similarly, right Cross Hop completion time displayed large associationswith single leg right CMJ PP and LF. Lastly, JH, PF, PP, RPP, and LF during bilateral CMJ was significantly associated with right Cross Hop completion time (see Table 3).

Up Three-Back One

Peak Power, RPP, and LF during left single leg CMJ displayed moderate associations with completion time for the left Up Three-Back One agility maneuver. PF, PP, and LF during bilateral CMJ presented moderate associations with left Up Three-Back One completion time (see Table 3). Completion time during the right Up Three-Back One agility maneuver was moderately associated with right single leg CMJ JH, PP, RPP, and LF. Landing Forceduring bilateral CMJ displayed a moderate association with right Up Three-BackOne completion time (see Table 3).

Table 3. Vertical Countermovement Jump Performance Measures and Agility Tests Correlations

	Spearman's Rho			
	CH Left (s)	**CH Right (s)**	**UT-BO Left (s)**	**UT-BO Right (s)**
SL CMJ Left Jump Height (cm)	-0.57**	-0.56**	-0.35	-0.32
SL CMJ Left Peak Force (N)	-0.55**	-0.55**	-0.33	-0.27
SL CMJ Left Relative Force (N/kg)	-0.06	-0.06	-0.08	-0.15
SL CMJ Left Peak Power (W)	-0.71**	-0.74**	-0.45*	-0.34
SL CMJ Left Relative Power (W/kg)	-0.59**	-0.58**	-0.37*	-0.33
SL CMJ Left Landing Force (N)	-0.49**	-0.52**	-0.47**	-0.39*
SL CMJ Right Jump Height (cm)	-0.23	-0.24	-0.3	-0.40*
SL CMJ Right Peak Force (N)	-0.31	-0.26	-0.16	-0.21
SL CMJ Right Relative Force (N/kg)	0.03	0.05	-0.11	-0.19
SL CMJ Right Peak Power (W)	-0.64**	-0.69**	-0.49*	-0.51**
SL CMJ Right Relative Power (W/kg)	-0.29	-0.27	-0.35	-0.40*
SL CMJ Right Landing Force (N)	-0.62**	-0.64**	-0.28	-0.39*
DL CMJ Jump Height (cm)	-0.58**	-0.59**	-0.34	-0.28
DL CMJ Peak Force (N)	-0.62**	-0.71**	-0.45*	-0.34
DL CMJ Relative Force (N/kg)	-0.20	-0.27	-0.24	-0.25
DL CMJ Peak Power (W)	-0.67**	-0.75**	-0.40*	-0.28
DL CMJ Relative Power (W/kg)	-0.58**	-0.65**	-0.36	-0.32
DL CMJ Landing Force (N)	-0.61**	-0.59**	-0.44*	-0.36*

*Note: CMJ = Countermovement Jump; SL = Single Leg; DL = Double Leg; CH = Cross Hop;UT-BO = Up Three- Back One.*Correlation is significant at the 0.05 level** Correlation is significant at the 0.01 level*

Agility Performance Predictors

Tables 4 & 5 display the linear regression performed for the left and right Cross Hop agility maneuvers. For the unilateral left Cross Hop, models 1 and 2 were statistically significant, conversely model 3 was not. Likewise, model 1 and 2displayed statistically significance, however, model 3 did not for the unilateral right Cross Hop (see Tables 4 & 5).

Table 4. Left Cross Hop Multiple Linear Regression

	ß	**SE ß**	***B***	**p-value**	**R^2**	**model p-value**
MODEL 1						
Constant	9.61	0.61			0.21*	0.01
Left CMJ PP	-0.01	0.01	-0.46	0.01		
MODEL 2						
Constant	9.97	0.82			0.22*	0.04
Left CMJ PP	-0.01	0.01	-0.34	0.19		
Left CMJ LF	0.00	0.01	-0.16	0.51		
MODEL 3						
Constant	9.93	1.06			0.22	0.17
Left CMJ PP	0.01	0.01	-0.64	0.93		
Left CMJ LF	0.00	0.01	-0.24	0.54		
DL CMJ PP	0.00	0.01	-0.29	0.67		
DL CMJ PP	0.00	0.01	-0.08	0.82		

*Note:CMJ = Countermovement Jump; PP = Peak Power; LF = Landing Force; ß = unstandardized beta co-efficient; SE ß = standard error of ß; B = standardized beta co-efficient.(Model 1) Left countermovement jump peak power. (Model 2) Left countermovement jump peak power & left countermovement jump landing force. (Model 3) Left countermovement jump peak power & left countermovement jump landing force & bilateral countermovement jump peak power & bilateral countermovement jump landing force*Model significant at the 0.05 level*

Table 5. Right Cross Hop Multiple Linear Regression

	ß	**SE ß**	***B***	**p-value**	**R^2**	**model p-value**
MODEL 1						
Constant	10.94	1.08			0.20*	0.02
Right CMJ PP	-0.02	0.01	-0.45	0.02		
MODEL 2						
Constant	11.31	1.13			0.24*	0.03
Right CMJ PP	-0.01	0.01	-0.33	0.11		
Right CMJ LF	0.00	0.01	-0.23	0.27		
MODEL 3						
Constant	10.95	1.27			0.32	0.06
Right CMJ PP	-0.01	0.01	-0.35	0.12		
Right CMJ LF	0.00	0.01	-0.12	0.69		
DL CMJ PP	-0.01	0.00	-0.40	0.13		
DL CMJ PP	0.01	0.01	-0.25	0.42		

*Note:CMJ = Countermovement Jump; PP = Peak Power; LF = Landing Force; ß = unstandardized beta co-efficient; SE ß = standard error of ß; B = standardized beta co-efficient.(Model 1) Right countermovement jump peak power(Model 2) Right countermovement jump peak power & right countermovement jump landing force(Model 3) Right countermovement jump peak power & right countermovement jump landing force & bilateral countermovement jump peak power & bilateralcountermovement jump landing force. *Model significant at the 0.05 level*

Discussion

The purpose of this study was to determine the association between measures of unilateral and bilateral CMJ performance and unilateral agility in recreationally trained individuals.Additionally, predictors of unilateral agility performance were explored.It was hypothesized that there would be significant associations between measures of CMJ performance and unilateral agility completion time. The main findings of this study demonstrate no significant differences in unilateral agility completion time across both agility maneuvers. However, significant differences in JH, PF, PP, and RPP between left and right limbs during CMJ were present. Additionally, a moderate to very large association between unilateral agility maneuver completion time and certain measures of unilateral and bilateral CMJ performance. This partially supports our main hypothesis since not all measures of CMJ displayed a significant association with unilateral completion time. Moreover, a model containing PP and LF appear to explain a significant portion of variance during unilateral agility completion time.

Both PP and LF during bilateral and unilateral CMJ were strongly associated with completion time during both unilateral agility maneuvers. In the present study, the association between LF and agility completion time ranged from -0.36 to -0.64 constituting a moderate to large relationship. The PP achieved during bilateral and unilateral CMJ displayed an even stronger relationship with unilateral agility (r = -0.40 to -0.75). These values parallelearlierresearchthat has explored the relationship between agility and jumping performance in an adolescent and young adult population (Henry et al., 2016; Vescovi & McGuigan, 2008; Zapartidis, Makroglou, Kepesidou, Milacic, & Makri, 2018). For instance, Vescovi et al. (2008), found that lower body power, as measured by the bilateral CMJ, was significantly correlated with both the pro agility test (high school: r = -0.36; college: r = -0.61) and Illinois agility test (high school: r = -0.47; college: r = -0.55) in female high school and collegiate soccer players.These associations between PP and LF with agility completion time may be attributed to the importance of rapidly developing forces in a short amount of time to propel the body in a given direction. For instance, individuals displaying large amounts of LF coupled with the efficient use of the stretch shortening cycle could have contributed to shorter contact times and greater propulsive forces enabling a faster completion of the agility maneuver. Furthermore, greater ability to generate muscular power has been attributed to increased levels of acceleration and faster completion times of ground-based activities such as sprinting over relatively short distances(Morin et al., 2012). Therefore, greater muscular power capacity may have contributed to increased levels of acceleration allowing participants to complete the agility maneuver faster. Despite the associations found in the present study between CMJ performance measures and unilateral agility, the strength of the association, although still significant, was reduced for the Up Three-Back One maneuver.

The Cross Hop involves increased lateral movement and requires the individual to cover more distance in a single bound compared to the Up Three-Back One agility maneuver (see Figure 1). Thus, this may explain why the associations during the Up Three-Back One agility maneuver were reduced compared to the Cross Hop; greater muscle force and rate of force development may be needed during the Cross Hop compared to the Up Three-Back One agility maneuver. Previous research has reported a difference in kinetics and kinematics of double and single leg lateral jumping compared to broad jumping. These differences in joint angles, knee and hip movements, as well as landing forces may have contributed to the differences in association strength observed between the agility maneuvers and PP and LF during CMJ (Taylor, Ford, Nguyen, & Shultz, 2016). Interestingly, Lockie et al.(2014) reported stronger associations between single leg lateral jumps and both the 505 agility (left = -0.47; right = -0.47) and T-tests (left = -0.67; right = -0.55) compared to the unilateral standing broad jump (505, left = -0.37, right = -0.48; T-test, left = -0.56, right = -0.57. This, despite a lower total distance achieved during the single leg lateral jumps compared to the single leg standing broad jumps.This provides some degree of support to the study's present findings. Furthermore, prior research has suggested that in order to effectively change direction, emphasis is placed on lateral movement and lowering the center of mass (Spiteri, Cochrane Wilkie, Hart, Haff, & Nimphius, 2013; Wheeler & Sayers, 2010).

Differences between variables of interest between right and left limbs during the CMJ may have also contributed to differences observed in correlational strength with agility performance. The correlational strength between measures of the single leg CMJ and agility were stronger for the left limb (see Table 3). Interestingly, the left limb also displayed significantly higher JH, PF, PP, and RPP compared to the right limb (see Table 2). Hence, an overall decrease in variables of interest during right single CMJ is likely, at least partially, responsible for the weaker associations with unilateral agility compared to the left limb. Although the present study is unable to determine the exact cause of the discrepancies observed between left and right CMJ performance; leg dominance, joint stiffness, and balance may be the cause (Bishop, Read, McCubbine, & Turner, 2018; Maloney, Richards, Nixon, Harvey, & Fletcher, 2017; McElveen, Riemann, & Davies, 2010).

For both the left and right Cross Hop maneuvers, the common variance explained by the regression models including PP and LF ranged between 20-24%. A previous study exploring sprint and change of directionabilityamong young physical education students reported that single leg CMJ performance ($R^2 = 0.24$; $p<0.05$) was the best predictor of change of direction in female students (Meylan et al., 2009). Lower body muscular force as a predictor of agility has also been reported in male rugby players. In fact, authors report a significant relationship between CMJ and 505 agility performance (r = -0.54; $p<0.01$), with lower body rate of force development during the jump squat among the best predictors of performance during the 505-agility test ($R^2 = 0.60$) (Swinton, Lloyd, Keogh, Agouris, & Stewart, 2014). However, other studies have found lower predictive ability of the CMJ with agility performance. A study by Negrete et al.(2000) reported a significant, yet low predictive ability of CMJ on agility performance ($R^2 = 0.14$; $p<0.05$). Differences in findings pertaining to predictive ability of the CMJ may be attributed to the methodology used to evaluate change of direction/agility. In the present study, participants performed agility maneuvers on a single leg. In contrast, previous studies solely implemented bilateral agility tests(Meylan et al., 2009; Negrete & Brophy, 2000; Swinton et al., 2014). Yet, study findings support that despite performing unilateral and not bilateral agility maneuvers, the predictive ability of the PP and LF associated with CMJ for agility performance remains.It is apparent that agility is a multifacetedphysical fitness characteristic that cannot solely be explained by kinetics obtained fromjumping.

Other variables that may account for unexplained variance in the current model may includelower body muscular strength, balance, and linear speed(Sekulic, Spasic, & Esco, 2014; Sekulic et al., 2013; Spasic, Uljevic, Coh, Dzelalija, & Sekulic, 2013). For example, the frequent perturbations to the center of mass during agility necessitates neuromuscular control which is also needed during dynamic balance (Sekulic et al., 2013).Linear speed utilizes similar mechanisms such as the stretch shortening cycle and high lower body angular velocities to move the body through space (Spasic et al., 2013). Thus, study results coincide with previous literature exploring the predictive ability of measures obtained during the CMJ and agility performance.

It should be noted that there are other characteristics not measured during this study which may have an association with unilateral agility such as coordination, flexibility, motor control, and cognitive variables. Additionally, the findings from the present study are applicable to the population observed; young recreationally active adults, and the type of jump conducted; CMJ. Hence, findings may differ from other populations such as older adults, professional or collegiate athletes, and rehabilitating individuals or associations utilizing the drop jump or broad jump. Lastly, the present study was cross-sectional, thus, a longitudinal study incorporating unilateral jump training may substantiate the magnitude of impact on unilateral agility performance. For instance, a previous study reported that after 8 weeks of lower limb strength training, peak power during the bilateral CMJ was significantly improved in addition to agility performance (Hammami et al., 2017). Notwithstanding these limitations, this is the first studythat explored CMJ performance variables associated with unilateral agility performance and sought to determine if certain CMJ variables predict unilateral agility performance.

Conclusions

The findings of this study suggest that a moderate to very large association exist between certain CMJ performance variables during both unilateral and bilateral jumping with unilateral agility. The associations observed for unilateral CMJ JH, PP, and LF with unilateral agility indicate the underpinning mechanisms may be similar for both movement patterns. Furthermore, lateral agility movement (Cross Hop) displayed higher association with CMJ variables suggesting that improved bilateral and unilateral CMJ may translate to better lateral agility movements. Therefore, sporting activities requiring lateral agility movement (ice hockey, martial arts, basketball, etc.) may benefit from the assessment of unilateral agility (Cross Hop) and CMJ in addition to inclusion of unilateral CMJ training.Moreover, PP and LF during unilateral jumping can explain up to 24 % of the variance observed in unilateral agility, as measured by the Cross Hop agility maneuver. Consequently, it is evident that agility performance is a multifaceted ability. However, coaches and individuals may desire to focus on muscular power and landing ability since the stretch shortening cycle and rate of force development necessary for improved vertical jumping may be the mechanisms behind the associations observed with unilateral agility.

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