Concurrent Plyometric And Endurance Training Effects On Aerobic Fitness-Performance In Adult Endurance Athletes: A Systematic Review With Meta-Analysis

Lisa Annemarie Connelly

CONCURRENT PLYOMETRIC AND ENDURANCE TRAINING EFFECTS ON AEROBIC FITNESS-PERFORMANCE IN ADULT ENDURANCE ATHLETES: A SYSTEMATIC REVIEW WITH META-ANALYSIS

by

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This thesis, submitted by Lisa Annemarie Connelly in partial fulfillment of the requirements for the Degree of Master of Science in Kinesiology and Public Health Education from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

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Department	Kinesiology and Public Health Education
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Lisa Annemarie Connelly LAT,ATC

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ABSTRACT

Numerous training modalities have been used to improve aerobic fitness and performance. Concurrent strength and endurance training is considered an effective modality to improve aerobic outcomes, although little is known about the effectiveness of concurrent plyometric (jump) training. The aim of this systematic review and meta-analysis was to determine the effectiveness of plyometric training on aerobic fitness (operationalized as maximal oxygen uptake [$\dot{V}O_{2max}$] and running economy [RE]) and performance (time trial performance). Five online databases were used to identify peer-reviewed studies published from 1980 onwards — the year the first concurrent training study was published. Studies were included if they used a randomized control trial design and matched these criteria: population (endurance-trained adult runners with at least 3 months training experience), intervention (concurrent plyometric training lasting at least 6 weeks), comparison (normal endurance training), and outcomes (changes in aerobic fitness and performance). Separate random effects meta-analyses were conducted for each outcome, with standardized mean differences (SMD) and percent mean differences (PMD) calculated. Four studies, using short periods (6 to 9 weeks) of small to moderate frequency (1 to 3 sessions per week) and moderate to high volume (~1000 to ~4000 jumps) concurrent plyometric training, met the inclusion criteria. Concurrent plyometric training had a moderate favorable effect on RE (SMD [95% CI]: 0.73 [0.35 to 1.11]; PMD: ~4.4%), a small favorable effect on time trial performance (SMD [95% CI]: 0.21 [−0.26 to 0.68]; PMD: ~2.6%), and a negligible effect on $\dot{V}O_{2max}$ (SMD [95% CI]: 0.04 [−0.50 to 0.58]; PMD: ~0.8%). In conclusion, concurrent plyometric training is an effective training modality to improve RE in endurance-

trained adult runners, and has implications for runners who do not routinely perform plyometric exercise.

CHAPTER 1

INTRODUCTION

Endurance sports (e.g., running, cycling, swimming, and triathlon) are very popular among people of all ages, with participation rates progressively increasing in recent decades. For example, Statista (https://www.statista.com/statistics/190303/running-participants-in-the-us-since-2006/) reports that running participation in the United States has increased from 38.7 million in 2006 to 48.5 million in 2015. Over time, alternative training methods have also been used to complement traditional sports-specific training (e.g., resistance training). Although resistance training has been used for centuries, endurance-trained athletes have only recently used it as a complementary training modality. A popular misconception among endurance-trained athletes is that resistance training results in the development of "bulky" muscles, which will negatively affect their ability to perform endurance exercise (Peak Performance, 2013). With this in mind, resistance training that does not involve the lifting of heavy weights to increase physical performance, such as plyometric training, may be more appealing to endurance-trained athletes.

Endurance training programs have traditionally consisted of interval training focused on the prescription of duration and intensity of the training activity that work on various performance outcomes. Pate and Branch (1992) reported on the training practices of successful endurance-trained athletes and observed that in the 1980s and 1990s, different intensities and durations of sport-specific interval training was the focus, yet they make no mention of other training modalities for aerobic outcomes. Endurance training has been shown to improve different components of aerobic fitness including maximal oxygen uptake ($\dot{V}O_{2max}$), running economy (RE), and lactate/ventilatory threshold (Jones & Carter, 2000). On the other hand, Tanaka and Swensen (1998) reported that concurrent endurance and resistance training not only improved aerobic fitness and performance, but also benefitted anaerobic power.

Numerous reviews have indicated that resistance training is beneficial to both physiological- and performance-based outcomes in endurance-trained athletes. A systematic review on the effects of different forms of resistance training on aerobic outcomes indicated that six or more weeks of resistance training, in combination with traditional endurance training, improved running time trial performance by an average of 2.9% and RE by 4.6% (Yamamoto, 2008). Similarly, a narrative review by Munekani and Ellapen (2015) suggested that concurrent resistance and endurance running training improved RE without concomitant improvements in $\dot{V}O_{2max}$ or lactate threshold. A meta-analysis by Balsalobre-Fernandez (2015) estimated that mixed-modal resistance training (e.g., a mixture of maximal resistance and plyometric training) in combination with traditional aerobic training significantly improved RE by 2.3±2.1% in middle- and long-distance runners. While Balsalobre-Fernandez (2015) included studies that used plyometric training, they unfortunately did not separately report the effect of plyometric training. More recently, a meta-analysis on the effects of explosive training (including plyometric training) and heavy weight training on RE reported concurrent training methods improved RE by 3.9±1.2% (explosive training, 4.8±1.5%; heavy weight training, 3.7±2.7%), with positive effects seen within a few weeks (Denadai et. al., 2016).

Plyometric training or “jump training” is defined as a set of stretch-shorten cycles that emphasize fast short range of motion movements which incorporate counter-movements and maximal ballistic recruitment of muscles (LaChance, 1995). Plyometric training has the ability to increase the stiffness of the muscles allowing the body to use and store energy more efficiently, and reduce contact time with the ground to help reduce energy expenditure (Barnes & Kilding, 2014). The overall goal of plyometric training is to develop muscular rate of force development and musculotendionous stiffness. While several studies (Turner, Owings, & Schwane, 2003; Spurrs, Murphy, & Watsford, 2003; Ramírez-Campillo et al., 2014) have examined the effects of concurrent plyometric and endurance training (henceforth called “concurrent plyometric training”), to date there has not been a systematic review and meta-analysis of the effects of plyometric training on aerobic fitness and performance outcomes in endurance-trained adult runners. The aim of this study is to systematically review and meta-analyze studies that have examined the effect of concurrent plyometric training on aerobic fitness and performance in endurance-trained adult runners.

CHAPTER 2

METHOD

2.1 Protocol and registration

The systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) and is available from http://www.crd.york.ac.uk/. The registration number for this review is CRD42016051641. This study was conducted and reported in accordance with the Preferred Reporting Items for Systematic review and Meta-analysis Protocols (PRISMA-P) statement for reporting systematic reviews (Moher et al., 2015).

2.2 Eligibility criteria

The participants, intervention, comparison, outcome and study designs (PICOS) framework (Schardt, Adams, Owens, Keits, & Fontelo, 2007) was used to help delineate study parameters for the research question to incorporate into the search strategy.

2.2.1 Participants

Endurance-trained adult (aged ≥18 years) runners were included in this study. An individual was considered to be endurance-trained if they had at least 3 months of endurance running training experience.

2.2.2 Intervention (exposure)

A concurrent plyometric training program, where plyometric training was performed in addition to traditional endurance training, was the intervention. The plyometric training program needed a minimum of 4 weeks to the intervention, and had to almost completely comprise plyometric training (i.e., comprise at least 90% plyometric exercise).

2.2.3 Comparison

Normal endurance training over the course of the experiment was the control group.

2.2.4 Outcomes

The changes in measures of aerobic fitness (e.g., RE, $\dot{V}O_{2max}$) and/or aerobic performance (e.g., time trial performance) were the outcome measures reported. Descriptive pre- and post-test data (e.g., sample sizes, means, and standard deviations) must have been reported.

2.2.5 Study designs

Only randomized control trials (RCTs) published in the peer-reviewed scientific literature were included. Note, systematic reviews were not included, however the reference lists of relevant systematic reviews were examined for potentially relevant RCTs.

2.3 Information sources

A systematic search of the literature was completed on the 28th of February 2017 in PubMed (National Center for Biotechnology Information [NCBI]), MEDLINE (OVID interface), SPORTDiscus (EBSCO interface), Cumulative Nursing and Allied Health Literature (CINAHL; EBSCO interface) and Cochrane Central Register of Controlled Trials (OVID interface). The search was range started in the year 1980 when Hickson et al. (1980) published the first landmark concurrent training study. The search strategy was developed in consultation with an academic librarian experienced in systematic review searching and peer-reviewed by another librarian using the PRESS standard (Mcgowan, Sampson, & Lefebvre, 2010) (Supplement 1).

2.4 Search

The search was performed with search fields limited to abstract, title and keywords. Search terms within a group were combined by the Boolean OR, and were independently entered before groups of search terms were combined by the Boolean AND. Proximity operators were also used to search for the root word for some of the search terms. The first group of search terms identified the intervention concurrent training (concurrent training, or jump training, or explosive training, or plyometric* training). The second group identified the outcome measures aerobic fitness/performance (aerobic fitness, or aerobic performance, or endurance performance, or running economy, or cardiorespiratory fitness, or cardiovascular fitness). The third group identified the participants' training status (aerobic athlete*, or endurance athlete*, or runner*, or running). The full search strategies for each database are shown in Supplement 2. Search filters were also used. For example, the following filters were used when searching the EBSCO interface: the database filter (CINAHL or SPORTDiscus), the language filter (for English only articles), and the source filter (for the publication title). These filters and strategies varied according to the searched database or interface.

2.5 Study selection

Two researchers executed database-specific search strategies. All bibliographic records were extracted as text files and imported into RefWorks software (version 2.0; ProQuest LLC, Ann Arbor, MI, USA) with duplicates subsequently removed. Two reviewers screened all potentially relevant titles and abstracts against inclusion criteria, with exclusion by both reviewers required for exclusion. Full text copies were obtained by a single reviewer and then independently screened by two reviewers against inclusion criteria, with consensus by both reviewers required for final inclusion. A third reviewer resolved discrepancies if a consensus could not be reached between reviewers. The reference lists of included studies and relevant systematic reviews were examined to identify additional studies. Email contact with the corresponding authors of included studies was made when necessary, in order to provide clarification, to avoid "double counting" previously reported data, and/or to request additional data or studies. Only English language studies were included.

2.6 Data collection process

Descriptive data were extracted and entered into Excel (Microsoft Corp.; Redmond, WA, USA) using a standardized, pre-piloted study-specific template. Data were extracted from included studies into the database by a single reviewer, and checked for accuracy by a second reviewer.

2.7 Data items

The following study-specific descriptive data were extracted: age, gender, competitive standard, height, mass, body mass index (BMI), training status/experience, training volume, training exposure (training type, duration, volume, and session frequency and duration), aerobic fitness measure (e.g., running economy [RE], $\dot{V}O_{2max}$), aerobic performance measure (time trial performance), pre-test, post-test and/or change measures (sample sizes, means, standard deviations), and effect size data. Importantly, when several stages of an incremental exercise test were used for assessing RE, only data from the first three stages were extracted and included in the meta-analysis as per the recommendation of Denadai et al. (2017). Training status was operationalized as recreationally trained ($\dot{V}O_{2max}$ ≤55 mL/kg/min), well trained ($\dot{V}O_{2max}$ between 55 and 65 mL/kg/min), and highly trained ($\dot{V}O_{2max}$ >65 mL/kg/min) (Denadai et al., 2017). If $\dot{V}O_{2max}$ was not measured, then the description of training status adopted in each study was used. In addition, included studies were screened for the presence of confounding variables with data extracted if available.

2.8 Quality assessment

Quality assessment was assessed using the Physiotherapy Evidence Database (PEDro) tool for RCTs, a tool that demonstrates good test-retest reliability (Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). The PEDro scale comprises 11 criteria designed for assessing methodological quality, which help to identify RCTs that are likely to be internally valid (i.e., believable) and those that present sufficient statistical information to interpret the results. All criteria contributed equally to the overall PEDro score which ranges from 0 to 10 points. Criterion 1 was excluded from scoring in this study as it relates to external validity. Quality assessment was interpreted using scores of 0–3, 4–5, and 6–10 as thresholds for poor, moderate, and high quality. Two reviewers independently assessed quality, with consensus achieved by discussion, and discrepancies resolved by a third reviewer if necessary.

2.9 Summary measures and synthesis of results

Meta-analyses were performed in Review Manager (RevMan) software (v5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Separate random effects meta-analyses were conducted to determine the effect of concurrent plyometric training on RE, $\dot{V}O_{2max}$, and time trial performance. Mean differences (standardized mean differences [SMDs] and percent mean differences [PMDs]) and 95% confidence intervals were calculated for each study-outcome group. Mean differences for each outcome measure were weighted by the inverse of the pooled variance, with experimental effects calculated relative to the control group. Positive mean differences indicated favorable experimental effects and negative mean differences indicated unfavorable experimental effects.[1] SMDs were qualitatively interpreted using Hopkins et al. (2009) thresholds of 0.2, 0.6, 1.2, 2.0, and 4.0 as small, moderate, large, very large, and extremely large, respectively, with SMDs <0.2 considered to be negligible. The chances of the "true" effect being negligible (SMDs <0.2 and >−0.2), favorable (SMDs ≥0.2), or unfavorable (SMDs ≤−0.2) were also calculated, with chances qualitatively interpreted using the following scale: <0.5%, most unlikely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and >99.5%, most likely (Hopkins, Marshall, Batterham, & Hanin, 2009). The I^2 statistic of inconsistency was used to examine statistical heterogeneity (i.e., between-study variability), with values of 25%, 50% and 75% used as thresholds for small, moderate, and large, respectively (Higgins et al., 2003). Funnel plot asymmetry analysis was not conducted to assess the risk of publication bias because: (a) the power of the test to distinguish chance from real asymmetry is too low when there are fewer than 10 studies, and (b) it is not recommended when the included studies are of similar size (Higgins & Green, 2011).

[1]Note, while lower post-test vs. pre-test values for RE (e.g., oxygen costs or caloric equivalents) and time trial performance are favorable (as indicated by negative mean differences), for completeness all RE and time trial performance data were corrected such that positive mean differences indicated favorable intervention effects and negative mean differences indicated unfavorable intervention effects.

CHAPTER 3

RESULTS

3.1 Study selection

A total of 2,789 records were identified through database searches, with 2,089 records remaining after de-duplication. After screening titles and abstracts, nine articles were retained for full-text review, of which four were included in this systematic review and meta-analysis. Figure 1 outlines the identification of the included studies.

3.2 Study characteristics

All four included studies employed an RCT design and were published in English between 2003 and 2015. These studies represented 90 endurance-trained adult runners (78% or 70/90 male), ranging from 7 to 17 per study-outcome group, and included recreationally trained, well trained, and highly trained runners. Participants were from three countries (Australia, Chile, and the United States) with mean ages ranging from 22.1±2.7 to 34.2±2.6 years. Interventions ranged from 6 (n=3) to 9 weeks (n=1), the number of plyometric training bouts ranged from 1 to 3 sessions per week, and the total number of jumps completed ranged from ~1000 to ~4000. Table 1 describes the included studies and Table 2 describes the concurrent plyometric training interventions in detail.

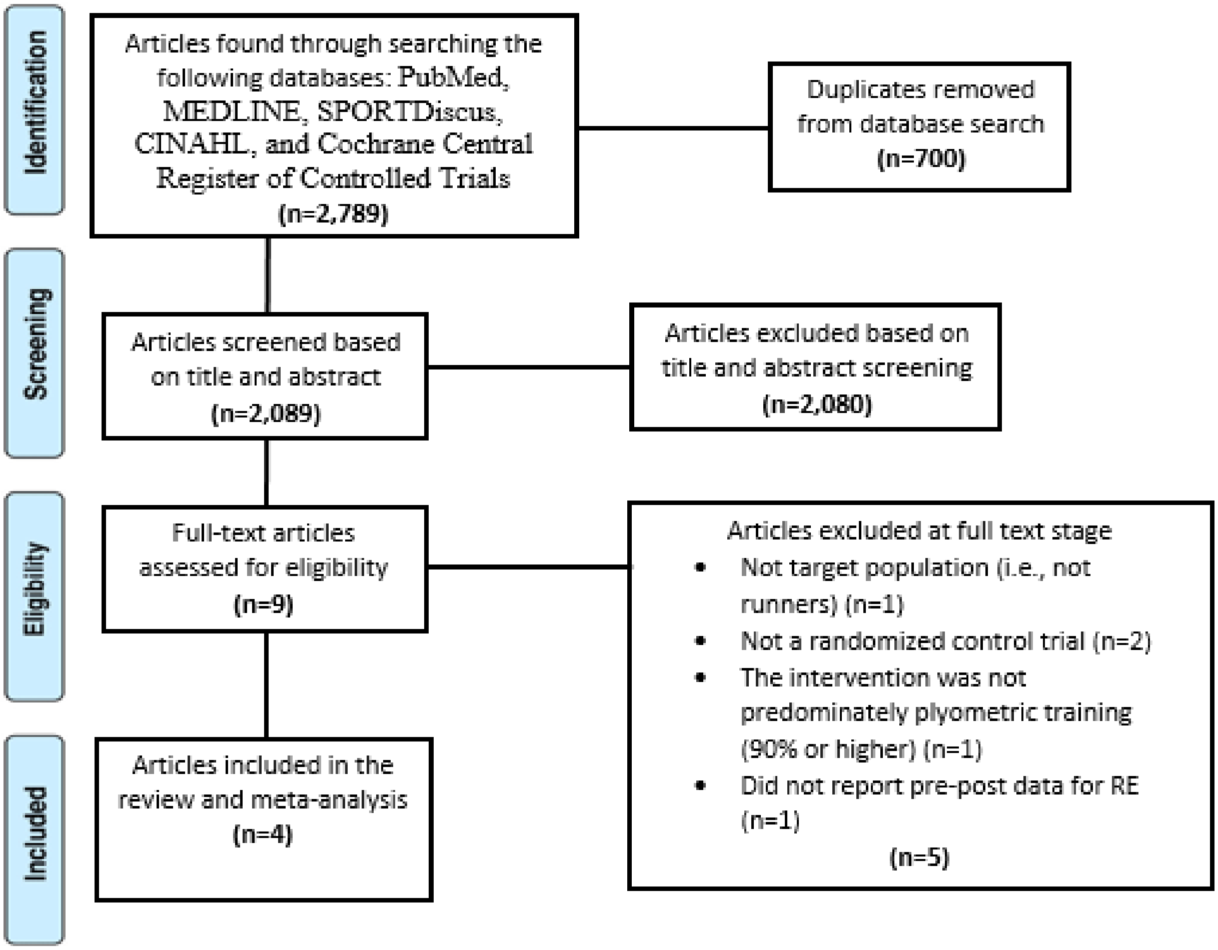

Figure 1. PRISMA-P flow chart outlining the flow of studies through the review.

3.3 Methodological quality

There was perfect agreement between the two reviewers when assessing methodological quality using the PEDro scale. Collectively, the included studies were of moderate to high quality, ranging from 6/10 (*n*=3) to 7/10 (*n*=1). None of the studies scored positively for the three blinding criteria, with only one study scoring positively for concealed allocation. All studies scored positively for measures of at least one key outcome, receipt of intervention or control condition, between-group statistical comparisons, and point and variability measures. The assessments of methodological quality of both reviewers are presented in Supplement 3.

Table 1. Description of the included studies.

Study	Intervention group (n)	Control group (n)	Age in years (mean±SD)	Sex	Mass in kg (mean±SD)	Height in cm (mean±SD)	Training status	Training volume	Training experience with plyometric training
Pellegrino et al. (2015)	11 (7M+4F)	11 (7M+4F)	E: 32.5±2.0 C: 34.2±2.6	M+F	E: 68.2±3.9 C: 71.0±3.6	E: 171.8±2.7 C: 170.5±2.2	Recreationally trained	No volume data available	No previous experience with plyometric training in past three months
Ramírez-Campillo et al. (2014)	17 (9M+8F)	15 (10M+5F)	22.1±2.7	M+F	E: 60.0±3.8 C: 59.8±6.1		Well trained	67±19 km/week	No explosive strength training in past six months
Saunders et al. (2006)	7	8	E: 23.4±3.2 C: 24.9±3.2	M	E: 67.6±9.7 C: 68.0±7.7		Highly trained	107±43 km/week	
Spurrs et al. (2003)	8	9	25.0±4.0	M	72.4±5.5	178.0±4.0	Well trained	60–80 km/week	None within the past three months

Note: E=Experimental (concurrent plyometric training group); C=Control; M=Male; F=Female; SD=standard deviation; km=kilometer; kg=kilogram; cm=centimeter; kg/m^2=kilograms per meter squared; Fitness level: recreationally trained ($\dot{V}O_{2max}$ ≤55 mL/kg/min); well trained ($\dot{V}O_{2max}$ between 55 and 65 mL/kg/min); highly trained ($\dot{V}O_{2max}$ >65 mL/kg/min) (Denadai et al., 2017).

Table 2. Description of the concurrent plyometric training interventions for the included studies.

	Training program			*Outcomes (shown as both SMDs and PMDs)*		
Study	**Jumps (total)**	**Frequency**	**Duration (weeks)**	**Running economy (RE)**	**Maximal oxygen uptake ($\dot{V}O_{2max}$)**	**Time trial performance**
Pellegrino et al. (2016)	#900–3,420	2 sessions/week (weeks 1–3) 3 sessions/week (weeks 4–6)	6	*7.7 km/h* E: 0.16 SDs or 0.5% ↑ C: 0.62 SDs or 1.8% ↓ *9.2 km/h* E: 0.38 SDs or 1.0% ↑ C: 0.93 SDs or 2.3% ↓ *10.6 km/h* E: 0.40 SDs or 1.3% ↑* C: 1.01 SDs or 2.9% ↓*	E: 1.23 SDs or 5.2% ↑* C: 0.66 SDs or 3.1% ↑	*3.0 km time trial* E: 0.66 SDs or 2.6% ↑* C: 0.34 SDs or 1.6% ↑
Ramírez-Campillo et al. (2014)	#1,080	2x<30 min session/week	6			*2.4 km time trial* E: 0.39 SDs or 3.9% ↑* C: 0.11 SDs or 1.3% ↑
Saunders et al. (2006)	3,728	2x30 min sessions/week (week 1) 3x30 min sessions/week (weeks 2–9)	9	*16.0 km/h* E: 0.27 SDs or 3.8% ↑ C: 0.09 SDs or 1.3% ↑ *18.0 km/h* E: 0.33 SDs or 4.1% ↑* C: 0.06 SDs or 0.7% ↓	E: 0.07 SDs or 0.7% ↑ C: 0.35 SDs or 3.0% ↑	
Spurrs et al. (2003)	#2,064	2 sessions/week (weeks 1–3) 3 sessions/week (weeks 4–6)	6	*12.0 km/h* E: 0.42 SDs or 6.7% ↑* C: 0.04 SDs or 0.5% ↓ *14.0 km/h* E: 0.42 SDs or 6.4% ↑* C: 0.04 SDs or 0.5% ↑ *16.0 km/h* E: 0.28 SDs or 4.1% ↑* C: 0.04 SDs or 0.5% ↓	E: 0.23 SDs or 3.3% ↑ C: 0.62 SDs or 6.4% ↑	*3.0 km time trial* E: 0.13 SDs or 2.7% ↑* C: 0.09 SDs or 0.8% ↑

Note: because multiple stages of an incremental exercise test were used to assess RE, only data from the first three stages were extracted and included in the meta-analysis. E=Experimental (concurrent plyometric training group); C=Control; SMD=standardized mean difference; PMD=percent mean difference; SDs=standard deviations (i.e., standardized units); *=statistically significant at the 5% level; min=minute; km=kilometer; km/h=kilometers per hour; denotes statistical significance at the 5% level; ↑=improvement (favorable effect) in outcome variable; ↓=decline (unfavorable effect) in outcome variable. #=estimated data.

3. 4 Synthesis of results

3.4.1 Running economy

RE change data were available from three studies representing 54 endurance-trained adult runners. Concurrent plyometric training most likely had a moderate favorable effect on RE (mean SMD [95% CI]: 0.73 [0.35 to 1.11]; mean PMD: ~4.4%) (Figure 2). All eight study-speed-specific concurrent plyometric training effects were positive (favorable), ranging from possibly negligible (SMD [95%CI]: 0.16 [−0.86 to 1.17]) to most likely large (SMD [95%CI]: 1.77 [0.76 to 2.79]) improvements in RE (Figure 2). The heterogeneity for concurrent plyometric training on RE was negligible (I^2=19%).

Study	Speed	SMD (95%CI)
Pellegrino et al. (2015)	10.6 km/h	1.77 (0.76 to 2.79)
Pellegrino et al. (2015)	9.2 km/h	1.36 (0.41 to 2.30)
Pellegrino et al. (2015)	7.7 km/h	0.85 (−0.03 to 1.73)
Spurrs et al. (2002)	12.0 km/h	0.51 (−0.46 to 1.48)
Spurrs et al. (2002)	14.0 km/h	0.44 (−0.53 to 1.40)
Saunders et al. (2006)	18.0 km/h	0.39 (−0.64 to 1.41)
Spurrs et al. (2002)	16.0 km/h	0.33 (−0.63 to 1.30)
Saunders et al. (2006)	16.0 km/h	0.16 (−0.86 to 1.17)
Overall effect (95%CI)		**0.73 (0.35 to 1.11)**

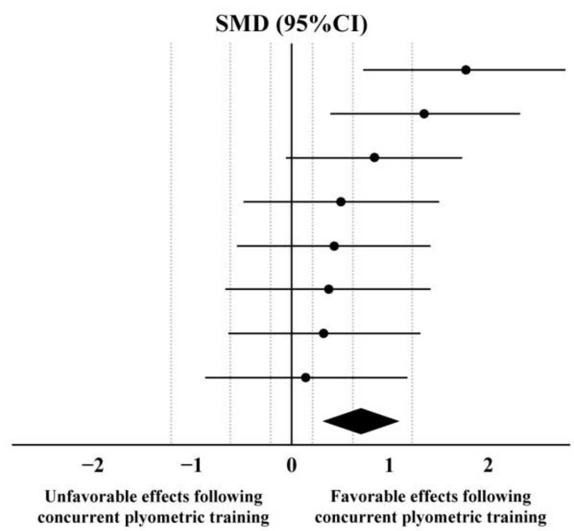

Figure 2. Forest plot of the standardized concurrent plyometric training effects (and 95% confidence intervals [CIs]) on running economy (RE). The black dots represented the study-speed-specific standardized mean differences (SMD) and the solid horizontal lines represented the 95%CIs. Positive SMDs indicated favorable experimental effects and negative SMDs indicated unfavorable experimental effects. The dashed vertical lines represented the standardized thresholds for small, moderate, and large.

3.4.2 Maximal oxygen uptake ($\dot{V}O_{2max}$)

$\dot{V}O_{2max}$ change data were available from three studies representing 54 endurance-trained adult runners. Concurrent plyometric training possibly had a negligible effect on $\dot{V}O_{2max}$ (mean SMD [95% CI]: 0.04 [−0.50 to 0.58]; mean PMD: ~0.8%) (Figure 3). Study-specific concurrent plyometric training effects ranged from possibly small declines in $\dot{V}O_{2max}$ (SMD [95%CI]: −0.26 [−1.22 to 0.70]) to possibly small improvements in $\dot{V}O_{2max}$ (SMD [95%CI]: 0.47 [−0.38 to 1.32]) (Figure 3). The heterogeneity for concurrent plyometric training on $\dot{V}O_{2max}$ was negligible (I^2=0%).

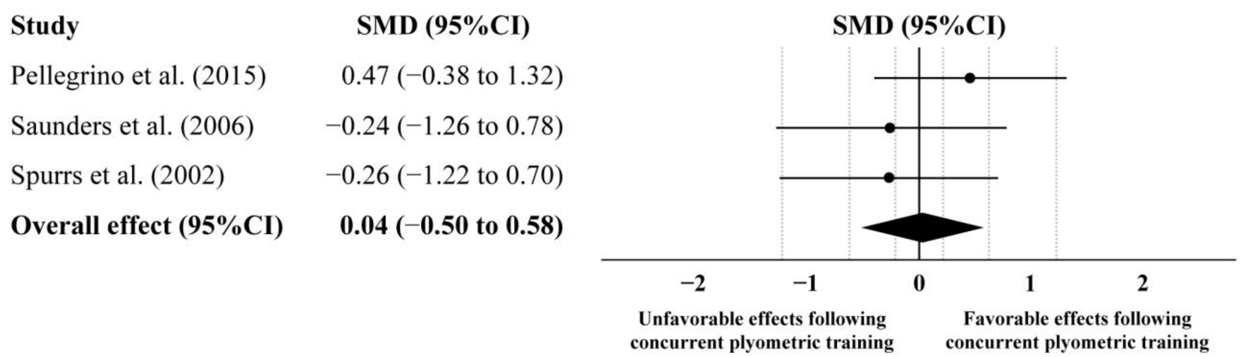

Figure 3. Forest plot of the standardized concurrent plyometric training effects (and 95% confidence intervals [CIs]) on maximal oxygen uptake ($\dot{V}O_{2max}$). The black dots represented the study-specific standardized mean differences (SMD) and the solid horizontal lines represented the 95%CIs. Positive SMDs indicated favorable experimental effects and negative SMDs indicated unfavorable experimental effects. The dashed vertical lines represented the standardized thresholds for small, moderate, and large.

3.4.3 Time trial performance

Time trial performance change data were available from three studies representing 71 endurance-trained adult runners. Concurrent plyometric training possibly had a small favorable effect on time trial performance (mean SMD [95% CI]: 0.21 [−0.26 to 0.68]; mean PMD: ~2.6%) (Figure 4). All study-specific concurrent plyometric training effects were positive (favorable), ranging from possibly negligible (SMD [95%CI]: 0.15 [−0.80 to 1.10]) to possibly small improvements in time trial performance (SMD [95%CI]: 0.24 [−0.45 to 0.94]) (Figure 4). The heterogeneity for concurrent plyometric training on time trial performance was negligible (I^2=0%).

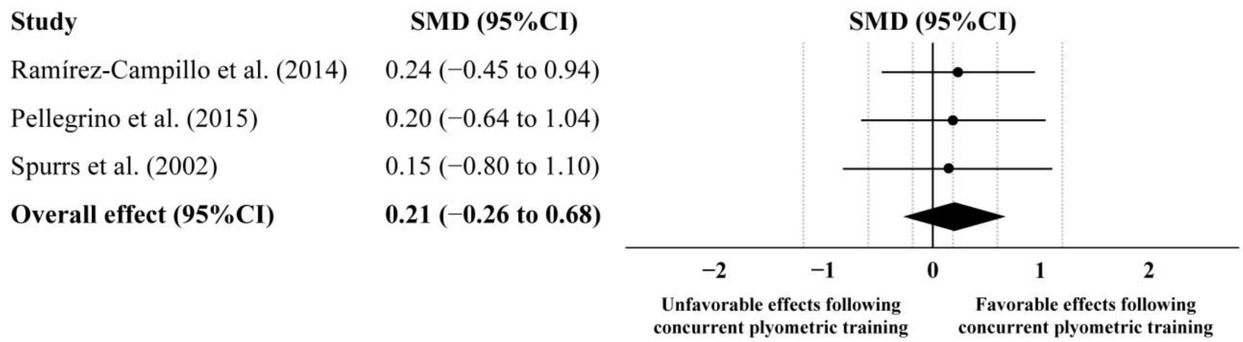

Figure 4. Forest plot of the standardized concurrent plyometric training effects (and 95% confidence intervals [CIs]) on time trial performance. The black dots represented the study-specific standardized mean differences (SMD) and the solid horizontal lines represented the 95%CIs. Positive SMDs indicated favorable experimental effects and negative SMDs indicated unfavorable experimental effects. The dashed vertical lines represented the standardized thresholds for small, moderate, and large.

CHAPTER 4

DISCUSSION

This review meta-analyzed four RCTs to quantify the effect of concurrent plyometric training on aerobic fitness-performance in endurance-trained adult runners. It showed that concurrent plyometric training: (a) most likely had a moderate favorable effect on RE (0.73 standard deviations [SDs] or ~4.4%); (b) possibly had a negligible effect on $\dot{V}O_{2max}$ (0.04 SDs or ~0.8%); and (c) possibly had a small favorable effect on time trial performance (0.21 SDs or ~2.6%).

This review found that plyometric training had the largest favorable effect on RE. The primary mechanism responsible for increased RE with plyometric training appears to be increased musculotendinous stiffness augmenting the performance of the stretch-shortening cycle (Spurrs, Murphy, & Watsford, 2003; Saunders et al., 2006; Dumke, Pfaffenroth, McBride, & McCauley, 2010; Pellegrino, Ruby, & Dumke, 2016) Musculotendinous stiffness has been positively associated with increased running economy in highly trained (Spurrs, Murphy, & Watsford, 2003; Saunders et al., 2006; Ramírez-Campillo et al., 2014) and recreationally trained runners (Pellegrino, Ruby, & Dumke, 2016). Both strength and plyometric training (primarily used countermovement jumps) have been found to increase stretch-shortening cycle task performance and musculotendinous stiffness, with the greatest task execution change appearing to be eccentric peak and rate of force development after training (Cormie, McGuigan,

& Newton, 2010; Chimera, Swanik, Swanik, & Straub,2004). It is speculated that the enhanced eccentric force development would reduce muscle fascicle lengthening and increase tendon lengthening during the stretch-shortening cycle (Cormie, McGuigan, & Newton, 2010). These adaptations, along with other neuromuscular changes enhancing force production (Chimera, Swanik, Swanik, & Straub, 2004; Aagaard & Andersen, 2010), would be advantageous during running as it would facilitate the storage and utilization of elastic energy during foot strike.

Given the small number of studies included in this meta-analysis, it was not possible to confidently examine the influence of moderator variables such as subject characteristics (e.g., age, sex, training status) and training program elements (e.g., training frequency, training volume, program length) on the outcome variables. This meta-analysis did, however, show that short periods (6–9 weeks) of small to moderate frequency (1–3 sessions per week) and moderate to high volume (~1000 to ~4000 jumps) concurrent plyometric training are effective in improving the RE of runners. While this meta-analysis could not determine whether relatively longer training periods or higher training volumes resulted in larger improvements in RE, evidence from Saunders et al. (2006) suggested that longer training periods are probably required given they observed negligible changes in RE after five weeks of concurrent plyometric training and small improvements after nine weeks. Furthermore, a recent meta-analysis showed that the benefit of explosive training and heavy weight training on RE increased with time (6–8 weeks, small benefit; 12–14 weeks, moderate to large benefit) but did not change with training frequency (Denadai et al., 2017). Substantial increases in plyometric training volume however, while potentially beneficial, are also likely to negatively impact endurance training volume, which could in turn negatively impact RE. Furthermore, even over short periods of concurrent plyometric training, it is unknown whether periodic adjustment of training volume and intensity are required to optimize RE benefits.

An athlete's baseline fitness level, training level and training experience, may also influence the concurrent plyometric training effect. It is likely that untrained and recreational runners are more responsive to plyometric training and therefore experience a larger improvement in RE than well trained or highly trained runners. Relative to untrained and recreational runners, well trained and highly trained runners are probably closer to their ceiling and have relatively less margin for improvement due to physiological, psychosocial, physical, biomechanical, and training based differences (Smoliga, 2017). Evidence from this review suggests that this may be the case for concurrent plyometric training because the magnitude of RE improvement was larger for recreationally trained runners (mean SMD [95% CI]: 1.28 [0.74 to 1.83]; see Pellegrino et al., 2015 in Figure 2) than for well trained runners (mean SMD [95% CI]: 0.43 [−0.13 to 0.98]; see Spurrs et al., 2002 in Figure 2) and highly trained runners (mean SMD [95% CI]: 0.27 [−0.45 to 0.99] see Saunders et al., 2006 in Figure 2) despite similar training volumes and frequencies. In contrast, the improvement in RE following concurrent explosive and heavy weight training has been shown to be similar in individuals of different training levels (Denadai et al., 2017). Alternatively, the effect of concurrent plyometric training on RE might be due to differences in test running speeds. Further examination of Figure 2 suggests that the magnitude of improvement in RE decreased with increased running speed (r [95%CI]: −0.71 [−0.94 to −0.01]). However, given that testing speeds were chosen to optimize RE in the sampled individuals by matching them to training/competition speeds (i.e., slower testing speeds for recreationally trained runners and faster testing speeds for well trained and highly trained runners), it is more likely that the magnitude of the plyometric training effects on RE was a function of differences in training level/experience rather than differences in testing speeds.

Aerobic performance is largely explained by three physiological factors — $\dot{V}O_{2max}$ (the highest rate at which an individual can consume oxygen during exercise), running economy (the metabolic cost of any given intensity of exercise), and fractional utilization of oxygen (the percentage of $\dot{V}O_{2max}$ that can be sustained for any given length of time) (Léger, 1996). A meaningful improvement in 2.4–3.0 km time trial performance in response to concurrent plyometric training was expected, because a moderate improvement in RE was observed, even despite a negligible change in $\dot{V}O_{2max}$ (note, the effect of concurrent plyometric training on the fractional utilization of oxygen is unknown). While this review showed that concurrent plyometric training possibly had a small favorable effect on time trial performance (mean SMD [95% CI]: 0.21 [−0.26 to 0.68]), the small number of included studies meant that statistical confidence was lacking. It could be that larger improvements in RE (e.g., potentially via longer duration concurrent training programs) are necessary to meaningfully benefit time trial performance. Given that different time trials (distance run tests) impose different physiological demands, a moderate improvement in RE may not therefore translate to the same improvement in shorter vs. longer time trials. For example, factors such as $\dot{V}O_2$ kinetics and anaerobic capacity will be relatively more important for shorter time trials, whereas $\dot{V}O_{2max}$ and RE will be relatively more important for longer time trials (Péronnet & Thibault, 1989). Plyometric training may also benefit time trial performance through a mechanism other than RE (e.g., neuromuscular and/or anaerobic adaptation), although the effect is likely to be small.

Using a rigorous systematic review and meta-analytical strategy, this review represents the current best synthesis of the effects of concurrent plyometric training on aerobic fitness-performance in endurance-trained adult runners. Unlike other reviews examining the effect of multiple concurrent explosive training modalities (Denadai et al., 2017; Munekani & Ellapen, 2015), this study examined only the effect of concurrent plyometric training to isolate a specifc training modality. A common issue with any systematic review is that the synthesis of evidence is only as strong as the studies that it contains (Weir, Rabia, & Ardern, 2016). Fortunately, this review included only data from RCTs of moderate to high methodological quality, which when pooled, resulted in negligible heterogeneity and high confidence in the overall effects.

While this review was adequately powered to detect the overall concurrent plyometric training effect on RE, the low participant and study numbers meant that it was unfortunately underpowered to confidently detect the effect on $\dot{V}O_{2max}$ and time trial performance. The results of this review are also limited to endurance-trained adult runners who undertook short periods of small to moderate frequency and moderate to high volume concurrent plyometric training. The small number of included studies also meant that it was not possible to confidently conduct sub-group analyses examining the impact of moderator variables on the overall effects.

In conclusion, this review indicates that short periods of concurrent plyometric training result in meaningful improvement in RE in endurance-trained adult runners, and negligible to small changes in $\dot{V}O_{2max}$ and time trial performance, respectively. This improvement in RE is the likely function of better elastic energy return and explosive strength due to plyometric training effects on the stretch shortening cycle and musculotendinous stiffness. These results have implications for endurance-trained adult runners who do not routinely perform plyometric exercise. Future concurrent plyometric training studies should examine the time-course of changes in RE, the long-term training effects, and whether similar effects are observed for other endurance-trained athletes (e.g., cyclists or triathletes).

APPENDICES

Appendix A
PRESS standard

forum, by advancing community objectives of achieving the highest possible search quality (Mashima & Takahashi, 2008). We have selected a 'no derivative work' license, as the elements of the checklist are evidence based. We assert that they should be used without amendment or local adaptation. If new evidence is generated, the authors undertake to update the checklist accordingly.

Finding a suitable and willing peer reviewer is an additional challenge for anyone wishing to have their search peer reviewed. We are currently exploring a PRESS Forum where librarians/ expert searchers can submit their own searches for peer review and identify searches from other librarians/expert searchers and peer review them. A prototype forum was developed to define the important elements for an effective, interactive peer review forum. It was premised on the existence of strong community and the values of reciprocity that characterize the library and information profession. The pilot forum presaged the phenomenal rise of web-based social networking and used a programmed database as a back-end. A new PRESS Forum is being developed using newer social networking tools to ensure sustainability.

Table 1
Evidence Based Assessment Form for the Peer Review of Electronic Search Strategies (PRESS EBC)

PRESS EBC Assessment Form

1. Translation of the research question:

☑ Adequate

☐ Adequate with recommendations

☐ Needs revision   Provide an explanation or example

Succinct and well-explained

2. Boolean and proximity operators:

☑ Adequate

☐ Adequate with recommendations

☐ Needs revision   Provide an explanation or example

Demonstrates understanding of appropriate use.

3. Subject headings:

☑ Adequate

☐ Adequate with recommendations

☐ Needs revision   Provide an explanation or example

demonstrates understanding of when to use subject heading and when to use keywords

4. Natural language / free-text:
- [x] Adequate
- [ ] Adequate with recommendations
- [ ] Needs revision Provide an explanation or example

Understands which terms to use for best results

5. Spelling, syntax and line numbers:
- [x] Adequate
- [ ] Adequate with recommendations
- [ ] Needs revision Provide an explanation or example

Description of research and thought process behind search strings is clear and well-described.

6. Limits and filters:
- [x] Adequate
- [ ] Adequate with recommendations
- [ ] Needs revision Provide an explanation or example

limits and filters fit well with current research

7. Search strategy adaptations:
- [x] Adequate
- [ ] Adequate with recommendations
- [ ] Needs revision Provide an explanation or example

Searches adapted for needs of different databases

Annie Nickum, BSN MLIS
Research and Education Librarian
Library of the Health Sciences
University of North Dakota

Table 2

Elements for the Peer Review of Electronic Search Strategies (PRESS EBC Elements)

Translation of the research question	✓ Has the research question been translated correctly into search concepts (e.g. PICO), i.e. does the search strategy match the research question? ✓ Are the search concepts clear? ✓ Are there 'too many' search concepts? ✓ Are any of the search concepts too narrow or too broad? ✓ Does the search appear to retrieve too many or too few records?
Boolean and proximity operators	✓ Are there any mistakes in the use of Boolean or proximity operators? ✓ Are there any mistakes in the use of nesting with brackets? ✓ If NOT is used, is this likely to result in any unintended exclusions? ✓ Could precision be improved by using proximity operators (e.g. adjacent, near, within) instead of AND. ✓ Is the width of any proximity operators correct?
Subject headings	✓ Are the subject headings relevant? ✓ Are subject headings missing? ✓ Are any subject headings too broad or too narrow? ✓ Are subject headings exploded where necessary and vice versa? ✓ Are sub-headings attached to subject headings? (Floating subheadings may be preferred.) ✓ Are sub-headings used instead of relevant subject headings and vice versa? ✓ Are both subject headings and *natural language terms* (see below) used for each concept? o If there is a reason provided for not doing so, does the reason appear sound?
Natural language (also free-text or text-word)	✓ Does the search miss any spelling variants in free-text? ✓ Does the search miss any synonyms? ✓ Does the search miss truncation or truncate at the wrong point? ✓ If an acronym or abbreviation is used, is the full term also included? ✓ Are apparently irrelevant or excessively broad natural language terms used?
Spelling, syntax and line numbers	✓ Are there any spelling errors? ✓ Are there any errors in system syntax or wrong line numbers?
Limits and filters	✓ Do any of the limits used seem unwarranted? ✓ Are any filters used appropriate for the topic? ✓ Are any potentially helpful limits or filters missing? ✓ Is starring (restrict to focus) used and if so, is there adequate justification for this?
Search strategy adaptations	✓ Does the searcher indicate that the search strategy has been adapted for additional databases and / or interfaces? ✓ Are the adaptations available for review and correct?

Appendix B
Database search terms

PubMed
concurrent jump training on endurance performance
concurrent plyometric training on endurance athletic performance
plyometric training on aerobic fitness in endurance athletes
concurrent explosive training on aerobic performance
((explosive training) AND aerobic training) AND aerobic fitness
(jump training) AND running economy
plyometric training) AND endurance athlete
(plyometric training) AND running
((concurrent training) AND explosive training) AND endurance performance
((plyometric training) OR explosive training) AND endurance athlete
Plyometric training and running economy

SportDISCUS
Plyometric training and aerobic performance
Plyometric training and runners
Concurrent training and plyometric training and endurance performance
Concurrent training and explosive training and endurance performance
Concurrent training and plyometric training and cardiovascular fitness
Concurrent training and plyometric training and cyclist
Concurrent training and plyometric training and cycling
Aerobic training and plyometric training
Explosive training and endurance training and running
Jump training and endurance performance
Jump training and endurance training and aerobic performance
Jump training and endurance training and running economy
Concurrent training and plyometric training and running economy
Plyometric training and running economy

MEDLINE
Plyometric training and endurance performance
Jump training and running economy
Plyometric training running economy and runner
Plyometric training Aerobic training
Plyometric training and aerobic fitness and endurance performance
Explosive training and concurrent training and endurance performance
Explosive training and aerobic training and running economy
Explosive training and cardiovascular fitness
Plyometric training or jump training and endurance athlete
Plyometric training and running economy and endurance athlete

Jump training and running economy and endurance athlete
Concurrent training and plyometric training and aerobic training
Concurrent training and explosive training and cyclist

CINAHL
Concurrent training and pl+yometric training and endurance performance
Plyometric training or explosive training and endurance performance
Explosive training or plyometric training and running economy
Explosive training and aerobic fitness
Jump training and running economy and endurance athlete
Plyometric training and cardiorespiratory fitness and cardiovascular fitness
Concurrent training and plyometric training and cardiovascular fitness
Concurrent training and plyometric training and cardiorespiratory fitness
Concurrent training and plyometric training and runner
Concurrent training and plyometric training and cyclist
Concurrent training and explosive training and cyclist
Concurrent training and explosive training and running
Concurrent training and explosive training or jump training
Concurrent training and endurance athlete and explosive training or jump training
Concurrent training and endurance athlete and aerobic fitness

Cochrane Library
Concurrent training and plyometric training
Concurrent plyometric training and aerobic training with endurance athletes
Plyometric training and aerobic performance
Explosive training and endurance performance
Concurrent plyometric training and running economy
concurrent explosive training and running economy
concurrent plyometric training and aerobic fitness
concurrent plyometric training and cardiorespiratory fitness
concurrent explosive training and cardiovascular fitness
plyometric training and runners and running economy
explosive training and runners and running economy
explosive training and runners and aerobic performance

Appendix C
Assessment of methodological quality

Research Lead (LC).

PEDro score criteria (Connelly)	*Spurrs et al. (2003)*	*Saunders et al. (2006)*	*Ramírez-Campillo et al. (2013)*	*Pellegrino et al. (2015)*
Eligibility criteria were specified (non-scoring)	yes	yes	yes	yes
Subjects were randomly allocated to groups	1	1	1	1
Allocation was concealed	0	0	1	0
The groups were similar at baseline regarding the most important prognostic indicators.	1	1	1	1
There was blinding of all subjects.	0	0	0	0
There was blinding of all therapists who administered the therapy.	0	0	0	0
There was blinding of all assessors who measured at least one key outcome	0	0	0	0
Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.	1	1	1	1
All subjects for whom outcome measures were available received the treatment or control condition as allocated, or, where this was not the case, data for at least one key outcome were analyzed by ‘‘intention to treat.’’	1	1	1	1
The result of between-group statistical comparisons is reported for at least one key outcome.	1	1	1	1
The study provided both point measures and measures of variability for at least one key outcome.	1	1	1	1
Total score	**6**	**6**	**7**	**6**

Research Assistant (KC).

PEDro score criteria (Carver)	*Spurrs et al. (2003)*	*Saunders et al. (2006)*	*Ramírez-Campillo et al. (2013)*	*Pellegrino et al. (2015)*
Eligibility criteria were specified (non-scoring)	yes	yes	yes	yes
Subjects were randomly allocated to groups	1	1	1	1
Allocation was concealed	0	0	1	0
The groups were similar at baseline regarding the most important prognostic indicators.	1	1	1	1
There was blinding of all subjects.	0	0	0	0
There was blinding of all therapists who administered the therapy.	0	0	0	0
There was blinding of all assessors who measured at least one key outcome	0	0	0	0
Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.	1	1	1	1
All subjects for whom outcome measures were available received the treatment or control condition as allocated, or, where this was not the case, data for at least one key outcome were analyzed by ‘‘intention to treat.’’	1	1	1	1
The result of between-group statistical comparisons is reported for at least one key outcome.	1	1	1	1
The study provided both point measures and measures of variability for at least one key outcome.	1	1	1	1
Total score	**6**	**6**	**7**	**6**

REFERENCES

Aagaard, P., & Andersen, J. (2010). Effects of strength training on endurance capacity in top-level endurance athletes. *Scandinavian Journal of Medicine and Science in Sports*, 20, 39–47.

Balsalobre-Fernández, C., Santos-Concejero, J., & Grivas, G.V. (2015). The effects of strength training on running economy in highly trained runners: A systematic review with meta-analysis of controlled trials. *Journal of Strength and Conditioning Research*, *30(8)*, 2361–2368.

Barnes, K.R., & Kilding, A.E. (2015). Strategies to improve running economy. *Sports Medicine*, *45(1)*, 37–56.

Berg, K. (2003). Endurance training and performance in runners. *Sports Medicine*, *33(1)*, 59–73.

Chimera, N.J., Swanik, K.A., Swanik, C.B., & Straub, S.J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of athletic training*, 39(1), 24

Cohen J. (1988) *Statistical power analysis for the behavioral sciences* (2nd ed). New Jersey: Lawrence Erlbaum.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. *Medicine & Science in Sports & Exercise*, 42(9),1731–1744.

Daniels, J. & Daniels, N. (1992). Running economy of elite male and elite female runners. *Medicine & Science in Sports & Exercise*, *24(4)*, 483–489.

Denadai, B.S., de Aguiar, R.A., de Lima, L.C.R., Greco, C.C., & Caputo, F. (2016). Explosive training and heavy weight training are effective for improving running economy in endurance athletes: A systematic review and meta-analysis. *Sports Medicine*, *47(3)*, 545–554.

De Villarreal, E.S.S., Kellis, E., Kraemer, W.J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *Journal of Strength & Conditioning Research*, *23(2)*, 495–506.

Dumke, C. L., Pfaffenroth, C. M., McBride, J. M., & McCauley, G. O. (2010). Relationship between muscle strength, power and stiffness and running economy in trained male runners. *International journal of sports physiology and performance*, 5(2), 249–261.

Hickson, R.C. (1980). Interference of strength development by simultaneously training for strength and endurance. *European Journal of Applied Physiology and Occupational Physiology*, *45*, 255–263.

Higgins J.P.T., & Green, S. Cochrane Handbook for Systematic Reviews of Interventions Version 5.1.0 (updated March 2011). The Cochrane Collaboration, 2011. http://handbook.cochrane.org

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3–12.

Jones, A.M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine, 29(6)*, 373–386

Jung, A.P. (2003). The impact of resistance training on distance running performance. *Sports Medicine*, 33(7), 539–552.

LaChance, P. (1995). Plyometric exercise. *Strength & Conditioning Journal, 17(4)*, 16–23.

Léger, L. (1996). Aerobic performance. In, D. Docherty, ed. Measurement in pediatric exercise science (pp. 183–223). Champaign, IL; Human Kinetics.

Maher, C.G., Sherrington, C., Herbert, R.D., Moseley, A.M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy, 83(8)*, 713–721.

McGowan, J., Sampson, M., & Lefebvre, C. (2010). An evidence based checklist for the peer review of electronic search strategies (PRESS EBC). *Evidence Based Library and Information Practice, 5(1)*, 149–54.

Millet, G. P., Jaouen, B., Borrani, F., & Candau, R. (2002). Effects of concurrent endurance and strength training on running economy and $\dot{V}O_2$ kinetics. *Medicine & Science in Sports & Exercise*, *34*(8), 1351–1359.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., & PRISMA-P group (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 4*:1.

Munekani, I., & Ellapen, T.J. (2015). Does concurrent strength and endurance training improve endurance running? A systematic review: sport science. *African Journal for Physical Health Education, Recreation and Dance*, *21(1.1)*, 46–58.

Pate, R.R., & Branch, J.D. (1992). Training for endurance sport. *Journal of Medical Science and Sports Exercise*, *24(9)*, 340–343.

Peak Performance, (2013, August 12th). Is strength training really beneficial for endurance athletes? Retrieved from: http://www.bodybuilding.com/fun/peak45.htm

Pellegrino, J., Ruby, B.C., & Dumke, C.L. (2016). Effect of plyometrics on the energy cost of running and mhc and titin isoforms. *Medicine & Science in Sports & Exercise*, *48(1)*, 49–56.

Péronnet, F., & Thibault, G. (1989). Mathematical analysis of running performance and world running records. *Journal of Applied Physiology*, 67(1), 453-465.

Ramírez-Campillo, R., Álvarez, C., Henríquez-Olguín, C., Baez, E. B., Martínez, C., Andrade, D.C., & Izquierdo, M. (2014). Effects of plyometric training on endurance and explosive strength performance in competitive middle-and long-distance runners. *Journal of Strength & Conditioning Research*, *28(1)*, 97–104.

Saunders, P.U., Pyne, D.B., Telford, R.D., & Hawley, J.A. (2004). Factors affecting running economy in trained distance runners. *Sports Medicine*, *34(7)*, 465–485.

Saunders, P.U., Telford, R.D., Pyne, D.B., Peltola, E.M., Cunningham, R.B., Gore, C.J., & Hawley, J.A. (2006). Short-term plyometric training improves running economy in highly trained middle and long distance runners. *Journal of Strength & Conditioning Research*, *20(4)*, 947–954.

Schardt C., Adams M.B., Owens T., Keits S., & Fontelo P. (2007) Utilization of the PICO framework to improve searching PubMed for clinical questions. *BMC Medical Informatics and Decision Making*, *7*:16.

Smoliga, J.M. (2017). What is running economy? A clinician's guide to key concepts, applications and myths. *British Journal of Sports Medicine*, *51(10)*, 831–832.

Spurrs, R.W., Murphy, A.J., & Watsford, M.L. (2003). The effect of plyometric training on distance running performance. *European Journal of Applied Physiology*, *89(1)*, 1–7.

Statistics and facts on Running and Jogging. (n.d.). Retrieved November 19, 2016, from https://www.statista.com/statistics/190303/running-participants-in-the-us-since-2006/

Tanaka, H., & Swensen, T. (1998). Impact of resistance training on endurance performance a new form of cross-training? *Sports Medicine*, *25(3)*, 191–200.

Turner, A.M., Owings, M., & Schwane, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. *Journal of Strength & Conditioning Research*, *17(1)*, 60–67.

Weir A., Rabia S., & Ardern C. (2016). Trusting systematic reviews and meta-analyses: All that glitters is not gold! *British Journal of Sports Medicine, 50*, 1100–1101.

Yamamoto, L.M., Lopez, R.M., Klau, J.F., Casa, D.J., Kraemer, W.J., & Maresh, C.M. (2008). The effects of resistance training on endurance distance running performance among highly trained runners: A systematic review. *Journal of Strength & Conditioning Research*, *22(6)*, 2036–2044.