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Section III – Sports Training

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A Meta-Analysis on the Effect of Complex Training on Vertical Jump Performance

by
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Complex training (CT) is a strength training intervention performed by completing all the sets of a resistance exercise followed by a series of high-velocity/plyometric exercise/s. The purpose of this novel study was to conduct a meta-analysis on the effect of CT on vertical jump (VJ) performance. Five electronic databases were searched using terms related to CT and the VJ. Studies needed to include randomized trials comparing CT with traditional resistance training (RT)/plyometric training (PLYO)/control (CON) lasting ≥ 4 weeks and the VJ as a dependent variable. Seven studies qualified for the meta-analysis with two studies differentiating VJ performance from CT and RT, two studies comparing VJ performance of CT and PLYO, and two studies establishing the difference in VJ performance between CT and CON. Results indicated similar improvement in VJ performance from CT and RT ($p = 0.88$). On the other hand, greater VJ performance in CT than PLYO was identified (ES = 0.86; 95% CI 0.24, 1.47; $p = 0.01$). CT also showed significantly greater enhancement in VJ compared to CON (ES = 1.14; 95% CI 0.60, 1.68; $p < 0.01$). In conclusion, CT can serve as alternative training from RT in improving VJ performance. On the other hand, CT is a better option in VJ enhancement than PLYO and CON.

***Key words**: vertical jump, countermovement jump, strength training, plyometrics.*

Introduction

Designing strength training programs for power enhancement has been a constant challenge among practitioners. In the recent decade, complex training (CT) has been receiving a notable attention as one of the interventions for improving power (Carter and Greenwood, 2014; Ebben, 2002; Lesinski et al., 2014). CT is a strength training scheme that integrates resistance training and high-velocity/plyometric training in a single session. One variation of CT is performed by completing all the sets of a resistance exercise followed by a series of high-velocity/plyometric exercise/s (Ebben, 2002). The purpose of this novel study was to administer a meta-analysis on the effect of CT on vertical jump (VJ) performance.

Methods

Search Strategy

PRISMA guidelines for literature of databases (GoogleScholar, SPORTDiscus, World of Science, SpringerLink, and PubMed) were utilized from all time points until January 30, 2018 (Moher et al., 2009). The search terms and Booleans included (complex training) OR (contrast training) OR (combined weight training and plyometrics) OR (combined strength training and plyometrics) OR (combined resistance training and plyometrics) AND (vertical jump or jump performance). Manual searches from references were also carried out. Inclusion criteria were: 1) randomised trials peer-reviewed in English; 2) CT intervention that compared any resistance training (RT) or plyometric training (PLYO) or a control (CON) wherein COM involved completing all the sets of a resistance exercise succeeded by a series of high velocity/plyometric exercises; 3) availability of pre and post VJ data executed with a countermovement; and, 4) training intervention performed at least twice a week with duration of ≥

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4 weeks.

Data Extraction

A single investigator (JP) who is a certified strength and conditioning specialist with more than 10 years of experience and holds a master's degree in applied sport and exercise science assessed the eligibility of studies. In the first stage, titles and abstracts of identified articles were examined for relevance. Reference lists of included articles were also checked for possible inclusion. Full-text articles of potential studies were retrieved and assessed individually during the second stage. The second investigator (HP) who is an assistant professor specializing in sports training research independently checked the data extraction administered by JP. Both investigators rated the included studies for 'risk of bias' using an eight-point scale from the Consolidated Standards of Reporting Trials (CONSORT) statement where each item was answerable by 0 (absently or inadequately described) or 1 (explicitly described and present) (Altman et al., 2001). A score of 0-2 was regarded as having a high risk of bias, 3-5 with medium risk, and 6-8 considered as having a low risk of bias. A consensus between the first and second investigator was reached for any disagreement presented in data extraction and CONSORT output.

Statistical Analysis

A free meta-analysis tool (RevMan ver 5.3, The Nordic Cochrane Centre, Copenhagen) was utilized to examine VJ height in comparison with COM and RT/CON/PLYO. Standardized mean differences (difference in mean outcomes between groups/standard deviation of the outcome among participants) was used to derive effect size (ES) and interpreted with the following criteria: .2 – small effect; 0.5 - moderate effect; 0.8 – large effect (Cohen, 1988; Zlowodzki et al., 2007).

Results

The literature search uncovered 1067 potential articles and two articles were identified from reference lists. Removal of duplicates (n = 345) left 742 articles. After screening of the title and abstracts, 83 articles underwent a more detailed evaluation and led to the exclusion of 76, thus, leaving 7 articles for meta-analysis (de Villareal et al., 2011; Fayed, 2015; Ferrete et al., 2014; Franco-Márquez et al., 2014; Lyttle et al., 1996; Rodríguez-Rosell et al., 2017; Saeed, 2013). Figure 1 presents the flow diagram of study selection.

CONSORT scores of the seven studies in meta-analysis showed only one study scoring 5 (Rodríguez-Rosell et al., 2017). There were four studies that scored 4 (de Villareal et al., 2011; Ferrete et al., 2014; Franco-Márquez et al., 2014; Lyttle et al., 1996). Lastly, two studies scored 1 (Fayed, 2015; Saeed, 2013). Table 1 displays the CONSORT scores of the studies.

Participants determined in the meta-analysis involved thirty-nine physical education students, 33 regional athletes, and 151 young athletes with CT interventions administered twice to three times a week lasting from 6 to 12 weeks. Two studies compared CT and RT (de Villareal et al., 2011; Rodríguez-Rosell et al., 2017). Two studies differentiated between CT and PLYO (de Villareal et al., 2011; Lyttle et al., 1996), while six studies compared CT and CON (Fayed, 2015; Ferrete et al., 2014; Franco-Márquez et al., 2014; Lyttle et al., 1996; Rodríguez-Rosell et al., 2017; Saeed, 2013). The characteristics of studies are presented in Table 2.

CT vs. RT

There was no significant difference in VJ performance between CT and RT at $Z = 0.15$, $p = 0.88$.

CT exhibited a 13.2% (95% CI 1.54 to 4.16 cm) improvement in VJ performance. On the other hand, RT showed a 12.5% (95% CI 1.39 to 4.21 cm) increase in VJ performance. The funnel plot of CT vs. RT is presented in Figure 2.

CT vs. PLYO

CT posted significantly greater enhancement in VJ performance than PLYO, $Z = 4.15$, $p = 0.01$, ES = 0.86 95% CI [0.24, 1.47]. CT showed a 15.9% (95% CI 2.71 to 6.59 cm) increase in VJ performance, while PLYO posted an 8.89% (95% CI 0.84 to 4.66 cm) VJ attenuation. The funnel plot of CT vs. PLYO is displayed in Figure 3.

CT vs. CON

CT significantly improved VJ performance compared to CON at $Z = 4.15$, $p < 0.01$, ES = 1.14 [0.60, 1.68]. CT improved VJ performance by 8.8% (95% CI 1.48 to 4.74 cm), whereas CON showed a 2.11% (95% CI -0.94 to 2.06 cm) increase in VJ performance. Figure 4 exhibits the funnel plot of CT vs. CON. Pre and post VJ data from CT and a comparison group is depicted in Figure 4.

Discussion

The aim of this novel study was to conduct a meta-analysis on the effect of CT on VJ performance wherein CT was defined as completing all the sets of a resistance exercise succeeded by a series of high-velocity/plyometric exercise/s. Results revealed that CT exhibited similar improvement in VJ performance with RT. On the other hand, CT posted greater enhancement in VJ performance when compared with PLYO. Similarly, CT showed superior VJ gains than CON. Enhancement in VJ performance with CT compared to PLYO/CON may be related to the added stimulus in CT that facilitated postactivation potentiation (PAP) (Gołaś et al., 2016; Robbins, 2005; Sale, 2002). PAP refers to the enhancement of performance from myosin phosphorylation and h-reflex excitation. In relation to this, VJ gains from CT may be related to cellular and hormonal adaptations favourable to power enhancement (Beaven et al., 2011; Labib, 2013). For example, Beaven et al. (2011) presented increased testosterone while enhancement in VJ performance after CT. Labib (2013) documented increased CD34/CD45 immune system stem cell secretion with improvement in the standing long jump after CT (Donovan and Koretzky, 1993; Sidney, 2014). It may be also possible that greater preservation of IIX muscle fibers is achieved with CT than PLYO/CON (Stasinaki et al., 2011). Greater selective recruitment of FTx muscle fibers in CT compared to PLYO/CON may have also occurred (Gołaś et al., 2016). On the other hand, non-significant difference in VJ improvement exhibited between CT and RT may point to possible fatigue induced by CT which may have masked possible potentiation effects (Häkkinen, 1993; Wilson et al., 2013).

Table 1

CONSORT Scores of Included Articles for Meta-Analysis

References	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Total
de Villareal et al.. (2011)	1	0	0	0	0	1	1	1	4
Fayed (2015)	0	0	0	0	0	1	0	0	1
Ferrete et al. (2014)	1	0	0	0	0	1	1	1	4
Franco-Márquez et al. (2015)	1	0	0	0	0	1	1	1	4
Lyttle et al. (1996)	1	1	0	0	0	1	1	0	4
Rodríguez-Rosell et al. (2017)	1	0	1	0	0	1	1	1	5
Saeed (2013)	0	0	0	0	0	1	0	0	1

Item 1 *- Were the groups comparable on baseline on key characteristics?*
Item 2 *- Did the study include a true control group (randomised participants - not a comparison group)?*
Item 3 *- Was the randomisation procedure adequatel described and carried out? y*
Item 4 *- Did the study report a power calculation and was the study adequately powered to detect intervention effects?*
Item 5 *- Were the assessors blinded to treatment allocation at baseline and posttest?*
Item 6 *- Did at least 80% of participants complete follow-up assessments?*
Item 7 *- Did the study analyses account for potential differences at baseline?*
Item 8 *- Did the study compute effect sizes?*

Table 2a

Characteristics of Studies

References	Participants		Training Modality		Outcome (VJ Height)
	N/sex	Age/discipline	Description	Frequency/ duration	
de Villarreal et al. (2011)	CT: 10M, F4; RT: 9M, 4F; PLYO: 9M, 3F	18-24 yrs; physical education students	CT: full squat (3-4 x 3-6 @ 60-80 RM) half-squat (3-4 x 2-6@ 0 MP to + 30% MP); loaded CMJ (3-4 x 2-5@ -30% MP to MP); rebound jumps (4-8 x 5@ BW)	3x/wk; 7wks	CT: pre < post RT: pre vs. post : NSD PLYO: pre vs. post: NSD
			RT:half squat (3-4 x 2-6 @ 0 MP to +30% MP)	3x/wk; 7 wks	
			PLYO: rebound jumps (4-8 x 5 @ BW)	3x/wk; 7 wks	
Fayed (2015)	CT: n = 10; CON: n = 10	14-16 yrs; young swimmers	CT: squat (3 x 12 RM) to vertical jump (3 x 10); bench press (3 x 12 RM) to medicine ball pass (3 x 10); barbell lunge (3 x 12 RM) to step jump (3 x 10); lat pulldown (3 x 12 RM) to overhead ball pass (3 x 10); abdominal crunches (3 x 12 RM) to medicine ball sit up and throw (3 x 10); decline press (3 x 12 RM) to zigzag drill (3 x 10)	3x/wk; 8 wks	CT: pre < post CON: pre vs post: NSD
			regular training	NS; 8 wks	
			CON: regular training	NS; 8 wks	
Ferrete et al. (2014)	CT: n = 11; CON: n = 13	8-10 yrs young soccer players	CT: 1/4 squat (2-3 x 6-8); 3 kg rebound jumps (3 x 4-6); full squat (3-5 x 6); partner resisted sprint (4 x 10 s); obstacle jump (3 x 5); sprint (4 x 20 m);	3x/wk; 8 wks	CT: pre < post CON: pre vs. post: NSD
			soccer training	3x/wk; 8 wks	
			CON: soccer training	3x/wk; 8 wks	

***CT** – complex training; **RT** – resistance training; **PLYO** – plyometric training; **CON** – control; **NS** – not stated; **NSD** – no significant difference; **VJ** – vertical jump; **CMJ** – countermovement jump; **RM** – maximal load in single repetition; **MP** – maximal power*

Table 2b

Characteristics of Studies

References	Participants		Training Modality		Outcome (VJ Height)
	N/sex	Age/discipline	Description	Frequency/ duration	
Franco-Márquez et al. (2015)	CT: n = 22; CON: n = 22	14-15 yrs young soccer players	CT: full squat (2-3 x 4-8 @ 45-58 RM); CMJ (3 x 5: weeks 2,4,6,8, 10,12 only); step phase triple jump (6 x 6-12); change of direction (3-5 x 10 s: weeks 1,3,5 ,7,9,11 only); sprint (3-4 x 20 m: weeks 2,4,6, 8,10,12 only)	2x/wk; 12 wks	CT > CON
			soccer training	4x/wk; 12 wks	
			match	1/wk; 12 wks	
			CON: soccer training	4x/wk; 12 wks	
			match	1/wk; 12 wks	
Lyttle et al (1996)	n = 33; CT: 11M; PLYO: 11 M; CON: 11 M	20-24 yrs various regional athletes	CT: bench press (1-3 x 6-10) to medicine ball throw (1 x 1-2); squat (1-3 x 6-10) to depth jump (1 x 1-2)	2x/wk; 8 wks	CT: pre vs. post: NSD PLYO: pre vs. post: NSD CON: pre vs. post: NSD
			PLYO: bench press throws (2-6 x 8); squat jumps (2-6 x 6-8)	2x/wk; 8 wks	
			CON: no training	8 wks	

Table 2c

Characteristics of Studies

References	Participants		Training Modality		Outcome (VJ Height)
	N/sex	**Age/discipline**	**Description**	**Frequency/ duration**	
Rosell et al. (2017)	CT: 10M; RT: 10 M; CON: 10M	semi-professional soccer	@ 45-60 RM); CMJ (3 x 5); change of direction (3-5 x 10 s); sprint (3-4 x 20 m)	6 wks	CT $>$ CON
			soccer training	4 x/wk; 6 wks	
			match	1/wk; 6wks	
			RT: full squat (2-4 x 3-6 @ 45-60 RM)	2x/wk; 6 wks	
			soccer training	4x/wk; 6 wks	
			match	1/wk; 6 wks	
			CON: soccer training	4x/wk; 6 wks	
			match	1/wk; 6 wks	
Saeed (2013)	n = 20; CT: 10F; CON: 10F	10-14 yrs young female volleyball players	CT: squat (3 x 12 RM) to vertical jump (3 x 10); bench press (3 x 12 RM) to medicine ball pass (3 x 10); barbell lunge (3 x 12 RM) to step jump (3 x 10); lat pulldown (3 x 12 RM) to ovehead ball pass (3 x 10); abdominal crunches (3 x 12 RM) to medicine ball sit up and throw (3 x 10); decline press (3 x 12 RM) to zigzag drill (3 x 10)	3x/wk; 9 wks	CT: pre $<$ post CON: pre $<$ post
			regular training	NS; 9 wks	
			CON: regular training	NS; 9 wks	

Table 3 4

VJ Performance in CT, PLYO, RT, and CON

	CT			Comparison Group		
		VJ (cm)			VJ (cm)	
	n	Pre	Post	n	Pre	Post
		Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD
RT						
de Villarreal et al. (2011)	14	17.5 ± 2.60	21.2 ± 2.50	13	16.9 ± 3.00	19.9 ± 2.90
Rodríguez-Rosell et al. (2017)	15	37.8 ± 3.90	39.8 ± 4.20	15	36.3 ± 4.10	38.9 ± 4.70
PLYO						
de Villarreal et al. (2011)	14	17.5 ± 2.60	21.2 ± 2.50	12	16.5 ± 2.80	18.2 ± 2.90
Lyttle et al. (1996)	11	52.8 ± 11.5	58.4 ± 9.30	11	50.8 ± 9.00	54.6 ± 8.50
CON						
Fayed (2015)	10	36.5 ± 1.61	41.2 ± 2.64	10	37.1 ± 1.75	38.7 ± 2.82
Ferrete et al. (2014)	11	22.3 ± 2.70	23.7 ± 3.50	13	20.2 ± 3.40	20.3 ± 3.20
Franco-Márquez et al. (2015)	22	33.2 ± 4.80	36.2 ± 6.50	22	33.2 ± 3.70	33.4 ± 3.70
Lyttle et al. (1996)	11	52.8 ± 11.5	58.4 ± 9.30	11	49.2 ± 3.50	49.2 ± 5.70
Rodríguez-Rosell et al. 2017	15	37.1 ± 3.80	37.0 ± 4.20	15	37.0 ± 6.80	36.1 ± 5.90
Saeed (2013)	10	22.3 ± 2.31	24.2 ± 2.12	10	21.1 ± 3.11	22.8 ± 2.64

Table 4

Subgroup Analysis for CT vs. CON

Group	Studies				Subgroup difference
	Reference	ES (95% CI)	I^2	p-value	p-value
Population Characteristics					
Age					
≥ 18 years	(Lyttle et al., 1996; Rodríguez-Rosell et al., 2017)	3.77(0.34, 7.20)	82.0	< 0.05	0.32
≤ 18 years	(Fayed, 2015; Ferrete et al., 2014; Franco-Márquez et al. 2015; Saeed, 2013)	1.92(0.60, 3.24)	74.0	< 0.01	
CT Training Strategy					
traditional	(Fayed, 2015; Lyttle et al., 1996; Saeed, 2013)	2.91(0.16, 5.67)	89.0	< 0.05	0.59
non-traditional	(Ferrette et al., 2014; Franco-Márquez et al., 2015; Rodríguez-Rosell et al., 2017)	2.12(1.21, 3.03)	14.0	< 0.01	

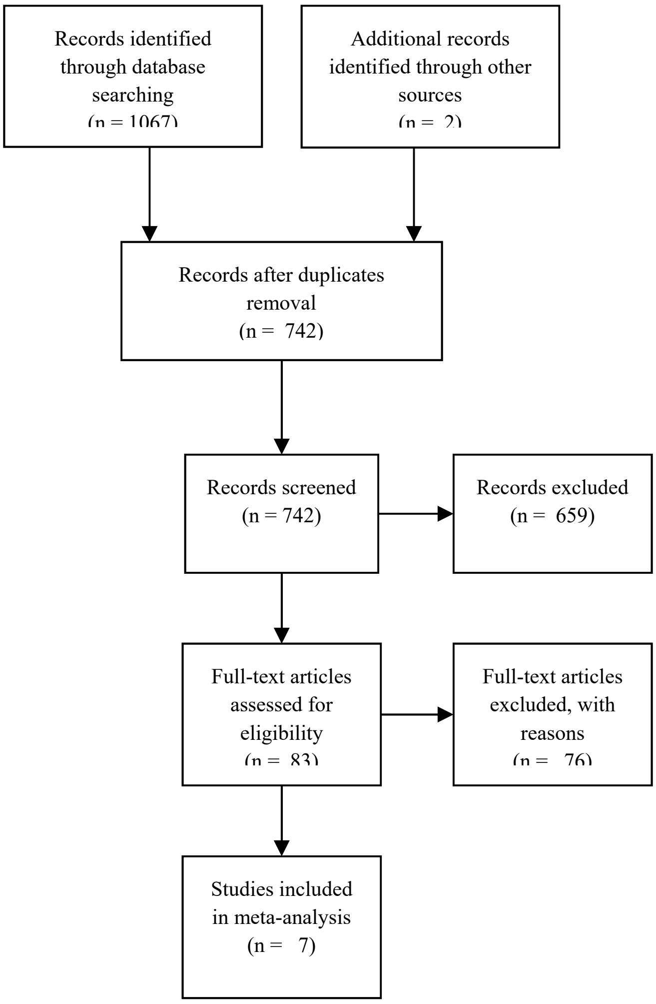

Figure 1

Flow Diagram of the Search Process

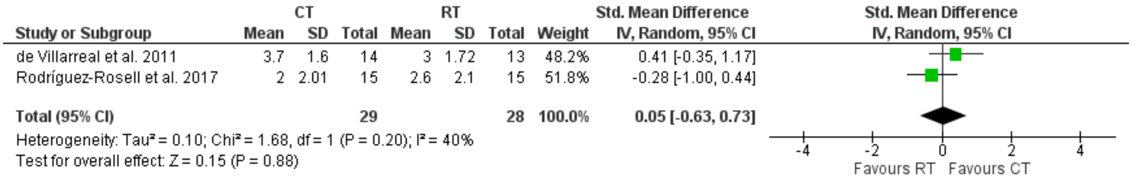

Figure 2

Forest Plot comparing VJ of CT and RT

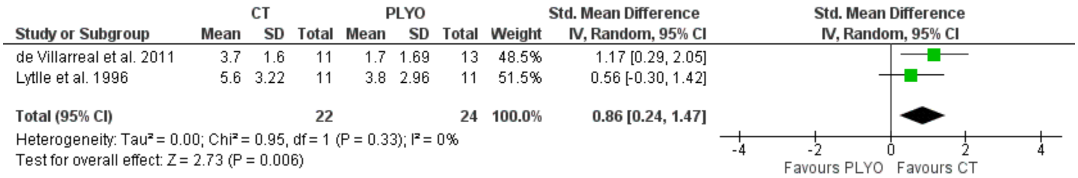

Figure 3

Forest Plot comparing VJ of CT and PLYO

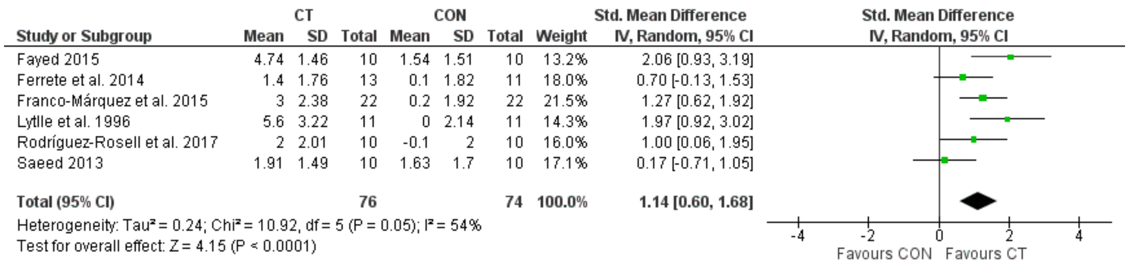

Figure 4

Forest Plot comparing VJ of CT and CON

Subgroup analysis was administered in CT vs. CON to determine possible moderators that led to superior VJ enhancement in CT. Researchers identified age (≥ 18 yrs vs. ≤ 18 yrs) and CT strategy (traditional vs. non-traditional) as covariates. It was found that both age groups exhibited greater VJ performance following CT than CON. However, no difference in VJ performance was observed between ≥ 18 yrs and ≤ 18 yrs in CT vs. CON. Furthermore, traditional and non-traditional CT modalities were analysed. Traditional CT involves a pair of exercises, while non-traditional CT is executed for 3 or more exercises. Utilizing traditional and non-traditional CT demonstrated greater VJ gains than CON. No difference in VJ enhancement was seen between traditional and non-traditional CT in CT vs. CON. Thus, age and CT strategy moderate VJ improvement in CT vs. CON. Subgroup analysis in CT vs. CON is presented in Table 4.

Limitations of this study are noteworthy of considerations. Firstly, heterogeneity in study designs with a small sample size involved in this study was observed. There was variety in complex training exercises, measurement of the VJ, and training populations. Thus, implications for the magnitude of inference from this study are limited. Subgroup analysis was only performed in CT vs. CON with few covariates due to scarcity of studies. Administration of such a method will help provide valuable insights into the findings of this study. The risk of bias of included studies ranged from high to moderate. Additionally, analysis utilizing comparison groups from other strength training schemes of similar volume (e.g. compound training, contrast loading) was not administered. Lastly, it should also be noted that only the VJ executed with countermovement mechanics was included as a dependent variable.

In conclusion, enhancement of the VJ is achieved interchangeably from CT and RT. However, utilizing CT is more effective than PLYO or CON in improving VJ performance.

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