REVIEW ARTICLE

Sports Med 2008; 38 (12): 1045-1063
0112-1642/08/0012-1045/$48.00/0

Understanding Change of Direction Ability in Sport

A Review of Resistance Training Studies

Matt Brughelli,[1] *John Cronin*,[1,2] *Greg Levin*[1] and *Anis Chaouachi*[3]

1 School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Joondalup, Western Australia, Australia
2 Institute of Sport and Recreation Research New Zealand, AUT University, Auckland, New Zealand
3 Research Unit ''Evaluation, Sport, Santé'', National Center of Medicine and Science in Sports (CNMSS), Tunis, Tunisia

Contents

Abstract . . . 1045
1. Search Strategy for Correlational and Training Sections . . . 1046
   1.1 Selection Method of the Studies Gathered during the Literature Search . . . 1047
   1.2 Evaluation of Methodological Quality of Training Studies . . . 1047
   1.3 Effect Sizes . . . 1047
2. Classification and Characteristics of Different Change of Direction (COD) Tests . . . 1048
   2.1 Reliability of the Different Tests . . . 1051
3. Correlational Research . . . 1051
   3.1 Delimitations and Limitations . . . 1054
   3.2 COD Tests . . . 1054
   3.3 Straight Sprinting Speed . . . 1054
   3.4 Strength and Power . . . 1055
   3.5 Maximal Leg Strength . . . 1055
   3.6 Leg Power (Expressed in Watts) . . . 1055
   3.7 Leg Power (Jump Height) . . . 1056
   3.8 Leg Power (Jump Horizontal Distance) . . . 1056
   3.9 Summary of Correlational Research . . . 1057
4. Training Studies . . . 1057
   4.1 Sprint Training . . . 1057
   4.2 Leg Strength and Power Training . . . 1058
   4.3 COD-Specific Training . . . 1059
5. Conclusions and Future Research Directions . . . 1060

Abstract

The ability to change direction while sprinting is considered essential for successful participation in most team and individual sports. It has traditionally been thought that strength and power development would enhance change of direction (COD) performance. The most common approach to quantifying these relationships, and to discovering determinants (physiological and mechanical) of COD performance, is with correlation analysis. There have not been any strength or power variables that significantly correlated with COD performance on a consistent basis and the magnitude of the correlations were, for the most part, small to moderate. The training studies in the literature that have utilized traditional strength and power training programmes, which involved exercises being performed bilaterally in the vertical direction (e.g. Olympic-style lifts, squats, deadlifts, plyometrics, vertical jumping), have mostly failed to elicit improvements in COD performance. Conversely, the training protocols reporting improvements in COD performance have utilized exercises that more closely mimic the demands of a COD, which include horizontal jump training (unilateral and bilateral), lateral jump training (unilateral and bilateral), loaded vertical jump training, sport-specific COD training and general COD training.

Agility has been defined as a rapid whole-body movement with change of velocity or direction in response to a stimulus.[1] Implicit in this definition is that agility comprises both a perceptual decision-making process and the outcome of this process, a change of direction (COD) or velocity. Of interest in this article is the COD component of agility. COD can be described as a movement where no immediate reaction to a stimulus is required, thus the direction change is pre-planned. Several authors have argued that COD ability is a prerequisite for successful participation in modern-day sports.[2-5] These arguments have been supported in the literature by talent identification/selection studies, which have reported that COD ability was the most important performance variable for (i) predicting player selection (soccer);[6] (ii) American National Football League draft status (wide receivers, running backs, defensive backs and quarterbacks);[7] (iii) predicting on-field performance (American football);[8] and (iv) for distinguishing between elite and sub-elite soccer players.[5] Given the proposed importance of COD ability in sporting performance, it would seem beneficial for strength and conditioning practitioners to identify those training techniques that may best optimize COD performance.

Sheppard and Young[1] have described a number of factors that are considered important in determining COD ability, which can be observed in figure 1 and include technical, speed and leg muscle qualities. Whilst such a model appears intuitively appealing, the function of deterministic models is to actually identify those factors that will predict performance and, if trained, will make a functional difference to the variable or component of interest. With this in mind, the purposes of this review are to identify the determinants of COD performance and to investigate the longitudinal training studies in this area. First, a number of COD tests have been classified into categories to enable a better understanding of whether speed and leg muscle qualities better predict certain types of COD tests. Secondly, the research that has quantified the relationship between COD and straight sprinting speed and leg muscle qualities are investigated. Thirdly, the longitudinal studies in this area that have assessed COD performance after a training intervention are critically reviewed. Finally, future research directions that could enhance our understanding of COD performance are suggested.

1. Search Strategy for Correlational and Training Sections

Four researchers independently searched the electronic databases of AUSPORT, Expanded Academic ASAP, ProQuest 5000, PubMed,

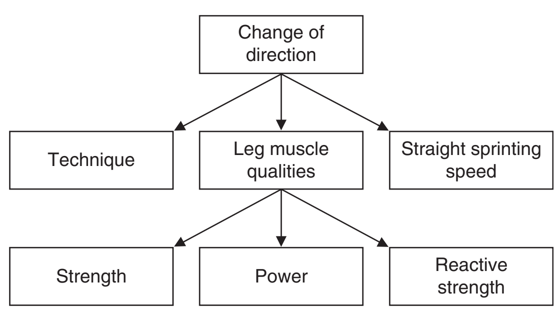

Fig. 1. Modified deterministic model of change of direction (reproduced from Sheppard and Young,[1] with permission from Taylor & Francis Ltd, http://www.tandf.co.uk/journals).

SPORTDiscus, Web of Science and Google Scholar for the years 1985–2007. The following keywords were used in different combinations: 'agility', 'leg strength', 'leg power', 'running', 'sprint', 'COD', 'speed' and 'multi-directional'.

1.1 Selection Method of the Studies Gathered during the Literature Search

The reviewers carried out the selection of studies in two consecutive screening phases. The first phase consisted of selecting articles based on the title and abstract. The second phase involved applying the selection criteria to the articles. Studies were chosen if they fulfilled the following two selection criteria: (i) the study detailed the COD test and outcome measures of leg strength, power and/or running speed; and (ii) the study must have been written in the English language and published as an article in a peer-reviewed journal or conference proceeding.

1.2 Evaluation of Methodological Quality of Training Studies

Evaluating the methodological quality of experimental research is often quantified with one of the following scales: (i) the Delphi scale; (ii) the PEDro scale; or (iii) the Cochrane scale. However, these scales are typically designed to investigate the specific methodological quality of healthcare research and interventions. Training studies that involve strength and conditioning interventions usually score very low on these methodological scales. For example, Markovic[9] conducted a meta-analysis on the effects of longitudinal plyometric training on jumping performance. The PEDro scale was used to quantify the methodological quality of each individual study. Of the 51 training studies analysed, the average score was a 4.6/10 with an overall range of 3–5/10. Furthermore, none of the 51 studies were able to accomplish items 3, 5, 6, 7 and 9. These items were as follows: allocation was sealed (item 3), blinding of the subjects (item 5), blinding the therapists who administered the treatment (item 6), blinding the testers (item 7), and intention-to-treat analysis (item 9). As can be observed from this analysis, many of the criteria are not relevant to strength and conditioning methodologies, such as blinding participants.

We feel that if exercise training studies are evaluated with the above-mentioned methodological scales, the quality of the studies (individually and as a whole) will be classified as poor. Thus, we have created an evaluation of methodological quality for exercise training that is derived from a combination of items from the previous three scales. It is thought that this scale would be appropriate if two goals were accomplished, which were not accomplished with the PEDro scale in Markovic:[9] (i) the best methodological studies scored highly; and (ii) the scale was sensitive with a wide range of scores from poor quality to high quality. This scale includes a 10-item scale (range 0–20) designed for rating the methodological quality of exercise training studies. The score for each criteria was as follows: 0 = clearly no; 1 = maybe; and 2 = clearly yes. The items included:

1. inclusion criteria were clearly stated;
2. subjects were randomly allocated to groups;
3. intervention was clearly defined;
4. groups were tested for similarity at baseline;
5. use of a control group;
6. outcome variables were clearly defined;
7. assessments were practically useful;
8. duration of intervention practically useful;
9. between-group statistical analysis appropriate;
10. point measures of variability.

As can be seen in table I and table II, the items that had the greatest range in scores (i.e. the most sensitive) included 2, 4, 7 and 10. From this information, it is recommended that future exercise training studies improve their methodological quality by including a control group, randomizing their subjects, including groups that have similar pre-values, and reporting the variability of their tests.

1.3 Effect Sizes

In the training section, the results of each strength and speed measurement have been presented in terms of p-values (<0.5) for statistical

Table I. Resistance training studies that have failed to improve change of direction (COD) performance

Study	Subjects	Frequency; duration of training	Type of training	Agility test	Results (effect size)	Quality score
Fry et al.[10]	10 female NCAA division 1 volleyball players	4×/wk; 12 wk	Performed traditional resistance training and plyometric training	t-test	+3.6% (0.76)	13
Cronin et al.[11]	40 recreationally active males and females	2×/wk; 10 wk	JSB and JS	Modified t-test	JSB group −0.7% JS group −1.4%	19
Tricoli et al.[12]	32 male physical education students	3×/wk; 8 wk	OL and VJ and control group	Box test	OL group −2.8% (0.66) VJ group −3.6% (0.82)	17
Hoffman et al.[13]	20 male NCAA division III football players	4×/wk; 15 wk	OL, PL and control group. Additional sprint and COD training for the final 5 wk for both groups (ten sessions)	t-test	OL group −1.6% (0.34) PL group −2.0% (0.5) Control group – no change	14
Kraemer et al.[14]	30 female college tennis players	3×/wk; 9 mo	NPT, PT and control group		PT group +5.0% (0.38) NPT group +2.8% (0.14) Control group – no	17
Hoffman et al.[15]	47 male NCAA division III football players	4×/wk; 15 wk	LSJ or USJ. Additional sprint and COD training for the final 5 wk for both groups (ten sessions), and a control group	t-test	LSJ group −2.8% (0.6) USJ group −1.8% (0.1) Control group – no change	16
Gabbett[16]	69 sub-elite male rugby league players	2×/wk; 9 wk	SSS group or TC group for rugby league	L-run	SSS group −0.5% (0.75) TC group −0.7% (1.0)	16
Harris et al.[17]	41 strength-trained males (could squat 1.4× body mass)	4×/wk; 9 wk	ST performed strength exercises at high intensities relative to 1RM. PO performed strength exercises at low intensities relative to 1RM., and combined group performed both of above	10-yd (9-m) shuttle run	ST group +1.0% (0.8) PO group +1.7% (1.3) Combined group −2.3% (1.4)	15

1RM = one repetition maximum; **JS** = jump-squat training on a modified leg-press machine without bands; **JSB** = jump-squat training on a modified leg-press machine with bands; **LSJ** = Olympic lifting and strength training with loaded; **NCAA** = National Collegiate Athletic Association; **NPT** = non-periodized resistance training group; **OL** = Olympic-lifting training; **PL** = power-lifting group; **PO** = power group; **PT** = periodized resistance training group; **SSS** = sport-specific skill-based training; **ST** = strength group; **TC** = traditional conditioning; **USJ** = unloaded squat jump training; **VJ** = vertical jump training.

significance, percentage change and effect sizes. Percentage changes in performance measures are commonly reported in the literature. However, calculation of percentage change does not take into consideration the variance of strength, power, COD and/or speed improvements.[30] By including the effect size (pre-test minus post-test divided by the standard deviation of the pre-test), the variance of each measurement is included, thus making it a standardized and more accurate description of the treatment effect.[30] The effect size allows us to compare the magnitude of the treatments on the outcome variables of interest between studies. We describe the effects as 'trivial', 'small', 'moderate' and 'large' based on the description of effects for untrained, recreationally trained and highly trained athletes.[30] Such classification means that effect sizes are not described in a uniform manner throughout the different populations.

2. Classification and Characteristics of Different Change of Direction (COD) Tests

Many different tests have been used to assess COD performance and more are continually

Table II. Resistance training studies which have shown improvements in change of direction (COD) performance

Study	Subjects	Frequency and duration of training	Type of training	Agility test	Results (SD)	Quality score
Gabbett et al.[18]	26 junior volleyball players	3×/wk; 8 wk	Sport-specific training based on the court (passing, setting, blocking and spiking, and small-sided games)	t-test	–5.2% (3.6)	14
Gabbett[19]	77 sub-elite rugby players; juniors group (n = 36) and seniors group (n = 41)	2×/wk; 14 wk	Sport-specific training including COD training and skill-based games	L-run	Juniors –17.7% (no SD) Seniors –16.2% (no SD)	15
Malisoux et al.[20]	8 healthy active males	3×/wk; 8 wk	SSC training including vertical jumping and horizontal jumping both performed bilaterally and unilaterally	6× 5-m shuttle run	–3.6% (2.1)	12
Young et al.[21]	27 recreational athletic males	2×/wk; 6 wk	Two groups performing ST with COD or ST without COD included in the sprint, and a control group	30-m with five CODs	STCOD group –2.7% (0.8) ST group – no change Control group – no change	15
McBride et al.[22]	26 resistance trained male athletes	2×/wk; 8 wk	JS30 or JS80 and a control group	t-test	JS30 –1.7% (1.2) JS80 –2.4% (1.3) Control group – no change	16
Dean et al.[32]	139 young adolescents	2×/wk; 4 wk	Running, jumping, movement and reaction-time training	Sideways shuffle	–3.2% (0.3)	10
Markovic et al.[24]	93 male physical education students	3×/wk; 10 wk	Two groups performing either ST or PT, and a control group	20-yd (18-m) shuffle	ST group –4.3% (1.1) PT group – no change Control group – no change	20
Cressey et al.[25]	19 NCAA division 1 soccer players	27 sessions; 10 wk	Sport-specific training with COD. One lower-body exercise/session was performed on either stable or unstable surface	t-test	Stable group –4.4% (1.0) Unstable group –2.9% (1.6)	14
Polman et al.[26]	36 elite female soccer players	2×/wk; 12 wk	Three groups performing sport-specific training: RT, SCE, SC	L-run	RT group –1.4% (0.6) SCE group –4.2% (1.6) SC group –3.8% (1.2)	18
Christou et al.[27]	18 adolescent male soccer players	2×/wk; 16 wk	One group performed CSST; one group performed the above with AGT and control group	10× 5-m shuttle runs	CSST group -4.0% (1.1) AGT group -5.4% (1.7) Control group – no change	19
Miller et al.[28]	28 recreational male and females	2×/wk; 6 wk	PL performed horizontal, vertical, and lateral hops, jumps and bounds. Also a control group	t-test	PL group –5.5% (0.7) Control group – no change	14
				Illinois agility test	PL group –2.9% (0.3) Control group – no change	
Deane et al.[29]	48 college-aged male and females	3×/wk; 8 wk	HF training group performed hip flexor strength training with elastic tubing. Also a control group	23.2-m shuttle run	Male HF group –10% (1.8) Female HF group –8.3% (1.1) Male control – no change Female control – no change	16

1RM = one repetition maximum; **AGT** = CSST and additional general strength training; **CSST** = COD training plus soccer-specific training; **HF** = hip flexor; **JS30** = jump squat training at 30% of 1RM; **JS80** = jump squat training at 80% of 1RM; **NCAA** = National Collegiate Athletic Association; **PL** = plyometric group; **PT** = plyometric training; **RT** = regular training; **SC** = speed, agility and quickness training plus COD training with no equipment; **SCE** = speed, agility and quickness training plus COD training with equipment; **SSC** = stretch-shortening cycle; **ST** = sprint training.

Table III. Characteristics of the different agility tests commonly used

Time to complete test	
0–5 sec	t-test,[11] 10-yd (9-m) shuttle,[17] 20-yd (18-m) shuffle,[24] 5-0-5[31]
5–9 sec	t-test,[13,15,25] 48-ft (14.6-m) sideways shuffle,[32] 4×5.8-m shuttle,[29] L-run,[18,26,19] tennis-specific shuttle,[14] zigzag test;[4] up and back[31]
>10 sec	10×5 m shuttle,[27] t-test,[3,10,22,28] 6×5-m shuttle,[20] Illinois,[31,28] Box test,[12] 30 m with 5 CODs,[21] slalom run,[33] hurdle test[33]
No. of CODs	
2–3	48-ft (14.6-m) sideways shuffle,[32] 4×5.8-m shuttle,[29] L-run,[18,26,16] 10-yd (9-m) shuttle,[17] tennis-specific shuttle,[14] 20-yd (18-m) shuffle,[24] zigzag test,[4] 5-0-5,[31] up and back[31]
4–6	t-test,[3,10,11,13,15,22,28,25] 6×5-m shuttle,[20] 30 m with 5 CODs[21]
>7	10×5 m shuttle,[27] Illinois,[31,28] box test,[12] slalom run,[33] hurdle test[33]
Primary application of force throughout the entire test	
Horizontal	10×5 m shuttle,[27] t-test,[3,25] 4×5.8-m shuttle,[29] L-run,[18,26,16] 10-yd (9-m) shuttle;[17] tennis-specific shuttle;[14] 6×5-m shuttle,[20] 20-yd (18-m) shuffle,[24] Illinois,[31,28] box test,[12] 30-m with 5 CODs,[34] zigzag test,[4] slalom run,[33] hurdle test,[33] 5-0-5,[31] up and back[31]
Lateral	48-ft (14.6-m) sideways shuffle[32]
Both	t-test[10,11,13,15,22,28]

COD = change of direction.

being developed in order for researchers to assess the specific demands of the sport for which they are used. Table III details those tests that have been used by researchers in this area as used in this review. As can be observed, there is a great deal of variety in the type and number of assessments that have been used to assess COD ability. We have attempted to classify each test into three areas (energetic requirements, type of force application and number of changes of direction) that may allow a better understanding of the relationships between these tests and variables of interest in this review.

The duration and intensity of the COD test will determine the relative contribution of the energy systems in providing the main source of fuel for performance. In his review article, Gastin[35] explains that the anaerobic energy system depends on phosphocreatine for the first 5 seconds of exercise and then utilizes the glycolytic energy pathway followed largely by energy produced from the aerobic system. Thus, tests of different durations may be subject to influences of energetics rather than just assessing COD ability. The complexity of each test can be categorized either by the number of changes of direction required or by the type of movements and forces that are primarily used throughout the test. Certain tests (shuttles or L-runs) can have as few as two or three directional changes, whereas others (Illinois test) can incorporate as many as 12 changes of direction. Each COD requires a braking force followed by a propulsive force, which in turn may increase the importance of eccentric-concentric force capability of muscle and endurance as the number of turns increase. The application of force during the actual COD is more difficult to determine because it would rely heavily on individual technique. However, it is accepted that lateral forces would be involved in certain COD movements such as those in a t-test when the COD is preceded by shuffling movements.

In terms of the interrelationships amongst these tests, some researchers have found that there was a significant correlation between the Illinois test and the up and back test ($r = 0.63$) and between the up and back test and a 5-0-5 test ($r = 0.51$), but no significant relationship between the Illinois test and the 5-0-5 test (0.25).[31] The researchers suggested that the results of most COD tests were independent from one another and they believed that this was a result of the duration and complexity of each COD test. We would also assert that in some circumstances this independence is due to differences in direction of force application and/or energetic requirements as discussed previously. However, the actual threshold at which the number of changes of directions and/or different forces and/or energetic requirements ensure that a test is a true measure of COD is far from clear. For example, Young et al.[34] found that a single 20° COD in an otherwise straight 20-m sprint produced almost identical results to the sprint with no COD.

Already it would seem a difficult if not impossible task to discern those factors that are important predictors of COD ability, given the huge variety of tests, the many components of COD ability and the ambiguity as to what constitutes a true 'COD' test. The reader needs to appreciate these complexities when reading the ensuing discussion and conclusions.

2.1 Reliability of the Different Tests

To date, not many authors have accurately reported the reliability coefficients of the COD test that they have used. The reliability and variation of the results are important especially for training studies when it is essential to know if the exercises performed result in a real and worthwhile change to the measured variable. Only nine studies have reported the reliability of their measurements (see table IV). This belies one of the limitations of research in this area as indicated by the methodological scores observed later in the review and discussed previously. Nonetheless, regardless of the duration of the test, the number of CODs, or the direction in which most of the forces were applied all the tests that have been used to measure COD ability, show similar reliability (intra-class correlation 0.8–0.96; coefficient of variation 1–5%).

3. Correlational Research

If we observe the model described in figure 1, we note that Sheppard and Young.[1] proposed that straight running speed and leg muscle qualities were important determinants of COD ability. One approach we can use to quantify the importance of straight running speed and leg muscle qualities to COD ability is to use correlational analysis. In this section, we have used correlational research that has been published in peer-reviewed journals or conference proceedings only (see table V), to insure some measure of methodological qualities was adhered to and have some confidence in our conclusions. Also, only isoinertial (constant gravitational load) strength and power measures were included in the analysis, as this is the resistance type

Table IV. Measurements of reliability for specific change of direction (COD) tests

Study	COD test	Reliability	Time to complete (sec)	Application of force throughout the entire test	No. of CODs
Christou et al.[27]	10× 5 m shuttle	ICC = 0.94 CV = 1.01%	20	Horizontal	9
Cronin et al.[11]	Modified t-test	ICC = 0.88 CV = 2.1%	4	Horizontal and lateral	4
Gabbett et al.[18]	L-run	ICC = 0.90 TEM = 2.8%	6	Horizontal	3
Gabbett[3]	t-test	ICC = 0.85 CV = 2.9%	11	Horizontal	4
Gabbett[19]	L-run	ICC = 0.90 TEM = 2.8%	6	Horizontal	3
Markovic et al.[24]	20-yd (18-m) shuffle	ICC > 0.9 CV < 4.1%	5	Horizontal	2
McBride et al.[22]	t-test	ICC = 0.94% TEM = 2.09	11	Horizontal and lateral	4
Tricoli et al.[12]	Box test	ICC = 0.80	16	Horizontal	11
Alricsson et al.[33]	Slalom run	ICC = 0.96 CV = 2.3%	>10	Horizontal	10
	Hurdle test	ICC = 0.90 CV = 4.9%	>10	Horizontal	7

CV = coefficient of variation; **ICC** = intra-class correlation; **TEM** = typical error of measurement.

Table V. Correlations between change of direction (COD) tests and measures of straight sprinting speed and leg muscle qualities

Study	Subjects (age)	Agility (time)	Component and correlations (r)
Buttifant et al.[36]	21 male junior national and state representative soccer players (16.1 ± 1.23 y)	20 m agility test (6.13 sec); 4 CODs	20-m sprint time (0.33)
Draper and Lancaster[31]	12 hockey and 6 Australian football players of representative level	Illinois agility test (17.28 sec); 9 CODs	20-m sprint time (0.472)[a]
		5-0-5 agility test (2.36 sec); 1 COD	20-m sprint time (0.055)
		Up and back agility test (6.26 sec); 1 COD	20-m sprint time (0.495)[a]
Hoffman et al.[37]	62 National Collegiate division III American football players (19.7 ± 1.4 y)	Three cone drills (~8 sec); 3 CODs	
		Dominant leg	Bilateral VJ (–0.34)
		Non-dominant leg	Bilateral VJ (r = –0.39)
		Dominant leg	Single non-dominant VJ (–0.36)
		Non-dominant leg	Single non-dominant VJ (–0.37)
Little and Williams[4]	106 male professional soccer players (division 1 and 2)	Zigzag test (5.34 sec); 3 CODs	10-m sprint time (0.346)[a] Flying 20-m sprint time (0.458)[a]
Marcovic[38]	76 male physical education students	Lateral stepping (7.24 sec)	Isoinertial squat (–0.17) Isometric squat (–0.25) One-leg rising (–0.3) SJ power (W/kg –0.15) Hopping power (W/kg –0.22) Standing LJ (–0.19)
		20-m shuttle run (5 sec)	Isoinertial squat (0.31) Isometric squat (0.03) One-leg rising (–0.44) SJ power (W/kg –0.35) Hopping power (W/kg –0.30) Standing LJ (–0.27)
		Slalom run (6.9 sec)	Isoinertial squat (–0.21) Isometric squat (0.08) One-leg rising (–0.35) SJ power (W/kg –0.33) Hopping power (W/kg –0.26) Standing LJ (–0.12)
Mayhew et al.[39]	53 College football players	SEMO agility run (10.92 sec); 5 CODs	1RM bench press (0.35) 10-yd (9-m) dash (0.50) 40-yd (37-m) dash (0.46)

Continued next page

Table V. Contd

Study	Subjects (age)	Agility (time)	Component and correlations (r)
Negrete and Brophy[40]	29 men and 31 women (24.5 y)	Diamond shape: males (~100 sec), females (~135 sec)	SLVJ height (–0.38)[a,b] SLHJ distance (–0.65)[a,b]
Pauole et al.[41]	College students (22.3 y)		
	Males (n = 152)	t-test (female average = 12.33 sec) 4 CODs	VJ height (–0.55)[a] 40-yd (37-m) sprint (0.73)[a]
	Females (n = 152)	t-test (male average = 10.54 sec)	VJ height (–0.49)[a] 40-yd (37-m) sprint (0.55)[a]
Peterson et al.[42]	First year college athletes (19.4 y) Males (n = 19)	t-test (male = 9.89 sec); 4 CODs	1RM squat (–0.169) 1RM squat/mass (–0.333) VJ height (–0.261) VJ peak power (–0.033) HJ (–0.613)[a] Sprint acceleration (–0.491)[a] Sprint velocity (–0.579)[a]
	Females (n = 36)	t-test (female = 11.48 sec)	1RM squat (0.408)[a] 1RM squat/mass (–0.633)[a] VJ height (–0.713)[a] VJ peak power (–0.210) HJ (–0.788)[a] Sprint acceleration (–0.630)[a] Sprint velocity (–0.693)[a]
Roetert et al.[43]	83 ranked male tennis players (11.62 ± 0.62 y)	Spider run (18.85 sec); 10 CODs	VJ height (r = –0.34)[a]
Young et al.[44]	18 senior football league players (18–22 y)	20-m COD (3 CODs)	
		Three 90° directional changes (5.14 sec)	Unloaded CMJ (r = –0.10) DJ (0.36) CMJ –50% BW (0.01) 20-m sprint time (0.27)
Young et al.[34]	15 male soccer, basketball, Australian football and tennis players (18–28 y)	7 × 8 m sprint with single directional changes at a variety of angles (1.65–2.85 sec)	Bilateral DJ (–0.35 to –0.65) Unilateral DJ (–0.23 to 0.71)

a Significant at $p < 0.05$ and less.

b This study normalized these measures by BW.

1RM = one repetition maximum; **BW** = bodyweight; **CMJ** = counter-movement jump; **DJ** = drop jump; **HJ** = horizontal jump; **LJ** = long jump; **SEMO** = Southeast Missouri; **SJ** = squat jump; **SLHJ** = single-leg horizontal jump; **SLVJ** = single-leg vertical jump; **VJ** = vertical jump.

encountered in most training environments. Inherent in calculating correlation coefficients is the assumption that a number of statistical criteria are met, namely normality, linearity, homoscedasticity and adequate sample size related to the number of variables being analysed. Many of the studies do not report or violate these assumptions, so the reader needs to be cognizant of this limitation and the interpretation of the results herewith.

3.1 Delimitations and Limitations

Delimitations refer to the populations to which generalizations can be safely made. A total of 795 athletes were used in the research cited in table V of which 576 (~73%) were males. In terms of age, most of the researchers used athletes in their twenties, two studies using for the most part younger athletes.[36,43] The sports most represented in this sample include soccer, Australian Rules and American football players, although 38% of the sample was made up of college students. Training status varied from professional athletes to college students. The results of the following analysis are most relevant to this demographic.

Limitations refer to the restrictive weakness of a study. Some of the limitations of the research used in this analysis relate to the statistical procedures discussed previously. For example, one assumption is that there is an adequate number of subjects per variable of interest. The studies of Young and colleagues[34,44] used 18 and 15 subjects to study the relationship between 8 and 14 variables, respectively. These studies clearly violate this assumption. Furthermore, when performing correlations using both male and female subjects, it is accepted practice not to pool the data, since the heterogeneity of the population will artificially inflate the correlation coefficient; this is evidenced in the study of Peterson et al.,[42] who present the pooled data as well as the data separated by gender. Negrete and Brophy;[40] however, present pooled correlations only, so their correlation statistics need to be viewed with caution.

In terms of the methodology, great variation was noted in the surfaces on which the tests took place (grass, artificial grass, indoor synthetic pitch, hardwood floors), timing equipment (stop watches to electronic timing gates), familiarization (Buttifant et al.[36] and Pauole et al.[41] were the only studies to mention any familiarization), test order (jumps to agility/speed tests and vice versa), data analysis (best performance data vs the average of a number of trials) and starting stances (a variety of standing stances to three-point starting stance). Comparing results between tests is further compounded by authors making slight modifications to existing agility tests, for example, the t-test. The reader needs to be cautious about any deductions made from the analysis given the delimitations and limitations described.

3.2 COD Tests

As can be observed from table V, a great variety of COD tests were used in the research reported. These tests necessitated different energetic requirements (~1.65 to ~135 seconds), CODs (2–10) and primary force production as described previously in section 2. Given this variety, it would seem difficult to reach any form of consensus as to the correlates or predictors of COD performance. Nonetheless, some discussion of best predictors of COD performance ensues. To describe the magnitude of the correlations, we use the work of Cohen,[23] who has written extensively in this area and has described the magnitude of correlations as: >0.5 is large, 0.5–0.3 is moderate, 0.3–0.1 is small, and anything <0.1 is insubstantial or trivial.

3.3 Straight Sprinting Speed

The relationship between straight running speed and COD tests is of interest on a number of counts. First, is running speed a determinant of COD, as the Young et al.[34] model suggests? Secondly, if so, then it should be sufficient to test the different qualities with the same test as there should be a great deal of shared variance between the tests. Thirdly, training to improve speed should improve COD and vice versa; this contention is discussed later in this article in section 4.1. In terms of the correlations reported in table V, most correlations between COD and straight running speed would be described as moderate (r = 0.3–0.5) the lowest correlate reported for the 20-m sprint and 5-0-5 agility test (r = 0.055) and the highest significant correlates reported in females between the t-test and sprint acceleration and velocity (r = –0.630 to –0.693). Sheppard and Young[1] stated that generally, the more changes in direction, the less the transfer from straight running speed to COD. This does not seem the case given the data above, the 5-0-5 test involving one COD, the t-test four CODs and the majority of the correlations of moderate magnitude regardless of the number of directions. In terms of the shared variance (i.e. coefficient of determination or R^2) between variables, it would seem that straight sprinting speed and COD seem to be, for the most part, separate motor qualities, the $R^2 < 50\%$ for all the research reported in table V.

3.4 Strength and Power

It has been proposed by Young et al.[34] that leg muscle qualities such as strength, power and reactive strength are important determinants of COD ability as indicated by their deterministic model. We believe that this classification overcomplicates the analysis, as most assessments that are included as measures of reactive strength are also representative measures of power. That is, measures of reactive strength such as the countermovement jump or drop jump are also measures of leg power. Perhaps a better classification would be to classify the power variables in terms of the direction of force application (i.e. vertical, horizontal and lateral) and whether the movement involves unilateral or bilateral force production.

3.5 Maximal Leg Strength

In terms of maximal isoinertial strength, only two studies have quantified the relationship between maximal isoinertial strength (with multi-joint and closed-chain exercises) and COD. Markovic[38] found mostly small correlations (r = –0.17 to –0.31) between their isoinertial squat (one repetition maximum [1RM]) in a Smith machine and their three COD tests. Peterson et al.[42] investigated the relationship between the 1RM (barbell squat) and COD (t-test) and found that the male correlation (r = –0.169) was weaker than the significant female correlation (r = 0.408). Given the direction of the association in females, it seems that the stronger people were slower, which may be explained by larger subjects lifting greater loads; however, as a result of their greater mass, their COD ability was compromised. Expressing maximal strength relative to bodyweight would account for this problem as evidenced in the results of Petersen et al.,[42] who found the male (r = –0.33) and female (–0.633) correlations to be stronger when expressed in such a fashion. Even given the expression of strength relative to mass, the shared variance between maximal strength and COD ability is <41% for the strongest correlates in both studies. This could be attributed to many factors such as the depth of squat assessment (i.e. range of motion 80–90° used in the studies cited) not simulating COD range of motion. Interestingly, the relationship (r = 0.03 to –0.25) between maximal isometric strength and COD was mostly trivial,[38] supporting the contention that static and dynamic movement have very little in common, i.e. shared variance.

3.6 Leg Power (Expressed in Watts)

Strictly speaking, in terms of power production, only two studies[38,42] investigated the relationship between power (W) and COD ability, so studies that have included jump height and distance measures will be included in this discussion. This is not technically correct as there is an assumption that jump height is a measure of leg power or at the very least closely related. We need only look at the work of Peterson et al.[42] to observe that this is not necessarily the case, the relationship between the height and peak power output of a vertical jump for females (r = 0.420) and males (r = 0.734) indicates minimal shared variance (~18–54%) between the measures, and as such we draw the reader's attention to this limitation. With this in mind, we first discuss those studies that have quantified power output and then discuss the relationship between other jump measures (height and distance) and COD ability.

Peterson et al.[42] used an indirect measure of power, as they calculated the power output for their bilateral vertical jump using the formula of Sayers et al.[45] They found trivial to small (r = –0.03 to –0.21) correlations between power output and the t-test for males and females, respectively. Markovic,[38] using a force platform to derive power output, found that the relative power output (W/kg) for a concentric-only squat jump was poorly to moderately related (r = –0.15 to –0.35) to the three tests of COD ability. Markovic[38] also tested the relationship between stretch-shorten cycle (SSC) leg power, as measured by a single-leg hop in place (ten jumps) and their tests of COD ability. The results were very similar to the squat jump, with the strength of most correlations classified as small (r < 0.30).

3.7 Leg Power (Jump Height)

The most common type of jump used to predict COD was the vertical jump and its derivatives, the outcome measure of interest and comparison being the height jumped. There are many different classification systems of vertical jumps from jumps without use of arms to use of arms, drop jumps from various heights, different contact times (e.g. slow SSC vs fast SCC, unilateral vs bilateral). In terms of the kinetic determinants of such jumps, the vertical ground reaction forces (VGRF) and the time over which the forces are applied would seem fundamental to jump performance. For the sake of simplicity and clarity, therefore, we will broadly classify all the different jumps that apply VGRF in a unilateral or bilateral manner, based on the premise that unilateral jump performance may be better related to COD ability, given all COD tests described in this article require unilateral propulsion. Regarding the tests of bilateral leg power, most studies that used males reported small to moderate correlations (–0.261 to –0.49) between the vertical jump test and the respective COD test. Two interesting observations were that the female correlations were typically stronger than the males (r = –0.55 to –0.713). Furthermore, the bilateral drop jump correlations (r = –0.31 to –0.65) reported by Young et al.[34] were typically stronger than other vertical jumps. However, we must be careful about making any conclusions given that this is the only study that has reported this relationship and it has methodological limitations in terms of the sample size and the amount of variables investigated. The unilateral findings were, for the most part, similar to the bilateral in that most correlations were small to moderate (r = –0.36 to –0.38) the exceptions being the unilateral drop jumps reported by Young et al.[34]

In summary, the majority of correlations between vertical leg power (jump height) and COD for males are moderate (mean r ≈ 0.4). That is, there is approximately 16% common variance between the tests of COD and leg power that use predominantly VGRF. For female college students, the relationship is higher (mean r = 0.63), which corresponds to a shared variance of 40%.

3.8 Leg Power (Jump Horizontal Distance)

Intuitively, it would seem more appropriate to use jump tests that not only involve the application of VGRF, but also horizontal ground reaction forces (HGRF) to predict COD performance, given that most human motion is a combination of these two types of forces. However, only three studies have investigated the relationship between horizontal jump performance and COD ability. Markovic,[38] using a bilateral long jump with arm swing, reported small correlations (r = –0.12 to –0.27) to their three tests of COD ability. Peterson et al.,[42] using a standing broad jump, found that horizontal jump distance was significantly correlated to the t-test for both males (r = –0.613) and females (r = –0.713). Once more, the female correlation coefficient was higher than the male. Finally, Negrete and Brophy[40] reported a correlation of r = –0.65 between a single-leg hop for distance and a diamond-shaped agility test. This correlation is most probably artificially elevated due to the pooling of the male and female subjects into a single sample. Nonetheless, this horizontal jump measure was greater than their vertical jump measure (r = –0.38). Furthermore, the Peterson et al.[42] horizontal jump correlations were greater than the vertical jump correlations. Given the results, it may be tentatively claimed that jumps that involve the combination of both HGRF and VGRF may better predict COD ability. However, there is still much unexplained variance between COD and horizontal jump measures and still a great deal more research needs to be conducted before definitive conclusions can be made.

3.9 Summary of Correlational Research

Given the delimitations, limitations and the great variety in COD tests and sprint test distances, it is difficult to disentangle any relationship between COD and leg strength and power qualities with any real certainty from the studies presented in this section. Also, it is important to note that the strength and significance of a relationship provide no insight into whether the relationship between two variables is causal. Correlational analysis, therefore, is of limited value in identifying the causal relationship between certain variables and COD ability. It is concluded that the preoccupation of correlational studies to find the best strength and/or power predictors of functional performance is fundamentally flawed due to other factors such as body mass, physique, flexibility, technique and leg strength qualities having diverse effects on the statistical models.

Sport practitioners and researchers are interested in determining the effect of various training programmes on the variable of interest, in this case COD. To do this, the changes in leg muscle qualities and straight running speed need to be mapped over longitudinal training interventions. Such an approach provides the focus for the remainder of this review. By adopting such an approach, it is hoped that those variables that strongly influence COD ability will be elucidated and, as a result, give the reader insight and focus as to what variables should be assessed, developed and monitored.

4. Training Studies

Several studies have reported improvements in functional performance (i.e. sprinting and jumping) after training for peak power, maximum strength and/or reactive strength.[12,46-49] It is thought that strength and power development would have a carry-over effect on COD performance. The following sections of this article will review the studies and training protocols that have enhanced COD performance, along with those that have failed to enhance COD performance.[10-13,15] We feel that this approach will give insight into the specific and effective COD training protocols. In addition, this approach will give information on why other COD training protocols have not been effective.

4.1 Sprint Training

Only two studies have investigated the effects of straight-ahead sprint training on COD and reported conflicting arguments. In the study of Young et al.,[21] one group of recreationally trained athletes performed straight-ahead sprint training (n = 13), and another group performed COD training (n = 13) for a 6-week period. The objectives of the study were to determine if sprint training transferred to COD performance, and if COD training transferred to sprint performance. The subjects in the training groups performed between 10 and 12 total sessions, which included 5–8 total sprints (20–40 m). The sprint-trained group significantly improved sprint times, but did not significantly improve COD times. Conversely, COD training improved COD times, but did not significantly improve sprint times. The conclusion was that sprint training and COD training were specific and do not readily transfer to each other.

Markovic et al.[24] also performed straight-ahead sprint training over a period of 10 weeks (3 sessions per week) with greater volume in each training session (9–12 total sprints). There were a total of 30 physical education students performing the sprint training, and each was assessed before and after training with the 20-yard (18-m) shuttle COD test. The sprint training significantly decreased 20-yard shuttle times by 4.3% with an effect size of 1.1 after the 10-week period. It should be noted that the samples used in both papers were not well trained athletes. Given the paucity of research, the conflicting results, the differences in COD tests used and the samples used in the research, it would seem difficult to arrive at a definitive conclusion on how straight sprint training affects COD ability in both recreational and well trained athletes.

4.2 Leg Strength and Power Training

There are several longitudinal studies that have attempted to improve COD performance with resistance training.[10-13,15] Since COD ability is thought to be influenced by strength and power, many authors have implemented the following training protocols: heavy lifts (e.g. squats, deadlifts, goodmornings, lunges), Olympic-style lifts, and plyometrics. Each of these protocols has been effective at enhancing strength, power and sprint performance in athletic and non-athletic populations. However, each of these studies has failed to improve COD performance (see table I). Hoffman et al.[13,15] performed traditional strength and power training over a 15-week period with division III American football players in the US. Neither of the studies elicited an improvement in COD performance as measured by the t-test. The athletes in Hoffman et al.[13] performed either Olympic-style lifts with strength exercises or strength exercises only. Both groups also performed COD and sprint training in the final 5 weeks (two sessions per week) of the 15-week period. The athletes in Hoffman et al.[15] performed a traditional strength and conditioning programme (e.g. Olympic-style lifts, squats, step-ups, deadlifts) for 15 weeks. One group performed jump squats in the final 5 weeks using both concentric and eccentric phases of contraction, and another group performed the jump squat exercise using the concentric phase only in the final 5 weeks. Both groups also performed agility and sprint training (two sessions per week) in the final 5-week cycle. It could be speculated that a 5-week speed and agility training period (ten total sessions) is not a sufficient training load/stimulus to significantly improve COD times in division III American football players.

Tricoli et al.[12] investigated the effects of Olympic-style weightlifting and vertical jump training on COD performance in recreationally active subjects. The subjects either performed the weightlifting exercises (high pulls, power clean, clean and jerk, half squat) or vertical jumps (single- and double-leg hops, drop jumps, half squat) for an 8-week period. No significant improvements were reported for COD performance. Similarly, Fry et al.[10] investigated the effects of a traditional strength-training programme (Olympic-style lifts and strength exercises), with plyometric training on COD performance in division I volleyball players. The athletes performed the training for 12 weeks in the off-season and did not significantly improve COD performance. Harris et al.[17] also investigated the effects of a similar strength and conditioning programme for 9 weeks on strength-trained males, and reported no significant changes in COD performance. Furthermore, Kraemer et al.[14] investigated the effects of a traditional periodized strength and conditioning programme on college female tennis players over a 9-month period. It was thought that a periodized strength and conditioning programme over a long period of time would elicit an improvement in most performance variables, including COD. However, COD times significantly increased after the training period (2.8–5.0%; effect size = 0.14–0.38). Lastly, Cronin et al.[11] investigated the effects of squat-jump training with a modified Smith machine, with and without elastic bands, on COD performance in recreationally active subjects. Neither intervention improved COD performance.

It could be speculated from the above studies that strength and power development in the vertical direction does not transfer to COD performance, which is typified by unilateral VGRF and HGRF production. However, one study has shown an improvement in COD performance with resistance training in the vertical direction.[22] The subjects in the study of McBride et al.[22] performed jump squats with either 30% or 80% of their 1RM, which was taken from the squat exercise, for 8 weeks. This is the only COD training study that has incorporated jumping with an external load. Both groups significantly decreased their times in the t-test (1.7–2.4%; effect size = 1.2–1.3) after the training period, with greater improvements in the heavier group (80% 1RM). Although the jump-squat exercise is performed in the vertical direction, it is different to the exercises presented above. As the subjects squat down, high velocities and eccentric forces are developed while the muscles elongate, similar to a COD. In order to take advantage of these high forces, a strong eccentric strength base would be needed, which could be developed through jump-squat training. Thus, it could be suggested that since strength and power training in the vertical direction does not appear to enhance COD performance, greater eccentric loading/training stimulus may be the reason for the enhanced COD performance.

In a study by Malisoux et al.,[20] recreationally active men performed 8 weeks of jump training and reported significant improvements in the shuttle run (6 × 5 m). The subjects performed both vertical and horizontal jumps (unilateral and bilateral). COD times significantly decreased (–3.6%; effect size = 2.1) after the training period. It should be noted that Malisoux et al.[20] scored a 12/20 on the methodological quality scale (see table I), due to receiving scores of zero on the following items: 2 (not randomizing groups), 4 (groups not similar at baseline) and 5 (no control group). Miller et al.[28] also reported improvements in COD performance after a 6-week training intervention that included vertical, horizontal and lateral jumping (unilateral and bilateral). COD times were significantly reduced for the t-test and the Illinois agility test (–5.5%; effect size = 0.7). It could be speculated that unilateral and bilateral horizontal jump training contributed more to the improvements in COD performance than vertical jump training, since other studies have reported no improvements in COD performance with vertical jump training alone. Alternatively, at the very least, a combination of both vertical and horizontal or lateral jumping-type movements are needed to elicit improvements in COD ability. The results of these two studies are encouraging for athletic populations, and suggest that the inclusion of horizontal and lateral jumping should be researched (i.e. movement mechanics and training effects) more thoroughly in the future. Unfortunately, there have been no studies that have investigated the effects of horizontal and/or lateral jump training versus vertical jump training on COD performance.

4.3 COD-Specific Training

The majority of training studies that have reported significant improvements in COD performance have performed either sport-specific COD training or traditional COD training (see table II). Gabbett et al.[18] investigated the effects of a volleyball-specific training programme on t-test times in junior female volleyball players. The training programme included technical and instructional coaching, coupled with skill-based games to develop passing, setting, serving, spiking, and blocking accuracy and technique. The training protocol lasted for 8 weeks and significantly decreased t-test times (–5.2%; effect size = 3.6). Polman et al.[26] found similar results in elite female soccer players with specific COD training. The athletes performed a 12-week training period (two sessions per week), which included soccer-specific and traditional speed, COD and power exercises. One group performed the exercises with additional equipment (resistance cords, k-boards, hurdles), and another group performed the exercises without the equipment. The COD test that was utilized involved sprinting and several CODs of 90° or 180° over 18 m. Both groups significantly improved COD performance (–3.8% to –4.2%; effect size = 1.2–1.6). It appears that sport-specific or traditional COD training alone can improve COD performance in female athletes over a period of 8–12 weeks.

Gabbett[19] investigated the effects of specific field training (including COD exercises) in combination with a traditional strength and conditioning programme on COD performance in junior and senior level rugby league players. The field training was performed twice a week for 14 weeks. General COD exercises were performed in the off-season, and specific COD exercises were performed in the pre-season. After the 14-week training period, COD performance significantly decreased COD times by −17.7% for the junior players and −16.2% for the senior players, respectively. In another rugby league study by Gabbett,[16] both traditional COD training and skill-based COD training were performed over a 9-week in-season period. The skill-based COD training involved exercises that were meant to improve rugby skills (e.g. passing, catching, tackling) and enhance COD performance. It was reported that both training groups maintained COD times over the competitive season.

Dean et al.[32] and Christou et al.[27] both investigated the effects of COD training on young athletes (12–16 years old) and reported significant improvements. The athletes in the study of Dean et al.[32] performed COD training for 4 weeks and reported a significant improvement in the 20-yard shuttle times (–3.2%; effect size = 0.3). It should be noted that Dean et al.[32] received a low score of 10/20 on the methodological quality scale (see table I), due to receiving a zero on the following items: 2, 4, 5 and 10. Christou et al.[27] also reported a significant improvement in COD times after 16 weeks of both COD training and strength and conditioning training in young soccer players (–4.0 to 5.4%; effect size = 1.1–1.7). The subjects in Christou et al.[27] performed traditional and soccer-specific COD exercises over the 16 weeks, and reported significant decreased in the shuttle run (10 × 5 m).

There are two COD training studies that have incorporated non-traditional training protocols. Cressey et al.[25] examined the effects of a strength and conditioning programme that included stable (stable group) and unstable surfaces (unstable group) during a variety of lower body exercises (lunges, squats, deadlifts). All subjects (male soccer players) also performed soccer-specific COD training, and both groups significantly decreased COD times (–2.9% to 4.4%; effect size = 1.0–1.6). Deane et al.[29] investigated the effects of hip flexor strength training with elastic tubing on COD performance in untrained subjects. After the 8-week intervention, COD times were significantly decreased (–8.3% to 10%; 1.1–1.8).

5. Conclusions and Future Research Directions

Given the limitations cited throughout this article, it is difficult to discern with any great certainty those factors that influence COD ability. The model proposed by Young et al.[34] is somewhat simplistic, and it is more likely that the model needs to view the determinants of COD ability as interrelated qualities, this combination of qualities explaining COD ability to better effect. Furthermore, there needs to be a great deal more research into those force/power qualities (e.g. horizontal and lateral) and technique factors that influence event- or sport-specific COD ability.

In terms of the training studies, traditional strength and power training methods (i.e. Olympic-style weightlifting, traditional strength training, plyometrics, and vertical jump training) have been shown to enhance functional performance (i.e. running and jumping) in athletic and non-athletic populations.[12,46-48] These training methods have been utilized in several training studies and are commonly used by strength and conditioning coaches.[50] However, these traditional training methods have failed to improve COD performance. We feel that this failure is due to the commonality in the design of these exercises, which include bilateral movements in the vertical direction. Conversely, COD movements occur unilaterally in the vertical-horizontal and/or lateral direction, and require anterior-posterior (breaking and propulsive) and medio-lateral force production. Unfortunately, there have been no studies that have investigated the correlations between unilateral horizontal jumping and COD performance. It could be speculated that since CODs require vertical-horizontal force production, horizontal jumping would be highly correlated with COD performance and could enhance COD performance with training. Furthermore, for those tests requiring lateral force production, the effect of lateral-type jumps needs to be investigated.

Improvements in COD performance seem better accomplished with the following types of exercise and training: general COD training, sport-specific COD training, jump squat training, unilateral and bilateral horizontal jump training. Not surprisingly, training that involves sprinting with direction changes (i.e. COD tests themselves) has been shown to enhance COD performance. The only other types of exercises that have enhanced COD performance have been horizontal jumping (in combination with vertical and lateral jumping) and loaded vertical jumping. Unfortunately, there have been no studies that have investigated the effects of primarily horizontal jump training (unilateral and bilateral) on COD performance. Since vertical jumping has failed to enhance COD performance, it is thought that the horizontal jump training enhanced COD performance. Therefore, the inclusion of such jumps in the athlete's assessment and training programme would seem fundamental to improved COD ability.

It is thought that since vertical jump and squat training have failed to enhance COD performance, the eccentric strength gained from the weighted vertical jumps enhanced COD performance. It could be speculated that the eccentric strength gained form weighted jumping could have been the stimulus for the enhanced COD performance. Unfortunately, there have been no studies that have investigated the effects of eccentric training on COD performance. Furthermore, improvements in COD performance have been reported over a range of subjects (young, recreational, sub-elite athletes, elite athletes) with these training methods. Thus, the findings of this article can be applied to a wide variety of athletes and subjects.

It is suggested that specific methods and exercises should be developed in order to enhance COD performance. These exercises should include horizontal and unilateral movements, closed-chain exercises, multi-joint movements and movements that can be safely and effectively overloaded, cost-effective and easy to implement. Research is needed on the relationships between these types of exercises and COD performance, and their training effects on COD performance. Furthermore, it appears that training involving COD movements themselves has been effective at improving COD performance.

Acknowledgements

No sources of funding were received in the preparation of this review and the authors have no conflicts of interest directly relevant to its contents.

References

1. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. J Sports Sci 2006; 24 (9): 919-32
2. Gil SM, Gil J, Ruiz F, et al. Physiological and anthropometric characteristics of young soccer players according to their playing position: relevance for the selection process. J Strength Cond Res 2007; 21 (2): 438-45
3. Gabbett TJ. A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. J Sports Sci 2006; 24 (12): 1273-80
4. Little T, Williams AG. Specificity of acceleration, maximum speed, and agility in professional soccer players. J Strength Cond Res 2005; 19 (1): 76-8
5. Reilly T, Williams AM, Nevill A, et al. A multidisciplinary approach to talent identification in soccer. J Sports Sci 2000; 18 (9): 695-702
6. Gil S, Ruiz F, Irazusta A, et al. Selection of young soccer players in terms of anthropometric and physiological factors. J Sports Med Phys Fitness 2007; 47 (1): 25-32
7. Mcgee K, Burkett L. The National Football League combine: a reliable predictor of draft status? J Strength Cond Res 2003; 17 (1): 6-11
8. Davis DS, Barnette BJ, Kiger JT, et al. Physical characteristics that predict functional performance in division I college football players. J Strength Cond Res 2004; 18 (1): 115-20
9. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med 2007; 41 (6): 349-55
10. Fry A, Kraemer WJ, Weseman C, et al. The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. J Strength Cond Res 1991; 5 (4): 174-81
11. Cronin J, McNair PJ, Marshall RN, et al. The effects of bungy weight training on muscle function and functional performance. J Sports Sci 2003; 21 (1): 59-71
12. Tricoli VA, Lamas L, Carnevale R, et al. Short-term effects on lower-body functional power development: weightlifting vs vertical jump training programs. J Strength Cond Res 2005; 19 (2): 433-7

13. Hoffman JR, Cooper J, Wendell M, et al. Comparison of Olympic vs traditional power lifting training programs in football players. J Strength Cond Res 2004; 18 (1): 129-35
14. Kraemer W, Hakkinen K, Triplett-Mcbride N, et al. Physiological changes with periodized resistance training in women tennis players. Med Sci Sport Exerc 2003; 35 (1): 157-68
15. Hoffman JR, Ratamess NA, Cooper JJ, et al. Comparison of loaded and unloaded jump squat training on strength/-power performance in college football players. J Strength Cond Res 2005; 19 (4): 810-5
16. Gabbett TJ. Skill-based conditioning games as an alternative to traditional conditioning for rugby league players. J Strength Cond Res 2006; 20 (2): 309-15
17. Harris G, Stone M, O'bryant H, et al. Short-term performance effects of high power, high force, or combined weight-training methods. J Strength Cond Res 2000; 14 (1): 14-20
18. Gabbett T, Georgieff B, Anderson S, et al. Changes in skill and physical fitness following training in talent-identified volleyball players. J Strength Cond Res 2006; 20 (1): 29-35
19. Gabbett TJ. Performance changes following a field conditioning program in junior and senior rugby league players. J Strength Cond Res 2006; 20 (1): 215-21
20. Malisoux L, Francaux M, Nielens H, et al. Stretch-shortening cycle exercises: an effective training paradigm to enhance power output of human single muscle fibers. J Appl Physiol 2006; 100 (3): 771-9
21. Young WB, McDowell MH, Scarlett BJ, et al. Specificity of sprint and agility training methods. J Strength Cond Res 2001; 15 (3): 315-9
22. McBride JM, Triplett-McBride T, Davie A, et al. The effect of heavy- vs light-load jump squats on the development of strength, power, and speed. J Strength Cond Res 2002; 16 (1): 75-82
23. Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale (NJ): Lawrence Erlbaum, 1988
24. Markovic G, Jukic I, Milanovic D, et al. Effects of sprint and plyometric training on muscle function and athletic performance. J Strength Cond Res 2007; 21 (2): 543-9
25. Cressey EM, West CA, Tiberio DP, et al. The effects of ten weeks of lower-body unstable surface training on markers of athletic performance. J Strength Cond Res 2007; 21 (2): 561-7
26. Polman R, Walsh D, Bloomfield J, et al. Effective conditioning of female soccer players. J Sports Sci 2004; 22 (2): 191-203
27. Christou M, Smilios I, Sotiropoulos K, et al. Effects of resistance training on the physical capacities of adolescent soccer players. J Strength Cond Res 2006; 20 (4): 783-91
28. Miller M, Herniman J, Ricard M, et al. The effects of a 6-week plyometric training program on agility. J Sports Sci Med 2006; 5: 459-65
29. Deane RS, Chow JWC, Tillman MD, et al. Effects of hip flexor training on sprint, shuttle run, and vertical jump performance. J Strength Cond Res 2005; 19 (3): 615-21
30. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res 2004; 18 (4): 918-20
31. Draper JA, Lancaster MG. The 505 test: a test for agility in the horizontal plane. Aust J Sci Med Sport 1985; 17 (1): 15-8
32. Dean W, Nishihara M, Romer J, et al. Efficacy of 4-week supervised training program in improving components of athletic performance. J Strength Cond Res 1998; 12 (4): 238-42
33. Alricsson M, Harms-Ringdahl K, Werner S, et al. Reliability of sports related functional tests with emphasis on speed and agility in young athletes. Scand J Med Sci Sports 2001; 11 (4): 229-32
34. Young WB, James R, Montgomery I, et al. Is muscle power related to running speed with changes of direction? J Sports Med Phys Fitness 2002; 42 (3): 282-8
35. Gastin P. Energy system interaction and relative contribution during maximal exercise. Sports Med 2001; 31 (10): 725-41
36. Buttifant D, Graham K, Cross K. Agility and speed in soccer players are two different performance parameters. In: Spinks W, Reilly T, Murphy AJ, editors. Science and football IV. London: Routledge, 2002: 329-32
37. Hoffman J, Ratamess N, Klatt M, et al. Do bilateral power deficits influence direction-specific movement patterns? Res Sports Med 2007; 15 (2): 125-32
38. Markovic G. Poor relationship between strength and power qualities and agility performance. J Sports Med Phys Fitness 2007; 47 (2146-JSM)
39. Mayhew JL, Piper FC, Schwegler TM, et al. Contributions of speed, agility and body composition to anaerobic power measurement in college football players. J Appl Sport Sci Res 1989; 3 (4): 101-6
40. Negrete R, Brophy J. The relationship between isokinetic open and closed kinetic chain lower extremity strength and functional performance. J Sports Rehab 2000; 9: 46-61
41. Pauole K, Madole K, Garhammer J, et al. Reliability and validity of the t-test as a measure of agility, leg power, and leg speed in college-aged men and women. J Strength Cond Res 2000; 14 (4): 443-50
42. Peterson M, Alvar B, Rhea M, et al. The contribution of maximal force production to explosive movement among young collegiate athletes. J Strength Cond Res 2006; 20 (4): 867-73
43. Roetert EP, Garrett GE, Brown SW, et al. Performance profiles of nationally ranked junior tennis players. J Appl Sport Sci Res 1992; 6 (4): 225-31
44. Young W, Hawken M, McDonald L, et al. Relationship between speed, agility and strength qualities in Australian Rules football. Strength Cond Coach 1996; 4 (4): 3-6
45. Sayers SP, Harackiewicz DV, Harman EA, et al. Cross-validation of three jump power equations. Med Sci Sport Exerc 1999; 31 (4): 572-7
46. Blazevich AJ, Jenkins DG. Effect of the movement speed of resistance training on sprint and strength performance in concurrently training elite junior sprinters. J Sport Sci 2002; 20: 981-90

47. Coutts AJ, Murphy A, Dascombe BJ, et al. Effect of direct supervision of a strength coach on measures of muscular strength and power in young rugby league players. J Strength Cond Res 2004; 18 (2): 316-23
48. Kotzamanidis C, Chatzopoulos D, Michailidis C, et al. The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players. J Strength Cond Res 2005; 19 (2): 369-75
49. Murphy AJ, Wilson GJ. The ability of tests of muscular function to reflect training-induced changes in performance. J Sport Sci 1997; 15: 191-200
50. Simenz C, Dugan C, Ebben W, et al. Strength and conditioning practices of national basketball association strength and conditioning coaches. J Strength Cond Res 2005; 19 (3): 495-504

Correspondence: *Matt Brughelli*, School of Exercise, Biomedical and Health Sciences, Edith Cowan University, 100 Joondalup Drive, Joondalup, Western Australia 6027, Australia.
E-mail: m.brughelli@ecu.edu.au

