Original Research

The Relationship between Change of Direction Speed in the Frontal Plane, Power, Reactive Strength, and Strength

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ABSTRACT

International Journal of Exercise Science 7(4) : 260-270, 2014. Change-of-direction speed (CODS) is an important quality to performance in multi-direction sports. The relationship between CODS in the frontal plane and power, strength, and reactive strength is largely unstudied. Twenty-three male college students participated in this study. The study used a Pearson's product-moment correlation to measure the relationship between CODS, power, strength, and reactive strength. A lateral shuffle test was used as the measure of CODS. A lateral hop for distance was used as the measure of power in the frontal plane. A countermovement vertical jump test was used as the measure of power in the sagittal plane. A depth jump was used as the measure of reactive strength in the sagittal plane. A 3RM squat test was used as the measure of strength. There was a moderate relationship between the lateral shuffle test and the lateral hop ($r = .541$, $p = .008$ and $r = .567$, $p = .005$), but no significant relationships with the countermovement vertical jump, depth jump, or squat test. These results suggest that power should be trained in all planes to improve CODS performance in multi-direction sports, and that CODS should be trained in its sport-specific context.

KEY WORDS: Agility, change of direction speed, power

INTRODUCTION

The ability to change directions quickly is important for success in most field and court sports. Basketball, for instance, has been found to require a change in movement every two seconds (1), making it a game of movement and agility. Agility requires the ability to brake, change direction, and accelerate again (28). These actions often occur when an athlete runs straight ahead and cuts - the athlete brakes, changes directions, and accelerates again - with a directional change of less than than 90-degrees, termed a redirection (15). Redirections from linear sprinting are common to most field and court sports, but some movements in sports such as soccer, basketball, and tennis require movements in the frontal plane, such as shuffling. As much as 41% of a basketball game with adolescent males was spent shuffling or backpedaling (1). Although agility has been viewed as a single entity (18), the manner in which one brakes, changes directions, and accelerates may differ between a shuffle and a redirection. A better understanding of frontal-plane movement may improve the testing and training of athletes in multi-direction sports.

Agility has been defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus (4, 33). The response to a stimulus has introduced the importance of perceptual skills to agility, and efforts in the literature have been made to differentiate simple or preplanned agility from universal agility (7, 13, 26, 29). Preplanned agility, also termed change-of-direction speed (CODS), is the physical component of agility without the perceptual or decision-making factors (40), whereas universal agility combines CODS with perceptual skills or the response to a stimulus (7, 13, 26, 29). Most studies of agility have tested preplanned agility or CODS, not universal agility (4).

Change-of-direction speed has been proposed to combine three factors: technique, straight-sprinting speed, and leg-muscle qualities (40). The leg-muscle qualities were proposed to be power, reactive strength, and strength (40). Strength has been defined as maximal force (16). Power has been defined as the rate of doing work (24). Reactive strength has been "defined as the ability to change quickly from an eccentric to a concentric contraction" (39, p. 90). Power uses a long stretch-shortening cycle (SSC) with ground contact times (GCT) longer than 250 milliseconds and large angular displacements of the hip, knee, and ankle, whereas reactive strength uses a short SSC with GCT between 100-250 ms and small angular displacements of the hip, knee, and ankle (14, 17, 31). The relationship between these leg-muscle qualities and CODS has been well-researched (3, 4, 5, 9, 23, 25, 33, 37), although these studies tested linear sprinting with redirections (4), which may explain the positive relationship between these tests and linear speed (4, 5, 9, 37, 40). Few studies have incorporated shuffling (4, 27, 30) despite its relative importance in some sports.

Simplifying CODS to linear sprinting and redirections ignores other movements such as shuffling and backpedaling. Within studies of different magnitudes of directional changes, a difference of 20 degrees, from a 40-degree cut to a 60-degree cut, led to a percent change of 11.3% over an 8-meter sprint (40). Because the magnitude of the redirection has affected a notable change over a short distance, a change in movement type from a straight-ahead sprint to a lateral shuffle could have a similar effect. Frontal-plane movements such as those used by soccer goalkeepers or basketball defensive players appear to be more dissimilar than redirections of different magnitudes, but these movements are largely unstudied (4, 27, 30), and their relationship to power, reactive strength, and strength remains unknown.

The purpose of this study was to determine the relationship between CODS in the frontal plane and power, reactive strength, and strength in college-aged males. A lateral shuffle test (LST) was used as the measure of CODS in the frontal plane. A lateral hop (LH) for distance was used as the measure of power in the frontal plane. A countermovement vertical jump test (CMVJ) was used as the measure of power in the sagittal plane. A depth jump (DJ) was used as the measure of reactive strength in the sagittal plane. A 3RM squat test (squat) was used as the measure of strength. The primary hypothesis was that CODS would be independent of power in the sagittal plane (CMVJ), but related to power in the frontal plane (LH). The second hypothesis was that the tests of different leg-muscle qualities in the same plane of movement (CMVJ and DJ; CMVJ and squat; DJ and squat; and LH and LST) would have a greater relationship than the tests of similar leg-muscle qualities in different planes of movement (LH and CMVJ).

METHODS

Participants
Twenty-three male university students volunteered for this study. The participant characteristics are in Table 1. The participants were enrolled in university activity classes such as weightlifting, soccer, or basketball that met twice per week for one hour in duration per class. Twelve participants reported no previous basketball experience, whereas 11 participants reported playing in the local Jr. NBA program prior to high school. No participant played basketball at the high-school level or beyond. None of the participants reported a significant ankle, knee, hip, or back injury in the prior 6 months. The study was approved by the University Institutional Review Board, and written participant consent was collected prior to the data collection.

The study used a cohort design. Each participant completed 7 tests: LST (right and left), LH (right and left), CMVJ, DJ, and squat. The LST, LH, CMVJ, and DJ were completed in a randomized order in 1 session; the squat test was completed separately.

Table 1. Participant Characteristics (n=23).

	Mean	SD
Age	21.87	2.62
Height (m)	1.77	0.085
Weight (kg)	75.69	15.25

Participants reported to the university’s sports medicine laboratory for testing. Participants were instructed to wear athletic clothes and shoes that they would wear to play basketball. Upon arrival, the participants presented a signed consent form, and filled out a survey that asked for their height, weight, age, injury history, and previous basketball playing experience. Next, the tests were explained and demonstrated to the participants, and the participants completed several sub-maximal and one maximal practice trial to familiarize themselves. After the familiarization period, the participants completed three test trials of each test. Participants were given 60-90 seconds to recover between trials (12). The testing took place on a multi-purpose floor in the laboratory. All tests started on a force plate (AMTI BP400600 Model, Watertown, MA) embedded in the floor.

Countermovement vertical jump test. A Vertec device was used to measure the height of the jumps to the nearest half inch (1.27 cm). To prepare the Vertec, the participants stood with both hands overhead and walked through the Vertec in order to measure their standing reach. The participants were instructed to use a nostep, countermovement jump. The participants were allowed to swing their arms, and were instructed to jump as high as possible and reach for the vanes with both hands over head. To begin the test, the participants stood in an upright standing position. When ready, the participants flexed at the ankles, knees, and hips to make a preliminary downward movement, then extended their ankles, knees, and hips to jump vertically. At the top of their jump, the participants hit the vanes. Their vertical jump was measured as the difference between the highest vane hit on their jump and their standing reach. Participants completed three jumps, and the best jump was used for analysis.

Depth Jump. The Vertec device was used to measure the height of the depth jump to the nearest half inch (1.27 cm). A 30 cm box was used for the depth jump (14, 22). The box was positioned directly behind a force plate. The participants were instructed to limit their ground contact time (GCT) between the drop from the box and the jump (39), as the DJ was the measure of reactive strength. To begin, participants stepped onto the box. The participants stepped off the box, dropped onto the force plate landing with both feet simultaneously, and jumped to hit the vanes. The height of their jump was measured as the difference between the highest vane hit on their jump and their standing reach. Their GCT was measured by the force plate. The height in millimeters was divided by the time on the ground in milliseconds to determine their reactive strength index (RSI; 14, 22). Participants completed three jumps. The best performance with a GCT under 250 ms was used for analysis.

Lateral hop test. The participants started in a standing position to the side of a starting line marked on the floor. When ready, they raised one leg off of the ground and flexed at the ankles, knees, and hips on their stance leg to make a preliminary downward movement. They extended their ankles, knees, and hips to hop medially in the frontal plane. Participants landed on the same leg to reduce the effects of leg length on the distance measurements. The distance of the LH was measured to the nearest millimeter from the starting line to the nearest part of the participant's foot at landing. The participants completed three trials on their right foot and three trials on their left foot. The best performance for each foot was used for analysis.

Lateral Shuffle Test. The Edgren Side-Step Test (ESST) has used solely shuffling movements (8, 16, 35) and is a prominent field test. However, the ESST used by the National Strength and Conditioning Association (16) differed from the original test (10), and others have reported their own versions (8, 35). There appears to be no consistent procedures for the ESST. The lateral shuffle test (LST) in this study was modified from the NSCA's version. The ESST was chosen because it is the only test consisting entirely of lateral movements (4). The LST was shortened in time (from 10 seconds to 5 seconds) to reduce the effects of fatigue, and in distance due to the constraints of the laboratory. Other tests of agility have been modified in a similar manner to increase sport-specificity (30, 37).

The LST used a three-meter distance with lines marked every half-meter. The participants started the test straddling the middle line. They moved laterally and crossed the last line before changing directions. The participants shuffled continuously for five seconds. The score was the number of lines crossed in the five seconds. Participants were instructed not to cross their feet during the duration of the test, and a trial was discarded if a participant crossed his or her feet. Participants were tested with their right foot (LST-R) and left foot (LST-L) as their initial push-off foot in a randomized order. The performances were captured on video (Flip Mino HD, Cisco Systems, Irvine, CA), and the scores were counted and confirmed via video analysis. During the video analysis, the time started on the first visible movement and concluded after five seconds. Participants completed three trials in each direction, and the best score in each direction was used for analysis.

3RM Squat Test: After a 10-15 minute break that included a walk from the laboratory to a weightlifting classroom in the same building, participants completed a 3RM 90-degree squat test. The 3RM test was chosen because the sub-maximal load was safer for athletes who may not have been regular weightlifters, and the 90-degree depth was closer to the true sport stance of athletes than a full squat. Participants were given a demonstration of the squat and given time to perform at least one set of a sub-maximal load as a warm-up and familiarization period. The pins on the squat rack were placed at the depth of the squat for safety reasons, and a certified strength coach spotted for the participants. A certified strength coach checked the depth of each repetition. When ready, participants performed three repetitions to a 90-degree depth. The initial weight was determined by asking participants for their best estimate of their maximum. After the initial set, the researcher asked the participants if they could have performed another repetition; if they answered positively, more weight was added, and the participants tried another set. The strength coach also checked for technique and stopped participants if the strength coach felt that continuing would be to their detriment. Participants used no more than three sets to reach the 3RM. The final completed performance was converted to kilograms and used in the analysis.

Statistical Analysis

SPSS (version 20.0, Chicago, IL) was used to analyze the data. A Cronbach's α was used to determine the reliability of the tests, and the Spearman-Brown Prophesy was used to determine the single-trial reliability. An ANOVA was used to determine the stability of the tests across trials. A one-way ANOVA was used to determine any differences between those with previous basketball experience and those with no previous basketball experience. A Pearson's product-moment correlation was used to determine if any of the personal characteristics had a significant relationship with the seven tests. A Pearson's product moment correlation was used to determine the relationship between the seven tests. Multiple regression analysis was used to determine the amount of variance in the test of CODS explained by the tests of power, reactive strength, and strength. Alpha level was set at $p < 0.05$.

RESULTS

A Cronbach's α was used to determine the internal consistency of the seven tests, and the Spearman-Brown Prophesy was used to determine the single-trial reliability. An ANOVA was used to test for the stability of the tests across trials. The results are shown in Table 2. The tests had good internal consistency meaning they were reliable for this study. The CMVJ, LST-R, and LST-L showed good stability, whereas the LH-R, LH-L, and DJ did not. The LH-R, LH-L, and DJ appeared to show a learning effect after the first trial.

Table 2. Internal consistency and stability of the three trials.

	Cronbach's Alpha	F	p	k
LST-R	0.960 (.887)[a]	2.411	0.100	3
LST-L	0.975 (.928)	2.021	0.143	3
LH-R	0.983 (.950)	11.190	<.001	3
LH-L	0.959 (.885)	12.063	<.001	3
CMVJ	0.983 (.950)	2.076	0.136	3
DJ	0.910 (.769)	10.499	<.001	3

a. Single trial reliability using the Spearman-Brown Prophesy

Multiple one-way ANOVAs were run to determine if any group differences between those who had played organized basketball prior to high school and those with no prior organized basketball experience existed in the seven tests. Because the lateral shuffle test used a movement pattern common to basketball but less common to other sports, prior playing and practicing experience may have given those with experience an advantage. There were no statistical differences between the two groups in any of the tests: LST-R, $F(1, 21) = .309$, $p = .584$; LST-L, $F(1, 21) = .259$, $p = .616$; LH-R, $F(1, 21) = 1.818$, $p = .192$; LH-L, $F(1, 21) = .969$, $p = .336$; CMVJ, $F(1, 21) = 3.307$, $p = .083$; DJ, $F(1, 21) = 2.631$, $p = .120$; 3ST, $F(1, 21) = .926$, $p = .347$. Therefore, all participants were grouped together for the remaining analyses.

A Pearson's product-moment correlation was used to determine the relationships between the participant characteristics and the seven tests. The only significant relationship between a participant characteristic and a test was between weight and the squat test, $r = .507$, $p = .014$.

The means and standard deviations for the seven tests are shown in Table 3. The LST is reported as the number of lines crossed within the 5-second period. The DJ is reported as the RSI, which divided the height of the jump (measured in mm) by the ground contact time (measured in ms). The other tests are reported in SI units of measurement (cm/kg).

Table 3. Mean and standard deviation for the seven tests.

	Mean	Std. Deviation	N
3RM Squat	97.62	28.02	23
LST R	20.91	2.92	23
LST L	20.65	3.08	23
LH - R	146.98	23.88	23
LH - L	147.76	25.48	23
CMVJ	55.33	10.35	23
DJ - RSI	2.05	0.45	23

LST (lateral shuffle test); LH (lateral hop); CMVJ (countermovement vertical jump); DJ (depth jump)

The inter-correlations for the seven tests are shown in Table 4. To determine the relationship between CODS in the frontal plane and power, correlations between the CODS (LST) and the test of power in the frontal plane (LH) and in the sagittal plane (CMVJ) were examined. The LST had a moderate relationship with the LH, between $r = .541$, $p = .008$ and $r = .567$, $p = .005$, but there was no statistically significant relationship between the LST and CMVJ. To determine the relationship between tests of the same leg-muscle qualities compared to tests of different leg-muscle qualities in the same plane of movement, correlations between the tests of power (LH and CMVJ), and the tests in the sagittal plane (CMVJ, DJ, squat) were examined. There was a strong relationship between the LH and CMVJ, $r = .849$, $p < .001$ (R) and $r = .800$, $p < .001$ (L). There was a strong relationship between the CMVJ and DJ, $r = .875$, $p < .001$. There was no statistically significant relationship between the squat and the CMVJ, or the squat and the DJ.

Table 4. Correlations for the seven tests.

		3RM Squat	DJ	CMVJ	LH-R	LH-L	LST-R	LST-L
3RM Squat	PC		.083	.121	.129	.148	.067	.097
			.707	.582	.557	.499	.762	.660
DJ	PC			.875**	.716**	.662**	.012	-.001
				.000	.000	.001	.958	.997
CMVJ	PC				.849**	.800**	.252	.287
					.000	.000	.246	.185
LH-R	PC					.958**	.548**	.541**
						.000	.007	.008
LH-L	PC						.567**	.542**
							.005	.008
LST-R	PC							.955**
								.000
LST-L	PC							

**. Correlation is significant at the 0.01 level (2-tailed).
PC: Pearson correlation

Multiple regression analysis was used to test if the tests of power, reactive strength, and strength significantly predicted CODS (the LST-R was used for analysis). The results of the regression indicated the five predictors (LH-L, LH-R, CMVJ, DJ, and 3ST) explained 60% of the variance, $R^2 = .599$, $F(5, 21) = 6.263$, $p = .001$.

DISCUSSION

The results from this study of 23 college-aged males supported the hypothesis that the CODS would have a greater relationship with power in the frontal plane than with power in the sagittal plane. There was a moderate relationship between the LST and LH and a low and non-significant relationship between the LST and CMVJ. The hypothesis that the tests of different leg-muscle qualities in the same plane of movement would have a greater relationship than the tests of the same leg-muscle qualities in different planes of movement had mixed results. The tests of the same leg-muscle qualities in different planes of movement (LH and CMVJ) had a strong relationship. The tests of different leg-muscle qualities in the same plane of movement had a strong relationship (CMVJ and DJ), moderate relationship (LH and LST), and low and nonsignificant relationship (CMVJ and squat; DJ and squat).

Countermovement vertical jump has been shown to predict performance in other tests of CODS (3, 30), but these tests used short sprints with directional changes. Foot placement, adjustment of strides to accelerate and decelerate, body lean, and posture have been identified as factors that affected technique (40). The moderate relationship between the LST and LH and the independence of the LST and CMVJ in this study may illustrate the difference between these factors in a shuffling movement and a redirection. These results support a study of college males which found no statistical relationship between CODS as measured by the T-test and CMVJ (30).

Many studies have investigated the relationship between strength and CODS with mixed results (6, 25, 33). Body posture has been found to be important in the transference of strength training to human movements and speculated that the phenomenon of posture specificity may be due to the neural input to the muscles (38). The angle at the hip in the frontal plane in a lateral shuffle is greater than the angle at the hip for a squat which may account for postural differences that affect the transference of strength to the CODS in the frontal plane. The results from this study support previous studies which found that concentric strength was a poor predictor of CODS (6, 33).

The independence of the LST with the CMVJ, DJ, and squat test suggest that the shuffling movements are technique-dependent and different than movements like running, cutting, and jumping. Power, reactive strength, and strength explained 60% of the variance of the LST, leaving 40% unexplained. In Young et al.'s (40) model, the two remaining factors for CODS were technique and straight-sprinting speed. Speed, acceleration, and agility have been found to be relatively unrelated (19), suggesting that the technique of shuffling may account for much of the unexplained variance in this study.

CODS involves the ability to brake, change direction, and accelerate again (28). In a shuffling movement like the one used in the test of CODS, the actions occur in the frontal plane. On a change of direction when shuffling, "optimal braking alignment occurs with the foot, shin, and thigh of the lead leg pointing at a 45-degree angle to the direction of braking" (15; p.11). This alignment of the foot, shin, and thigh when braking differs from the more vertical alignment used when squatting or jumping vertically. It is possible that the redirections with smaller angles of cuts correlate better with tests of vertical jump because of a smaller optimal angle of alignment on the cuts. These results suggest that athletes may need to train with these larger angles to improve performance of these actions.

There are five primary limitations to this study. First, there is a lack of validity information available for the ESST and other similar shuffling tests. Despite references to the ESST in the literature since 1932, and its frequent use in the field, no known studies have reported on its validity. The LST would appear to have face validity because the movement appeared to be similar to the movement used to play defense in basketball and therefore appeared valid (2). Second, the participants were all males. Third, the participants were college students enrolled in recreational activity classes, not basketball players. Roughly half of the participants had played organized basketball. Whereas shuffling is a basic movement pattern and a common transition movement in sports (18), the results may have differed with basketball players who practice shuffling movements every day. Fourth, there were no perceptual or decision-making components, so the findings are limited to CODS and not agility (40). Finally, the experience with squatting may have contributed to the lack of a significant relationship between the squat and the other tests. Whereas every participant had weightlifting experience, and several were enrolled in a weightlifting class, the training experience between participants varied. The relative novices may not have reached a true maximum due to unfamiliarity, discomfort, lack of confidence, or fear of injury. A leg press may have eliminated some confounding factors such as technique, experience, and core strength, which may have limited the less experienced participants.

This study examined CODS in the frontal-plane. Based on the results, multi-direction athletes should train power in all directions rather than relying on vertical or sagittal-plane power programs. Power-related training programs dominated by sagittal-plane movements have shown mixed results in terms of improving CODS performance (11, 21, 34, 36). The moderate relationship between power in the frontal plane and CODS in this study as well as improved CODS performance through multi-direction jump training programs (20, 23) suggests that the transference of power has a directional bias, potentially stemming from the posture involved in the movements (38). The results also suggest that the technique of CODS must be trained within its sport-specific context based on the initiation, transition, and actualization movement patterns of the sport (18).

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