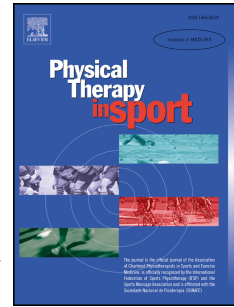


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Relationships between unilateral horizontal and vertical drop jumps and 20 metre sprint performance

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**RELATIONSHIPS BETWEEN UNILATERAL HORIZONTAL
AND VERTICAL DROP JUMPS AND 20 METRE SPRINT
PERFORMANCE.**

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Running Head: Horizontal versus vertical drop jumps

ABSTRACT

Objectives: The purpose of this study was to compare the relationships between horizontal (HDJ) and vertical drop jumps (VDJ) to sprint performance. **Design:** Exploratory Study. **Setting:** Laboratory. **Participants:** Nineteen male collegiate participants (22.5 ± 3.2 years, 181.1 ± 6.7 cm, 80.3 ± 9.6 kg). **Main outcome measures:** All participants performed VDJ and HDJ from a 20 cm height onto an AMTI force platform sampling at 1200 Hz before performing three 20 m sprints. **Sprint times** (5, 10, 15, 20, 5-10, 10-15, 15-20 m) were measured using a LAVEG speed gun. **Results:** All jump and sprint measures showed excellent within session reliability (ICC: 0.954 to 0.99). Pearson's and Spearman's correlations revealed significant ($p < 0.01$) moderate to high correlations between jump measures and sprint times (R : -0.665 to -0.769). Stepwise multiple regression revealed jump distance normalised by body height (HDJ) was the best predictor for 10, 20, 5-10, 10-15 and 15-20 m sprint times ($R^2 = 41\%$ to 48%). **Conclusions:** HDJ performance measures provide stronger relationships to sprint performance than VDJ's. Thus, HDJ's should be considered in test batteries to monitor training and rehabilitation for athletes in sprint related sports.

Keywords: functional tests; acceleration; reactive strength; stretch shorten cycle

INTRODUCTION

An important requirement in many sports is sprinting speed, thus, often strength and conditioning coaches, sports scientists and physiotherapists are interested in identifying what functional tests relate to sprinting speed. An important quality for sprinting is the ability to use the stretch-shorten cycle (SSC) during each footfall (Kryöläinen & Komi, 1995). SSC movements have been classified as slow (i.e., contact time > 250 ms) or fast (i.e., contact time < 250 ms) (Schmidtbleicher, 1992). With ground contact times for sprinting below 250 ms regardless of the duration of the sprint (Atwater, 1982; Schmidtbleicher, 1992; Hunter, Marshall & McNair, 2005; Coh & Tomazin, 2006), fast SSC ability is generally considered important for sprinting.

Traditionally fast SSC ability has been assessed by determining rebound height or reactive strength index (rebound [jump] height or flight time / contact time) from a bilateral vertical drop jump (VDJ). Instructions for performing drop jumps [DJ] (i.e., increased contact time, but greater rebound height) can greatly affect DJ performance (Young, 1995) and to assess fast SSC ability contact times need to be minimised. Therefore, reactive strength index [RSI] seems the preferred option for determining fast SSC ability. However, many studies have found no or weak relationships for RSI (Young et al., 1995; Young et al., 1996; Cronin & Hansen, 2005; McCurdy et al., 2010; Carr et al., 2015; Foden et al., 2015) or rebound height (McCurdy et al., 2010; Salaj & Markovic, 2011) compared to others where moderate to strong relationships have been found for rebound height (Mero et al., 1981; Bissas & Havenetidis, 2008; Kale et al., 2009; Barr & Nolte, 2011) and RSI (Hennessy & Kilty, 2001; Young et al., 2002). The lack of consensus in relationships between VDJ and sprint performance may be due to the differences in the subject

backgrounds, length of sprint involved (i.e., 20 vs. 100 m), and the ground contact times during VDJ compared to ‘acceleration’ or ‘maximum velocity phases’ of a sprint. It has been shown that contact times during VDJ are often above 250ms in moderately trained athletes (McCurdy et al. 2010; Barr & Nolte, 2011; Ball & Zanetti, 2012; Dobbs, Gill, Smart & McGuigan, 2015). Thus, do not match sprinting ground contact times (Schmidtbleicher, 1992; Hunter et al., 2005; Coh & Tomazin, 2006). Furthermore, given that ground contact times decrease as a sprint progresses from acceleration to maximum velocity phases (Atwater, 1982; Coh & Tomazin, 2006). This may influence which drop jump variable best predicts sprint performance over different phases. Therefore, research needs to evaluate which variable (rebound height or RSI) best predicts acceleration (<20 m) and maximum velocity sprint performance.

Another noteworthy aspect in the methods within the studies on VDJ and sprint performance is the use of either unilateral or bilateral VDJ. McCurdy et al. (2010) found normalised horizontal unilateral DJ distance was significantly related to 10 metre sprint performance ($R = -0.58$), whilst unilateral counter-movement jump (CMJ) height (left and right legs pooled) significantly related [$R = -0.61$] to 25 m sprint time. These findings were attributed to the fact that sprinting exclusively involves unilateral stance phases (McCurdy et al., 2010).

Another limitation of the VDJ as an assessment to predict short-sprint performance (i.e., <20 m), is that the test only emphasises vertical force and impulse production. Hunter et al. (2005) found that relative horizontal ($R^2 = 61\%$), and relative propulsive (anterior-posterior) impulse [$R^2 = 57\%$] during sprint ground contacts were much greater predictors of sprint velocity at the 16m mark than relative vertical impulse [$R^2 = 17\%$]). This further underlines the theory that the

ability to produce great horizontal force in early sprint phases significantly determines sprint performance (Hafez, Roberts & Seireg, 1985; Baumann, 1976).

In light of this, previous literature has compared vertical and horizontal jump tests in terms of their association to sprint performance. Maulder and Cronin (2005) found that horizontal jumps (horizontal squat, counter-movement and repetitive jumps) have greater predictive ability for 20 m sprint performance. In agreement with this, others have found horizontal jump tests (i.e., single and triple hop tests, standing long jumps) to be better predictors of short sprint performance (0 to 50 m) than vertical jump tests (i.e., squat and counter-movement jumps) (Habibi et al., 2010; Loturco et al., 2015a, Robbins, 2012). However, Robbins and Young (2012) found that the vertical jump test was more strongly related to the flying 18.3 sprint test, whereas Loturco et al., (2015b) found CMJ height had a marginally stronger correlation to 100m sprint time than horizontal jump distance ($R=-0.85$ vs. -0.81) and thus, suggests that characteristics associated with vertical force production may be more important for maximum speed.

The unilateral horizontal drop jump (HDJ) test was developed by Stålbom, Holm, Cronin and Keogh (2007) as an assessment that better reflects the movement demands of sprint ground contacts than traditional bilateral VDJ. Holm, Stålbom, Keogh and Cronin (2008) found significantly ($p<0.01$) moderate correlations between unilateral horizontal jump distance and jump distance normalised by body height ($R = -0.40$ to -0.61 , and $R = -0.44$ to -0.65 , respectively) and 0-5, 0-10, 5-10, 10-25 and 25 m sprint performance, with shorter distances (10 m) more strongly related ($R^2 = 66\%$) compared to longer distances [10-25m] ($R^2 = 49\%$). However, the authors did not compare relationships found to unilateral VDJ tests to help judge whether the unilateral HDJ test variables are better predictors of sprint performance

unlike McCurdy et al., (2010) as mentioned above. Dobbs et al. (2015) compared the relationships of mean and peak vertical and horizontal GRF produced during VDJ and HDJ (along with squat and counter-movement jumps), respectively with sprint performance (5, 10, 20 and 30 m) and reported that HDJ (both bi-, and unilateral) had stronger correlations with sprint performance at almost every distance recorded, substantiating the previous findings of McCurdy et al., (2010).

Based on the previous literature it can be suggested that the variables derived from the HDJ are better predictors of sprint performance than VDJ. However, limited research exists to substantiate this, in particular comparing the relationships between common DJ variables (i.e., rebound height, jump distance and RSI) and short sprint distances (i.e., 0-5, 5-10 m). Therefore, the aim of this investigation was to compare the relationships of various measures of unilateral VDJ and HDJ with sprint times over a range of splits within 20 metres (0-5 m, 0-10 m, 0-15 m, 0-20 m, 5-10 m, 10-15 m, 15-20 m). This study evaluated performance over specific phases of acceleration, which has not been previously investigated. It is hypothesised that the HDJ is a better predictor of sprint performance than the VDJ at all splits during a 20 metre sprint.

MATERIALS AND METHODS

Participants

Nineteen male collegiate team sport (Soccer and Rugby) athletes participated in the study. Mean \pm *SD* age, height and mass were 22.5 ± 3.2 years, 181.1 ± 6.7 cm, 80.3 ± 9.6 kg, respectively. All participants had at least 2 years resistance training experience. Participants were excluded if they were injured or recovering from injury and were not experienced with plyometric training. All subjects provided written

informed consent prior to participating in the study. Approval for the study was provided by the University's ethics committee. The study was conducted in accordance with the Declaration of Helsinki.

Research Design

The study involved a correlational design with the independent variables being vertical (rebound height, contact time and reactive strength index [RSI] rebound height/ contact time) and horizontal drop jump measures (horizontal jump distance, horizontal jump distance normalised by subject height, ground contact time, RSI (Jump distance/ contact time) (RSI), RSI normalised by body height). Sprint performance was assessed through 20 m sprints were 0-5m, 0-10m, 0-15m, 0-20m, 5-10m, 10-15m, 15-20m split times were determined to serve as dependent variables. Relationships between jump performance measures and sprint performance were explored. All subjects participated in a familiarization session prior to data collection in order to control for learning effects during data collection. Furthermore, all participants were requested not to engage in strenuous exercise 24 hours prior to testing that could induce muscle soreness, especially in lower body musculature. Failure to adhere to this led to exclusion from testing on that day.

Procedures

Each participant attended the lab on two occasions. The first occasion involved familiarization to the tests involved, with data collected on the subsequent occasion. During the familiarization session, the participants were given verbal instructions, a brief demonstration of the tasks and 3-5 trials per leg until they felt comfortable with the task to minimise learning effects during the jumps (Markovic,

Dizdar, Jukic, & Cardinale, 2004). Both DJ tests were carried out on both legs until performance plateaued with each leg (Booher, Hensch, Worrell, and Stikeleather, 1993), which was typically by the third trial. An increase in jump distance of less than 3 cm within three trials was deemed a plateau.

Before testing commenced, a standardised 10-12 minute warm up was performed that involved jogging, bounding, skipping, light runs and sprints. The test session involved 3 unilateral DJ's in horizontal and vertical directions on both right and left legs carried out in randomised order as well as three 20m maximal sprints. Each test was preceded by 2 practice jumps. All tests took place on an indoor running track.

Horizontal Drop Jumps (HDJ)

HDJ were performed by dropping off of a 20 cm high box adjacent to the short edge of an AMTI force plate (Watertown, Massachusetts, USA) sampling at 1200 Hz. The drop height was selected based on previous studies (Holm et al., 2008; McCurdy et al., 2010) and deemed appropriate from pilot research to ensure a short ground contact time during each jump. Participants began HDJ by allowing themselves to drop from the box onto the force plate (unilaterally) and then jump (rebound) for horizontal displacement, landing on both feet. Instructions were to "minimise contact time and maximise horizontal displacement". Horizontal displacement was measured using a tape measure mounted to the floor and was calculated from the point of toe-off to the heel of the foot nearer to the force plate when landed. Toe-off was a fixed point using tape on the force plate in line with the point where the tape measure started. The box was adjusted according to each

participant's preferred position so they naturally dropped just short of the tape. When the participants overstepped or landed well short of the tape, the trial was repeated. Participants were instructed to keep their hands on their hips throughout the jumps. Failure to do so resulted in repetition of that trial. Loss of balance shortly after landing as well as stepping or jumping from the box also resulted in repetition of that trial. A rest period of 45 seconds was given between each trial which Laffaye, Bardy and Tairar (2005) showed is a sufficient amount of rest during DJ's. The following variables were determined; jump distance, jump distance normalised by body height, contact time, reactive strength index (RSIH), and RSIH normalised by body height (NRSIH).

Vertical Drop Jump (VDJ)

The procedure, equipment and set up for VDJ were the same as for HDJ. VDJ were performed by the participants dropping one-footed from the box onto the force plate and then jump for maximal vertical displacement before landing on both feet. Instructions were to "minimise contact time and maximise jump height". Further instructions were to keep their hands on their hips throughout the jump and land with both feet on the force plate. Failure to adhere to all of these instructions resulted in repetition of that trial. Participants were given the same amount of rest (45 seconds) between each trial. The following variables were determined; rebound height, flight time, contact time and reactive strength index (RSI). Jump data from both DJ tests were acquired using Qualysis Track Manager software (V. 2.9) and later exported to MS Excel (Redmond, WA, USA) for further analysis.

Sprints

Participants were instructed to sprint as fast as possible along a 20m track whilst being tracked using a Sport-LAVEG (LDM 300 C, Jenoptik, Jena, Germany) sampling at 100 Hz. Further instructions were to sprint in a straight line and keep sprinting maximally until after the 20m mark was reached. Sprint times for all time splits (0-5m, 0-10m, 0-15m, 0-20m) as well as intermediate sprint times (5-10m, 10-15m, 15-20m) were determined for analysis. Data was analysed using the DAS3E software (v3.9, Jenoptik, Jena, Germany) using a smoothing factor of 5 points and extracting 0-5m, 0-10m, 0-15m, 0-20m, 5-10m, 10-15m, 15-20m sprint times.

Data Analysis

The key dependent variables measured during HDJ were jump distance, jump distance normalised (divided) by body height (NJD), contact time, RSIH, and NRSIH. Dependent variables ascertained from VDJ were rebound height, contact time and RSI.

RSIH was calculated by dividing jump distance by contact time. NRSIH was calculated in a similar manner as RSIH but using jump distance after being normalised by body height. Rebound height during VDJ was calculated using the formula $g \times T^2 / 8$, where g = gravity ($9.81 \text{ m} \cdot \text{s}^{-2}$) and T = Flight Time (s). Flight time during VDJ was determined as the time difference from when the vertical GRF descended (take-off) and ascended (landing) past 20 N. Similarly, contact times for both tests were defined as the time from when the vertical GRF ascended past 20 N to the point when descending past 20 N.

For both jump tests and sprints, the best trials respectively were used for statistical analysis. The best trials from each leg during HDJ were determined by the greatest distance jumped. In a case of two trials of equal distance, the trials with the shorter contact time were kept for statistical analysis. Similarly, the best VDJ trials from each leg were defined as the jump with the greatest height jumped, contact time served as a secondary determinant. During the sprints, the trial with the fastest 20m sprint time was deemed the best trial. To explore the within session reliability for each variable, the three best trials per subject were used for analysis.

Statistical Analysis

All data was statistically analysed using Microsoft SPSS (v20, Chicago, Illinois). Within session reliability of each variable was explored using intra-class correlation coefficients (ICC). Standard errors of measurement (SEM) [$SD_{POOLED} \times \sqrt{1 - ICC}$] and smallest detectable differences (SDD) [$(1.96 \times \sqrt{2}) SEM$] were calculated as described before (Kropmans, Dijkstra, Stegenga, Stewart & De Bont, 1999).

All DJ measures were averaged across limbs and used in subsequent statistical analysis. All variables were tested for normality using the Shapiro-Wilk test. Other than 5 and 15 m sprint time, RSIH and NRSIH, all variables showed normal distribution ($p > 0.05$). Pearson and Spearman's correlation coefficients were ascertained based on the normality of each variable to explore relationships between jump and sprint variables. Correlation coefficients were deemed trivial, low, moderate, high, very high, nearly perfect or perfect depending on the magnitude of the correlation (0.0, 0.1, 0.3, 0.5, 0.7, 0.9 or 1.0, respectively) as previously

suggested (Kale et al., 2009). Coefficients of determination ($R^2 \times 100$) were also calculated for normally distributed variables. To find the best predictor for sprint performance on each of the time splits, the three factors that correlated best to each time split were used for stepwise multiple regression analysis to ensure an adequate 5:1 ratio between sample size and predictor variables (Vincent, 1995). G*Power software (v3.1.9.2, Düsseldorf, Germany) was used to perform post-hoc statistical power calculations (Faul, Erdfelder, Buchner & Lang, 2009).

RESULTS

Means and standard deviations (average across limbs) as well as the intra class correlations co-efficients (ICC), standard errors of measurement (SEM) and smallest detectable differences (SDD) for each performance variable are displayed in Table 1. All variables were deemed highly reliable measures ($ICC \geq 0.945$; $p \leq 0.001$) and within session SDD% (SDD as percentage of the mean) were low (range 1.35 to 8.08%) except for contact time, rebound height, RSIH and NRSIH (Table 1).

Table 1. Mean \pm SD and reliability of each variable from vertical and horizontal drop jump tests as well as the sprints.

Measurement	Mean \pm SD	ICC	SEM	SDD	SDD (%)
<i>Horizontal Drop Jump Test</i>					
Jump distance (m)	1.72 \pm 0.33	0.96	0.03	0.08	4.65 %
N jump distance (m/BH)	0.96 \pm 0.21	0.989	0.01	0.03	3.13 %
Contact time (s)	0.42 \pm 0.02	0.945	0.02	0.05	11.9 %
RSIH ($m \cdot s^{-1}$)	4.42 \pm 0.35	0.978	0.19	0.54	12.22 %
NRSIH ($m/BH \cdot s^{-1}$)	2.45 \pm 0.19	0.967	0.13	0.36	14.69 %
<i>Vertical Drop Jump Test</i>					
RSI ($m \cdot s^{-1}$)	0.99 \pm 0.06	0.987	0.03	0.08	8.08 %
Contact time (s)	0.42 \pm 0.03	0.992	0.01	0.03	7.14 %
Rebound height (m)	0.19 \pm 0.01	0.957	0.01	0.02	10.53 %
<i>Sprint Performance Variables</i>					
5 m (s)	1.02 \pm 0.04	0.990	0.02	0.05	4.9 %
10 m (s)	1.74 \pm 0.63	0.993	0.02	0.05	2.87 %
15 m (s)	2.44 \pm 0.06	0.994	0.02	0.06	2.45 %
20 m (s)	3.09 \pm 0.07	0.995	0.02	0.06	1.94 %
5-10 m (s)	0.74 \pm 0.01	0.993	0.004	0.01	1.35 %
10-15 m (s)	0.68 \pm 0.01	0.991	0.004	0.01	1.47 %
15-20 m (s)	0.66 \pm 0.01	0.984	0.01	0.02	3.03 %

N = normalised by body height; RSI = reactive strength index (VDJ); RSIH = reactive strength index (HDJ); NRSIH = normalised reactive strength index (HDJ); BH= body height

Relationships between jump performance characteristics and sprint performance

High, statistically significant ($p < 0.05$), inverse correlations were found between jump distance and normalised jump distance (HDJ) and all split times (Table 2). Furthermore high and significant ($p < 0.05$) inverse correlations were found between rebound height during VDJ and all split times (Table 2), with the exception of 10m which was not significant ($p > 0.05$). Statistical power of these correlations

ranged between 0.99 and 1.00 for jump distance and 1.00 for all correlations involving normalised jump distance (HDJ) and rebound height (VDJ).

Best predictors of sprint performance over each time split

Based on the bivariate correlations, normalised jump distance, jump distance (HDJ) and rebound height (VDJ) were included in the stepwise multiple regressions for each dependent variable (sprint time splits). Normalised jump distance was the best predictor for 10 m, 20 m, 5-10 m, 10-15 m and 15-20 m with adjusted R^2 scores ranging from 41% to 48% (Table 3). Statistical power calculations revealed a range from 0.76 to 0.84.

Table 2. Relationships between all jump characteristics and sprint variables.

Variable		5 m	10 m	15 m	20 m	5-10m	10-15m	15-20m
<i>Horizontal Drop Jump Variables</i>								
Jump distance	R (unless stated)	$\rho = -.66^{**}$	-.57*	$\rho = -.66^{**}$	-.66**	-.63**	-.62**	-.66**
	R²		32%		43%	40%	38%	43%
Norm Jump Distance	R (unless stated)	$\rho = -.71^{**}$	-.67**	$\rho = -.71^{**}$	-.71**	-.71**	-.67**	-.72**
	R²		44%		49%	50%	45%	51%
Contact time	R (unless stated)	$\rho = -.06$	-.26	$\rho = -.08$	-.21	-0.06	-.02	-.03
	R²		7%		4%	<1%	<1%	<1%
RSIH	ρ	-.06	-.10	-.06	-.05	-.06	-.11	-.11
NRSIH	ρ	-.07	-.10	-.07	-.05	-.06	-.11	-.10
<i>Vertical Drop Jump Variables</i>								
RSIV	R (unless stated)	$\rho = -.15$	-.14	$\rho = -.22$	-.22	-.26	-.246	-.23
	R²		2%		5%	7%	6%	5%
Contact Time	R (unless stated)	$\rho = -.10$	-0.08	$\rho = -.04$	-.08	-.02	-.01	-.03
	R²		1%		1%	<1%	<1%	<1%
Rebound Height	R (unless stated)	$\rho = -.72^{**}$	-.55	$\rho = -.66^{**}$	-.58**	-.52*	-.51*	-.54*
	R²		31%		34%	27%	26%	29%

* $p \leq 0.05$; ** $p \leq 0.01$

Norm = Normalised, RSIH = Reactive Strength Index (HDJ), NRSIH = Normalised Reactive Strength Index (HDJ), RSI = Reactive Strength Index (VDJ).

Table 3. Stepwise multiple regression calculations for selected sprint times and the three best correlates.

Dependent Variable	Best Predictor	R ² (adj.)	Unstandardized coefficients		Standardized coefficient	t	Sig.
			B	Std. Error	β		
10 m	NJD	41%	-1.889	.514	-.665	-3.672	.002
20 m	NJD	46%	-2.261	.560	-.700	-4.041	.001
5-10 m	NJD	47%	-.360	.087	-.709	-4.146	.001
10-15 m	NJD	42%	-.328	.087	-.673	-3.755	.002
15-20 m	NJD	48%	-.354	.084	-.715	-4.220	.001

JD = Jump Distance, NJD = Normalised Jump Distance.

DISCUSSION

The aim of this study was to explore the relationships between unilateral HDJ and VDJ with sprint performance over 20 metres. Based on the literature (Holm et al., 2008; McCurdy et al., 2010; Dobbs et al., 2015) it was hypothesised that HDJ variables may demonstrate stronger relationships to 20m sprint performance than VDJ variables. The results showed that normalised jump distance in HDJ had a greater correlation with sprint performance over the majority of sprint distances compared to VDJ performance variables (i.e., rebound height).

The findings substantiate previous research (Maulder & Cronin, 2005; Habibi et al., 2010; Robbins, 2012; Loturco et al 2015a;) who reported higher correlations between horizontal jumps when compared to vertical jump tests and is due to similarities in horizontal force production between horizontal jumps and short sprints, which vertical jumps do not possess. Other researchers have also reached consensus in that horizontal jump assessments may have higher predictability for sprint performance (McCurdy et al., 2010). However, the present study found significantly greater correlations for HDJ compared to VDJ for sprint distances between 5 and 20 m, whereas McCurdy et al. (2010) found that HDJ was significantly related to 10 m sprint time only, with no relationship to 25 m sprint time reported. The present study is also the first study to consider all phases of the acceleration phase compared to previous studies whereby only 10 and 25 m sprint distances have been considered (Holm et al., 2008; McCurdy et al., 2010).

Further agreement with existing literature was reached as the best correlation between jump distance from the HDJ and sprint performance was achieved when it was normalised by body height (Holm et al., 2008), with the present study revealing additional stronger correlations for this method for sprint distances to 15 and 20 m

and split times 10-15 and 15-20m. This suggests that normalising for subjects standing height is an important consideration for utilising the HDJ test, especially when assessing athletes from sports where sprints greater than 5 m are regularly performed.

Many previous studies have preferred the use of RSI as the measure of DJ performance (Young et al., 1995; Young et al., 1996; Hennessy & Kilty, 2001; Young et al., 2002; Cronin & Hansen, 2005; McCurdy et al., 2010; Carr et al., 2015; Foden et al., 2015). However, the results of the present study suggest that rebound height (VDJ) and jump distance and normalised jump distance (HDJ) provide stronger relationships to short-sprint performance than RSI from VDJ and HDJ. This substantiates previous research (Holm et al., 2008; Shalfawi, Sabbah, Kailani, Tønnessen, & Enoksen, 2011; Barr & Nolte, 2011) and might be due to the inferior reliability compared to other DJ measures (Stålbom et al., 2007). As contact time is one of the two components of RSI, the findings could also be attributed to ground contact times (HDJ and VDJ) having very small correlations ($p > 0.05$) to any sprint times ($R \leq -0.295$, and $R \leq -0.103$, respectively). Carr et al., (2015) and Foden et al., (2015) both aimed to eliminate this by excluding all DJ trials with contact times longer than 200 ms so the contact times were closer to those during sprints but still found only a weak and non-significant correlation between RSI and short-sprint (5, 10 and 20 m) performance.

Interestingly, rebound height during VDJ showed a strong and significant ($p < 0.01$) relationship with 5m sprint distance ($R = -0.72$) but weaker, although still significant, relationships with subsequent split distances except 10m. This finding is in disagreement with McCurdy et al. (2010) who found no relationship between rebound (jump) heights during VDJ and sprints over 10 and 25 m. This discrepancy

in findings however may be caused by the use of different equipment (accelerometer) used for data collection in their study as well as the different sample, as all subjects in McCurdy et al. (2010) study were female soccer players. To the author's knowledge, no previous studies have explored the relationship between VDJ rebound height and 5 m sprint time. The results of the study suggest that vertical force production is also an important determinant of short sprint performance and VDJ should be used in test batteries of athletes involved in short-sprint related sports (i.e., rugby league, soccer, etc.). Furthermore, rebound height might be the preferred variable to report from the VDJ's rather than RSI when assessing athletes in sprint related sports where short distances (i.e., <20m) are most common.

As expected, the magnitude of the correlations between unilateral DJ measures and sprint performance in the present study was higher than for bilateral jumps in most of the previous research (McCurdy et al. 2010; Shalfawi et al., 2011). This finding has been explained by the exclusively one-legged stance phases during sprint running (McCurdy et al., 2010). However, it is important to note that the relationship between bilateral jumps and sprint performance may be influenced by the subjects' status. Vescovi and McGuigan (2008) compared the effects of competition level on the jump-sprint relationship and found greater explained variance of sprint performance in bilateral CMJ's when performed by female college level soccer players compared to high school level ($R^2=43\%$ to 60% vs. $R^2=24\%$ to 33% , respectively). This suggests that training status, fitness level, age and/or experience may affect the relationships between bilateral and unilateral jump measures and sprint performance. The results of the present study are based on University level team sport athletes with at least 2 years resistance training experience and were experienced with plyometric training. Thus, results may differ

with different populations of athlete. Future studies should explore the relationships found in this study with different sporting populations.

Previous research (Carr *et al.*, 2015; Foden *et al.*, 2015) exploring the relationship between drop jumping and sprint performance has excluded trials when contact times exceed 200 ms to ensure that the DJ's assess fast SSC and perhaps is a limitation of the present study. However, both studies involved bilateral DJ's, where it is easier for subjects to ensure short ground contact times, as the bilateral DJ is a less intense exercise than the unilateral DJ (Potach & Chu, 2008). It is noteworthy that the ground contact times during HDJ and VDJ in the present study were identical (0.42 ± 0.02 s and 0.42 ± 0.03 s, respectively) and similar to contact times reported by Holm *et al.* (2008) of 0.41 ± 0.06 s and McCurdy *et al.*, (2010) of 0.37 ± 0.09 s for the HDJ, but longer than those reported by Dobbs *et al.* (2015) of 0.304 ± 0.047 s. Furthermore, Carr *et al.* (2015) and Foden *et al.* (2015) both found CMJ height to be a greater predictor of short sprint performance (5, 10 and 20 m) than DJ RSI even with contact times controlled to not exceed 200 ms. This suggests that short sprint performance is better predicted by slow SSC ability, rather than fast SSC ability. Thus, the results of the present study suggest that besides the type of SSC used (slow or fast), other factors (i.e., unilateral, horizontal force production) influenced the relationship between HDJ and sprinting performance in this study.

Another limitation of the present study was the short sprint distance (20m) used. The choice of distance was based on the subjects used in the study (team sport athletes) and limitations in lab size. The use of 20 m provides an assessment of acceleration rather maximum velocity sprinting. Future research should be conducted using longer sprints, as the relationships observed in the present study may alter, as during maximum velocity sprinting there is more focus on vertical force generation

during ground contact to preserve the athlete's flight phase and attempt to maintain maximum running velocity for longer. A further limitation of this study was the heterogeneous sample used of team sport athletes from Soccer and Rugby. Further studies should explore relationships between jump and sprint performance in specific sporting groups (e.g. sprint track athletes).

Finally, although a cause-effect relationship cannot be ascertained, the results of the study may suggest that the use of HDJ's as a training exercise maybe valuable in training for the acceleration phase in athletes from sprint related sports. Future studies should evaluate the use of plyometric exercises emphasising the horizontal force component compared to exercises emphasising the vertical force component on sprint performance.

CONCLUSION

The findings of this study show that the unilateral HDJ is more closely related to short sprint performance over 20m than unilateral VDJ. Normalised Horizontal jump distance (by participant height) was found to be the best predictor for all split distances, with the exception of 0-5m. This variable can also be easily assessed in the field and thus, is an added advantage of the HDJ test for use with practitioners who are unable to access expensive lab based equipment (i.e., force platform). With regard to using the unilateral VDJ as an assessment, only rebound height found significant relationships to short sprint performance and thus, may be the preferred variable, rather than RSI which found no relationship to short sprint performance. Based on these findings, the HDJ is a recommended functional test for strength and conditioning coaches and physiotherapists to evaluate and monitor training and rehabilitation for athletes from sprint-related sports, respectively.

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REFERENCES

- Atwater, A. (1982). Kinematic analyses of sprinting. *Track and Field Quarterly Review*, 82, 12-16
- Ball, N.B., and Zanetti, S. (2012). Relationship between reactive strength variables in horizontal and vertical drop jumps. *Journal of Strength & Conditioning Research*, 26, 1407-1412
- Barr, M.J., and Nolte, V.W. (2011). Which measure of drop jump performance best predicts sprinting speed? *Journal of Strength & Conditioning Research*, 25, 1976-1982
- Baumann, W. (1976) Kinematic and dynamic characteristics of the sprint start. In: P.V. Komi (Eds.) *Biomechanics VB* (pp. 194-199). Baltimore: University Park Press.
- Bissas, A.L., and Havenetidis, K. (2008). The use of various strength-power tests as predictors of sprint running performance. *Journal of Sports Medicine and Physical Fitness*, 48, 49-54
- Booher, L.D., Hench, K.M., Worrell, T.W., and Stikeleather, J. (2010). Reliability of three single-leg hop tests. *Journal of Sport Rehabilitation*, 2, 165-170
- Carr, C., McMahon, J.J., and Comfort, P. (2015). Relationships between jump and sprint performance in first-class county cricketers. *Journal of Trainology*, 4, 1-5
- Coh, M., and Tomazin, K. (2006). Kinematic analysis of the sprint start and acceleration from the blocks. *New Studies in Athletics*, 21, 23-33

- Cronin, J.B. and Hansen, K.T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, 19, 349-357
- Dobbs, C.W., Gill, N.D., Smart, D.J., and McGuigan, M.R. (2015). Relationship between vertical and horizontal jump variables and muscular performance in athletes. *Journal of Strength & Conditioning Research*, 29, 661-671
- Faul, F., Erdfelder, E., Buchner, A., and Lang, A.G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149-1160
- Foden, M., Astley, S., McMahon, J.J., Comfort, P., Matthews, M.J., and Jones, P.A. (2015). Relationships between speed, change of direction and jump performance with cricket specific speed tests in male academy cricketers. *Journal of Trainology*, 4, 37-42
- Habibi, A., Shabani, M., Rahimi, E., Fatemi, R., Najafi, A., Analoei, H., and Hosseini, M. (2010). Relationships between jump test results and acceleration phase of sprint performance in national and regional 100 sprinters. *Journal of Human Kinetics*, 23, 29-35
- Hafez, A.M.A., Roberts, E.M. and Seireg, A.A. (1985). Force and velocity during front foot contact in the sprint start. In: D. A. Winter, R.W. Norman, R. P. Wells, K. C. Hayes and A. E. Patla (Eds.) *Biomechanics IX-B* (pp. 350-355). Champaign, IL: Human Kinetics.
- Hennesy, L., and Kilty, J. (2001). Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *Journal of Strength & Conditioning Research*, 15, 326-331

- Holm, D.J., Stålbom, M., Keogh, J.W., and Cronin, J. (2008). Relationship between the kinetics and kinematics of a unilateral horizontal drop jump to sprint performance. *Journal of Strength & Conditioning Research*, 22, 1589-1596
- Hunter, J.P., Marshall, R.N., and McNair, P. J. (2005). Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *Journal of Applied Biomechanics*, (21), 31-43
- Kale, M., Asçi, A., Bayrak, C., and Açıkada, C. (2009). Relationships among jumping performances and sprint parameters during maximum speed phase in sprinters. *Journal of Strength & Conditioning Research*, 23, 2272-2279
- Kropmans, T.J., Dijkstra, P.U., Stegenga, B., Stewart, R., and De Bont, L.G.M. (1999). Smallest detectable difference in outcome variables related to painful restriction of the temporomandibular joint. *Journal of Dental Research*, 78, 784-789
- Kryöläinen, H., and Komi, P.V. (1995). The neuromuscular system in maximal stretch shortening cycle exercises: Comparison between power- and endurance-trained athletes. *Journal of Electromyography and Kinesiology*, 5, 15-25
- Laffaye, G., Bardy, B., and Taiar, R. (2006). Upper-limb motion and drop jump: effect of expertise. *Journal of Sports Medicine and Physical Fitness*, 46, 238
- Loturco, I., D'Angelo, R.A., Fernandes, V., Gil, S., Kobal, R., Cal Abad, C.C, Kitamura, K., and Nakamura, F.Y. (2015a). Relationships between sprint ability and loaded/ unloaded jump tests in elite sprinters. *Journal of Strength and Conditioning Research*, 29, 758-764
- Loturco, I., Pereira, L.A., Cal Abad, C.C., D'Angelo, R.A., Fernandes, V., Kitamura, K., Kobal, R., and Nakamura, F.Y. (2015b). Vertical and horizontal jump tests are strongly associated with competitive performance in 100-m dash events. *Journal of Strength and Conditioning Research*, 29, 1966-1971

- Markovic, G., Dizdar, D., Jukic, I., and Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength & Conditioning Research*, 18, 551-555
- Maulder, P., and Cronin, J. (2005). Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. *Physical Therapy in Sport*, 6, 74-82
- McCurdy, K.W., Walker, J.L., Langford, G.A., Kutz, M.R., Guerrero, J.M., and McMillan, J. (2010). The relationship between kinematic determinants of jump and sprint performance in division I women soccer players. *Journal of Strength & Conditioning Research*, 24, 3200-3208
- Mero, A., Luhtanen, P., Vitasalo, J.T., and Komi, P.V. (1981). Relationships between the maximal running velocity, muscle fiber characteristics, force production and force relaxation of sprinters. *Scandinavian Journal of Sports Science*, 3, 16–22
- Potach, D.H., and Chu, D.A. (2008). Plyometric Training. In: T.R. Baechle, R.W. Earle (Eds). *Essentials of Strength Training and Conditioning* (pp.413-456). Champaign, Ill: Human Kinetics.
- Robbins, D.W. (2012). Relationships between national football league combine performance measures. *Journal of Strength & Conditioning Research*, 26, 226-231
- Robbins, D.W. and Young, W.B. (2012). Positional relationships between various sprint and jump abilities in elite American football players. *Journal of Strength & Conditioning Research*, 26, 388-397

- Salaj, S., and Markovic, G. (2011). Specificity of jumping, sprinting and quick change-of-direction motor abilities. *Journal of Strength & Conditioning Research*, 25, 1249-1255
- Schmidtbleicher, D. (1992). Training for power events. In: P.V. Komi (Eds.) *Strength and Power in Sport* (pp 381-395). Boston: Blackwell Science.
- Shalfawi, S.A., Sabbah, A., Kailani, G., Tønnessen, E., and Enoksen, E. (2011). The relationship between running speed and measures of vertical jump in professional basketball players: a field-test approach. *Journal of Strength & Conditioning Research*, 25, 3088-3092
- Stålbom, M., Holm, D.J., Cronin, J., and Keogh, J. (2007). Reliability of kinematics and kinetics associated with Horizontal Single leg drop jump assessment. A brief report. *Journal of Sports Science & Medicine*, 6, 261-264
- Vescovi, J.D., and McGuigan, M.R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of Sports Sciences*, 26, 97-107
- Vincent, W.J. (1995). *Statistics in Kinesiology*. Champaign, Illinois: Human Kinetics.
- Young, W. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics*, 10, 89-96
- Young, W., Hawken, M., and McDonald L. (1996). Relationships between speed, agility and strength qualities in Australian Rules football. *Strength Conditioning Coach*, 4, 3-6
- Young, W., James, R. and Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *Journal of Sports Medicine and Physical Fitness*, 42, 282-288

Young, W., McLean, B., and Ardagna, J. (1995). Relationships between strength qualities and sprinting performance. *Journal of Sports Medicine and Physical Fitness*, 35, 13-19

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Highlights

Relationships of horizontal and vertical drop jump tests to sprinting were compared

Rebound height was the best predictor of 5m sprint time

Normalised jump distance was the best predictor for all other sprint distances

Horizontal drop jump tests are advocated to assess athletes in sprint related sports