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Effects of Combined Strength Training Methods on Athletes and Healthy Participants on Sprint and Strength Performance: A Systematic Review and Meta-analysis of Controlled Studies

Efectos de los Métodos de Entrenamiento de Fuerza Combinados en Atletas y Participantes Saludables en el Rendimiento de Sprints y Fuerza: Una Revisión Sistemática con Metaanálisis de Estudios Controlados

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Abstract. The objective of this systematic review with meta-analysis was to examine the effects of combined strength training methods on sprint and Strength performance, compared to controls groups (CG).The meta-analysis included peer-reviewed articles that incorporated Combined Training (CT) groups in healthy participants and athletes, a CG, and a measure of sprint (5m, 10m, 20m and 30m) and strength (1RM squat). Using the random-effects model, effect sizes (ES; Hedge's g) were calculated for sprint and strength measures using means and SDs from pre- and post-tests for each dependent variable. Thirty-one studies were included, comprising 1,271 participants.CT improved sprint tests, 10m (ES = 0.67; 95% CI = 0.37 to 0.97; p < 0.001), 20m (ES = 0.45; 95% CI = 0.21 to 0.70; p < 0.001), 30m (ES = 0.46; 95% CI = 0.20 to 0.71; p < 0.001) and strength test, 1RM squat (ES = 1.53; 95% CI = 0.98 to 2.07; p < 0.001). Results based in a specific combination found a significant statistically effect type (p = 0.010; ES = 1.03) after PL combined with speed training compared to PL combined with strength in 30m sprint and a significant moderator effect was noted (p = 0.013; ES = 2.02) after PL combined with strength compared to PL combined with two or more training methods in 1RM squat.Combined strength training methods is an effective way to improve sprint and strength performance on healthy participants and athletes in comparison to control conditions.
Keywords: Agility, Speed, Acceleration, Plyometrics, Strength.

Resumen. El objetivo de esta revisión sistemática con metaanálisis fue examinar los efectos de los métodos combinados de entrenamiento de fuerza en el rendimiento de sprint y fuerza, en comparación con grupos de control (CG). El metaanálisis incluyó artículos revisados por pares que incorporaron métodos de entrenamiento combinado (CT) en participantes saludables y atletas, un CG y medidas de sprint (5m, 10m, 20m y 30m) y fuerza (1RM en sentadilla). Utilizando el modelo de efectos aleatorios, se calcularon tamaños de efecto (ES; g de Hedge) para las medidas de sprint y fuerza utilizando medias y desviaciones estándar de las pruebas pre y post para cada variable dependiente. Se incluyeron 31 estudios, con un total de 1,271 participantes. El CT mejoró las pruebas de sprint, 10m (ES = 0.67; IC del 95% = 0.37 a 0.97; p < 0.001), 20m (ES = 0.45; IC del 95% = 0.21 a 0.70; p < 0.001), 30m (ES = 0.46; IC del 95% = 0.20 a 0.71; p < 0.001) y la prueba de fuerza, 1RM en sentadilla (ES = 1.53; IC del 95% = 0.98 a 2.07; p < 0.001). Los resultados basados en una combinación específica encontraron un efecto estadísticamente significativo (p = 0.010; ES = 1.03) después del CT combinado con entrenamiento de velocidad en comparación con el CT combinado con fuerza en el sprint de 30m, y se observó un efecto moderador significativo (p = 0.013; ES = 2.02) después del CT combinado con fuerza en comparación con el CT combinado con dos o más métodos de entrenamiento en 1RM en sentadilla. Por lo tanto, los métodos combinados de entrenamiento son una forma efectiva de mejorar el rendimiento de sprint y fuerza en participantes saludables y atletas en comparación con condiciones de control.
Palabras clave: Agilidad, velocidad,aceleración, pliometria, fuerza

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Introduction

Actions of short-duration and maximal-effort, such as sprinting, characterized by being strength-power actions are decisive in different team sports (e.g., soccer, basketball). Faude et al., (2012) analysed 360 goals in the first German national league through video analysis. Of all the goals analysed, 45% of the players who scored a goal performed a straight sprint before scoring and most of them were scored without the ball and without an opponent. Also, the most frequent action for the assistant player in the goal actions was the sprint, in which most of them were carried out with the ball. Sprint-time comparisons among studies suggest professional players in the top European soccer leagues sprint relatively faster than professional players in lesser level soccer nations leagues (Haugen et al., 2014; Haugen et al., 2012, 2013). In 20m sprints differences of ~0.04-0.06 s (equivalent to 30-50cm) can be decisive in many sports in actions such as 1vs 1 duels where a position ahead of the opponent, with a shoulder forward or the body in front of the opponent allows to have a slight advantage (Haugen et al., 2014). It is important to achieve this increase in speed with respect to the opponent both in offensive and defensive positions because it can create an advantage or a space if the player is an attacker as well as eliminate an advantage or close a space to the opponent in a defensive position (Haugen et al., 2014; Vigne et al., 2010). Therefore, the chances of success will be increased with a greater capacity for acceleration and maximum speed.

Improving the sprint and strength-power performance does not depend on a single factor, but rather it depends on the combination of several factors that are interacting with each other. These factors include rate of force development, maximal force capacity, muscle coordination and stretch shortening cycle (SSC) use (Arabatzi et al., 2010; Fatouros et al., 2000). To improve sprint and strength performance, the use of different types of training has been studied. Among these methods we find plyometrics (PL), resistance training (RT), muscle electrostimulation (EMS), speed training, change of direction (COD) among others (Magyarosy & Schnizer, 1990; Sáez de Villarreal et al., 2013, 2015; Sáez de Villarreal et al., 2012; Sáez-Sáez de Villarreal et al., 2010; Włodarczyk et al., 2021).

It has been observed that there is a high correlation between sprinting, vertical jumping and change of direction with levels of strength, power and rate of force development (RFD) (Swinton et al., 2014). Specifically in football players, it has been found in a review of the literature that they need high levels of muscular strength in the lower body to be able to perform high-intensity actions more efficiently and with better results (Prieto et al., 2020; Suchomel et al., 2016). It has been demonstrated that strength and speed are key physical qualities for team sports in which power is a priority, such as football (Gissis et al., 2006; Reilly et al., 2000). Because of this phenomenon, strength and speed are considered predictors of success (Kaplan et al., 2009; Mujika et al., 2009). Finally, it is necessary to add that among the different methods that will be discussed below, the most commonly used training methods to improve both speed and strength are PL training, RT and overload sprint (Ramos & López, 2016).

Resistance training is the most commonly used exercise intervention for increasing muscular strength. RT is understood as a specialised form of training where individuals work against resistance provided by body weight or an external load in the form of free weights, medicine balls, elastic bands or weight machines in a controlled manner and eccentric/concentric actions (American College of Sports Medicine, 2009; Lloyd et al., 2014; Vissing et al., 2008) In the last decade, it has begun to be sought that the movements that are integrated into the RT are carried out with the intention of moving the external load as fast as possible (Franco-Márquez et al., 2015; McBride et al., 2002; Rodriguez-Rosell et al., 2017). The benefits obtained from RT in athletes includes increased ground reaction force generation capability, impulse (Aagaard et al., 2002) and RFD, therefore RT methods are highly used by coaches and researchers (Aagaard et al., 2002; Hoff et al., 2002; Hoff & Helgerud, 2004). After the application of a RT intervention these mentioned adaptations are attributed to increased strength, enhanced recruitment of motor units and increased firing rate of motor neurons (Häkkinen et al., 1984; Komi, 1986; Schmidtbleicher & Buhrle, 1987). One commonly employed field-based assessment of strength is the one-repetition maximum (1RM) test. As its name implies, the 1RM represents the maximum weight an individual can lift for a single repetition while maintaining proper lifting form (Grgic et al., 2020). The PL is a training method that is performed through jumping, hopping and bounding exercises both bilaterally and unilaterally, involving brief foot-ground contact times (e.g., short SSC movements) around 100-250 ms (i.e. high or long jumps) and long SSC characterized by duration greater than 250ms (i.e. CMJ) (Cormie et al., 2011b). The use of PL with male and female soccer players has been shown to improve muscular power, maximal strength, sprinting and acceleration capabilities (Ramirez-Campillo et al., 2020, 2021; Ramírez-Campillo et al., 2015). Additional training methods such as electrostimulation program or COD have shown to be useful in improving strength and speed performance (Babault et al., 2007; Beato et al., 2018; Filipovic et al., 2011). EMS involves artificially activation of the muscle offer neuromuscular stress and time-efficient benefits (Maffiuletti et al., 2009). Efficiently changing direction is crucial for success in multidirectional sports, where athletes encounter a diverse range of angles and approach velocities during sporting activities (Dos'Santos et al., 2018). Because each method obtains some benefits and all of them are interesting to improve the athlete's performance, combining several methods within the same training session seems to be an interesting idea for the organization of the training session. It has been shown that the combination of PL with RT within the same training session can produce greater increases in performance in speed (Fathi et al., 2019; Guadalupe-Grau et al., 2009) and strength (Guadalupe-Grau et al., 2009; Ronnestad etal., 2008). Combining RT with PL training has become an increasingly popular training method, since it has been shown in different studies that it obtains better results for power improvement when compared to the use of PL or RT in isolation (Adams et al., 1992; Fatouros et al., 2000; Zghal et al., 2019). Since the performance of the sprint cannot be attributed to a single component, but will depend on the combination of several, using a single method will not be as effective as combining several training methods to provide variation in stimulus and to increase the overall training adaptation (Haugen et al., 2014, 2019).

Due to the inconsistencies reported in the literature, with positive (ES = 4.19; 2.16; 2.22; 2.23) (Arede et al., 2019; Guadalupe-Grau et al., 2009; Hammami et al., 2019; Tricoli et al., 2005) and negative results (ES = -0.97; -0.345) (Perez-Gomez et al., 2008; Tricoli et al., 2005), due to the limitation of the sample size of the intervention study (simple size = 5; 6) (Alvarez et al., 2012; Redondo et al., 2014) and the lack of meta-analysis. Moreover, because so far, the systematic review and meta-analyses that have been done to date have analysed the combination of PL and strength within the same session, but only one systematic review has been found that analyses the combination of PL training with more than one methodology of training (speed, mobility, balance, etc.) (Ribeiro et al., 2021). For this reason, the idea of carrying out a systematic review with meta-analysis is because a meta-analysis seems to be necessary in order to have more evidence about whether it is interesting to combine several training methodologies within the same session. A meta-analysis can also provide valuable information for scientists and professionals to detect gaps and limitations related to PL combined with other training methods, providing suggestions to future avenues of research. However, to the authors' knowledge, so far, no review has attempted to meta-analyse the large number of studies available in the literature despite the great potential that can be obtained from the combination of PL with other methodologies of training in Sprint and strength performance. Therefore, the primary aim of this systematic review with meta-analysis was to examine the effects of PL combined with additional training methods (e.g., strength, speed, COD, EMS) on sprint and strength performance, compared with active/passive controls groups.

Methods

A systematic review with meta-analysis was conducted following the guidelines of the Cochrane Collaboration (Cumpston et al., 2019). Findings were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009).

Search Strategy

The electronic search was conducted on the following electronic databases: PubMed, and Web of Knowledge. It considered articles published up until July 2021. The following keywords, combined in pairs (e.g., "Plyometric" AND "combined"), were introduced in the selected databases: "plyometric", "combined", "plyometrics", "stretch-shortening cycle", "strength", "strength training", "resistance training" "sprint", "speed", "change of direction", "agility", "balance", "flexibility", "mobility" "electrostimulation", "surface electrostimulation"

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria are detailed in Table 1.

Table 1.
Inclusion and exclusion criteria for studies at the selection stage of the systematic review.

Category	Inclusion criteria	Exclusion criteria
Population	Studies with no restriction of population were considered for inclusion with no age or sex restrictions.	Participants with health problems (e.g., injuries, recent surgery), the intervention was not performed in humans.
Intervention	Studies with experimental groups performing a combination of training methods (e.g., plyometric combined strength).	Studies that do not perform comparison between plyometric training, strength training, or a combination of these training methods; used the complex training methodology; The duration of the intervention was less than three weeks; The training program that had been carried out was not clearly shown; used supplements; the training effect was acute; combined plyometrics with aerobic training.
Comparator	Traditional control group (i.e., athletes participating in regular training schedules) or specific control group (perform a specific training)	Absence of control group.
Outcome	At least one measure related to physical fitness (e.g., 10m sprint tasks) before and after the training intervention.	Lack of baseline and/or follow-up data; The results were not displayed clearly; the article was not in full text
Study design	Multi-arm trials.	Single-arm trials/observational studies.

Study Selection and Data Collection Process

Database searches were performed independently by 2 authors (C.L.M., and E.S.S.). After the removal of duplicates, abstracts were screened, and studies not related to the review's topic were excluded. The remaining articles that were not initially discarded were read. Then, independently, and blindly, 2 reviewers selected the studies for inclusion (C.L.M. and E.S.S.), according to the inclusion and exclusion criteria. If no agreement was achieved, a third party intervened (R.R.C.).

The current review focused on the physical fitness of athletes as the main outcome. Since strength and power characteristics are crucial during various athletic movements, measures of physical fitness were considered but not limited to: (1) maximal strength (1 repetition maximum), (2) linear sprinting (i.e., time; velocity). In cases where the required data were not clearly or completely reported, the authors of the study were contacted for clarification. If no response was obtained from the authors (after one attempts), or if the authors could not provide the requested data, the study outcome was excluded from further analysis. If data were only displayed in the form of figures but not tables, the study outcome was excluded from further analysis.

Data were extracted from the included studies using a form created in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Extracted data included the following information: the first author's name, year of publication, number of participants per group. We also extracted data regarding the participants' sex, age (years), body mass (kg), height (m), and previous RT/PL experience. If applicable, the type and level (e.g., professional, amateur) of sport practice were also extracted. Regarding programming parameters, we reported weekly frequency of training (days/week), duration (weeks).

Risk of Bias Assessment (Study Quality)

The methodological quality of selected studies that contained a control group was assessed with the Cochrane risk of bias tool (Higgins et al., 2011). Bias and study quality were assessed by (C.L.M., and E.S.S.) with any disagreements resolved by a third reviewer (R.R.C.). No studies were eliminated based on methodological quality regardless of the score obtained. The assessment for each of the 7 items includes the answer to a question. In response to this question, the term "Yes" was assigned when there is a low risk of bias, the term "No" was assigned when there is a high risk of bias and "Unclear" when there is not enough information. This evaluation scale has already been used by other reviews in this field using the same evaluation criteria (Cormier et al., 2020).

Summary Measures, Synthesis of Results, and Publication Bias

Studies were meta-analytically aggregated if three or more relatively homogeneous studies were available for the same outcome measure. Effect sizes (ES; Hedge's g) were calculated for jumping measures using means and SDs from pre- and post-tests for each dependent variable. For studies that reported standard error, SDs were calculated by multiplying the standard error with the square root of the sample size (Lee et al., 2015). Data were standardized using post-intervention SD values. The random-effects model was used to account for differences between studies that might affect the intervention effects (Deeks et al., 2008; Kontopantelis et al., 2013). The ES values were presented with 95% confidence intervals (95% CIs). The ES magnitudes were interpreted using the following scale: <0.2, trivial; 0.2-0.6, small; >0.6-1.2, moderate; >1.2-2.0, large; >2.0_4.0, very large; >4.0, extremely large(Hopkins et al., 2009). In studies including more than one intervention group, the sample size of the active and specific-active control group was proportionately divided to facilitate comparisons across multiple groups(Deeks et al., 2008). The impact of study heterogeneity was assessed using the I^2 statistic, with values of <25%, 25-75%, and >75% representing low, moderate, and high levels, respectively (Higgins & Thompson, 2002) . The risk of reporting bias was explored (with at least 10 studies) (Sterne et al., 2011) using the Egger's test (Egger et al., 1997), with $p<0.05$ implying bias. To adjust for risk of reporting bias, a sensitivity analysis was conducted using the trim and fill method (Duval & Tweedie, 2000) , with L_0 as the default estimator for the number of missing studies (Shi & Lin, 2019). All analyses were carried out using the Comprehensive Meta-Analysis software (Version 2.0; Biostat, Englewood, NJ, USA). The level of statistical significance was set at p <0.05.

Results

The initial search yielded 1,271 articles from databases and 11 from other sources. After duplicates removal, 333 remained and were screened by titles and abstracts. The remaining articles were screened based on the inclusion and exclusion criteria. After the study selection process, 31 studies were included (Figure 1).

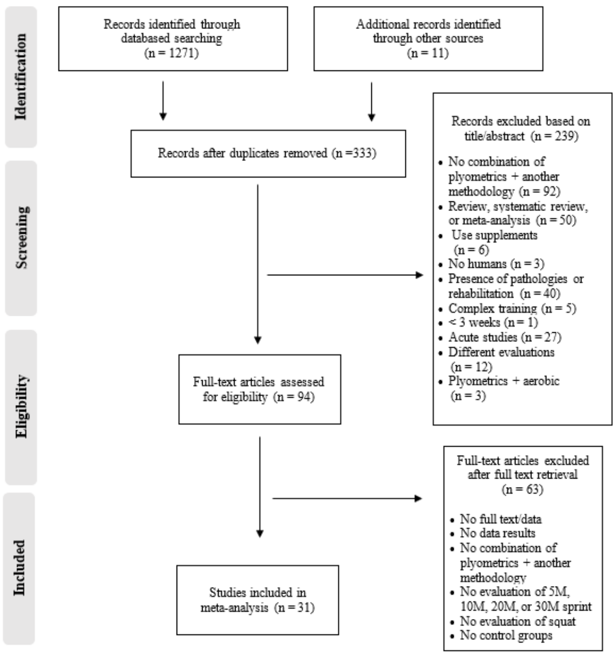

Figure 1. Flow diagram for the different stages of the systematic review process.

General characteristics of studies

The basic characteristics of the participants and the programming parameters of the combined interventions from the included studies are displayed in (Table 2).

Table 2.
Methodological quality. Risk of bias table: review of author´s judgmets about risk of bias item across all included studies (studies with control group)

	Random sequence generation (Selection bias)	Allocation concealment (Selection bias)	Blinding of participants and personnel (Performance bias)	Blinding of outcome assessment (Detection bias)	Incomplete outcome data (Attrition bias)	Selective reporting (Reporting bias)	Other bias
Álvarez 2012	+	-	-	-	+	+	+
Arede 2019	-	-	-	-	+	+	+
Bouteraa 2018	+	-	-	-	+	+	+
Chaouachi 2014	+	-	-	-	+	+	+
Falces 2021	+	-	-	-	+	+	+
Fathi 2019	+	-	-	-	+	+	+
Fatouros 2000	-	-	-	-	+	+	+
Faude 2013	+	-	-	-	+	+	+
Franco 2015	-	-	-	-	+	+	+
Guadalupe 2009	+	-	-	-	+	+	+
Hammami 2018	+	-	-	-	+	+	+
Herrero 2010	+	-	-	-	+	+	+
Kargafard 2020	-	-	-	-	+	+	+
Kijowksi 2015	+	-	-	-	+	+	+
Lyttlee 1996	+	-	-	-	+	+	+
Makhlouf 2018	+	-	-	-	+	+	+
Newton 1999	+	-	-	-	+	+	+
Otero 2017	-	-	-	-	+	+	+
Peña 2019	-	-	-	-	+	+	+
Pérez-Gómez 2008	+	-	-	-	+	+	+
Pienaar 2013	+	-	-	-	+	+	+
Qi 2019	+	-	-	-	+	+	+

Ramos 2014	+	-	-	-	+	+	+
Redondo 2014	+	-	-	-	+	+	+
Rodríguez 2016	+	-	-	-	+	+	+
Rodríguez 2017	+	-	-	-	+	+	+
Rodríguez 2017	+	-	-	-	+	+	+
Ronnestad 2008	+	-	-	-	+	+	+
Sáez de Villarreal 2015	+	-	-	-	+	+	+
Tricoli 2005	+	-	-	-	+	+	+
Zghal 2019	+	-	-	-	+	+	+

Study quality

The methodological quality of eligible studies is shown in Table 3. All studies should be considered at high risk of bias. Likewise, the overall assessment should be high risk of bias. Most studies (25/31, 70%) were at low risk of bias arising from randomization, and all studies had low risk of attrition bias, reporting bias, and other bias. High risk of performance and detection bias was found for every study, and high risk of selection bias was detected for most studies, there was only one exception.

Table 3.
Characterization of participants groups and training interventions.

	Nº subjects	Age (year)	Weight (kg)	Height (cm)	Gender	Years' exp	Strength exp	Fit	Group level	Sport	Treatment	Duration	Nº sessions	Test
Álvarez 2012	5	24.2	68.09	171.9	M	7.9	NR	NR	Reg	Golf	PL+RT	6	12	SQ
Arede 2019	9	14	56.2	165	M	5	YES	Good	Reg	Bask	PL+RT+SP+COD +BAL	8	32	10M
Bouteraa 2018	16	16	56.6	168	W	NR	NR	NR	REG	Bask	PL+BA	8	16	5M, 10M, 20M
Chaouachi 2014	14	13	45.9	158	M	0	NO	Re	No ath	No sport	PL+BA	8	24	5M, 30M
Falces Prieto 2021a	15	14.2	56.9	169	M	5	NR	Elite	Reg	Soc	PL+SP	8	16	10M, 20M
Falces prieto 2021b	15	17.2	65.3	171	M	5	NR	Elite	Reg	Soc	PL+SP	8	16	10M, 20M
Fathi 2019	20	14.7	68.7	177	M	NR	NR	Elite	Na	Vol	PL+RT	16	32	5M, 10M
Fatouros 2000	10	20	79.9	178	M	NR	NO	NR	NR	NR	PL+RT	12	36	SQ
Faude 2013	8	23.1	78.9	183	M	10	NR	Re	Reg	Soc	PL+RT+SP	7	14	10M, 30M, SQ
Franco-Márquez 2015	20	14.7	60.3	171	M	5	NO	Good	Reg	Soc	PL+RT+SP+COD	6	12	10M, 20M, SQ
Guadalupe 2009a	20	23.13	69.5	174.7	M	NR	NR	Re	NR	NR	PL+RT	9	27	30M, SQ
Guadalupe 2009b	8	22.3	61.7	168.5	W	NR	NR	Re	NR	NR	PL+RT	9	27	30M, SQ
Hammami 2018	14	14	69.3	178	M	4	YES	Elite	Na	Hand	PL+SP+COD	6	12	5M, 10M, 20M, 30M
Herrero 2010	11	21	80.2	179	M	0	NR	NR	No ath	No sport	PL+RT+EL	4	16	20M
Herrero 2010	8	21	79	172	M	0	NR	NR	No ath	No sport	PL+RT	4	16	20M
Kargafard 2020a	9	18	64.2	173	NR	NR	NR	Elite	Na	Soc	PL+SP+COD	6	12	30M
Kargafard 2020b	8	18	63.1	177	NR	NR	NR	Elite	Na	Soc	PL+ SP+COD	6	12	30M
Kijowksi 2015	9	21.2	79.5	182	M	NR	YES	NR	NR	No sport	PL+RT	4	8	SQ
Lyttlee 1996	11	24	72.5	178	M	NR	NO	NR	RE	Mix	PL+RT	8	16	20M, SQ
Makhlouf 2018a	20	11	36.6	147	M	3	NR	Elite	Na	Soc	PL+COD	8	16	10M, 30M
Makhlouf 2018b	21	11	36.9	145	M	3	NR	Elite	Na	Soc	PL+ BA	8	16	10M, 30M
Newton 1999	8	19	84	189	M	5	YES	Elite	Na	Vol	PL+RT	8	16	SQ
Otero-Esquina 2017a	12	17	69.4	176.7	NR	NR	NR	Elite	Inter	Soc	PL+RT+SP	7	7	10M, 20M
Otero-Esquina 2017b	12	17	69.4	176.7	NR	NR	NR	Elite	Inter	Soc	PL+RT+SP	7	14	10M, 20M
Peña 2019a	43	12.8	45.4	154.9	M	NR	YES	Good	Na	Soc	PL+RT	8	16	30M, SQ
Peña 2019b	36	13.8	55.8	165.9	M	NR	YES	Good	Na	Soc	PL+RT	8	16	30M, SQ
Peña 2019c	31	14.6	62.3	171.9	M	NR	YES	Good	Na	Soc	PL+RT	8	16	30M, SQ
Pérez-Gómez 2008	16	23.4	71.2	174.9	NR	NR	NR	NR	NR	NR	PL+RT	6	18	5M, 10M, 20M, 30M, SQ

Pienaar 2013	19	18.94	89.96	183.38	M	11	NR	Re	Na	Rug	PL+RT	4	12	5M, 10M, 20M
Qi 2019	31	10.6	37.5	142.9	NR	NR	NR	Re	NR	NR	PL+RT+SP	4	8	30M
Ramos Veliz 2014	16	20.43	81.43	180.33	M	8	NR	Good	Na	Wat	PL+RT	18	36	SQ
Redondo 2014	6	24.8	70.46	173.3	M	9.7	NR	NR	Na	Fen	PL+RT	6	12	SQ
Rodríguez-Rosell 2016	15	12.7	47.6	158	NR	3	NO	Good	NR	Soc	PL+RT+SP	6	12	10M, 20M,
Rodríguez-Rosell 2017a	10	24.5	74.5	176	NR	8	NO	Re	Reg	Soc	PL+RT+SP+COD	6	12	10M, 20M, SQ
Rodríguez-Rosell 2017b	15	12.6	46.3	158	NR	2	NO	NR	Reg	Soc	PL+RT+SP+COD	6	12	10M, 20M, SQ
Rodríguez-Rosell 2017c	14	14.6	59.6	170	NR	4	NO	Elite	Reg	Soc	PL+RT+SP+COD	6	12	10M, 20M, SQ
Rodríguez-Rosell 2017d	14	16.4	69.1	172	NR	6	NO	NR	Reg	Soc	PL+RT+ SP+COD	6	12	10M, 20M, SQ
Ronnestad 2008	8	24	73.5	180	M	NR	YES	Elite	Na	Soc	PL+RT	7	14	10M, SQ
Sáez de Villarreal 2015	13	15	57	168	NR	6	NR	Good	Na	Soc	PL+SP	9	18	5M, 10M
Tricoli 2005	8	22	73.4	179.4	M	NR	YES	Re	Amat	NR	PL+RT	8	24	10M, 30M, SQ
Zghal 2019	14	14.5	60.2	172	NR	5	NO	Good	Reg	Soc	PL+RT + SP	7	14	5M, 10M, 20M

Abbreviation's descriptions ordered alphabetically. Avalakov: AVA; Amat: Amateur; Balance: BA; Basketball: Bask; B: Both; Change of direction: COD; Electrostimulation: EL; Exp: Experience; F:Female; Fencing: Fen; Fit: Fitness; Flexibility: FL; Handball: hand; Int: International, M: Male; Mixed sports: Mix; Na: Nacional; No athletes: No ath; NR: No report; PL: Plyometrics; Reg: Regional, Re: Regular; RT: Resistance training; Rugby: Rug; Soccer: Soc; Speed: SP; Squat: SQ; Track and Field: Tra; volleyball: Vol, Water polo: War,

Meta-Analyses

Eight studies provided data for 5-m sprint performance, involving 8 experimental and 8 CG (pooled n = 240). Results showed a small non-significant effect of trained participants on 5-m sprint performance (ES = 0.39; 95% CI = -0.25 to 1.04; p < 0.228; I^2 = 83.1%; Figure 2) when compared to controls.

Results were not analysed as per athlete's involvement in specific-active or traditional-active CG, as only one study included specific-active control condition.

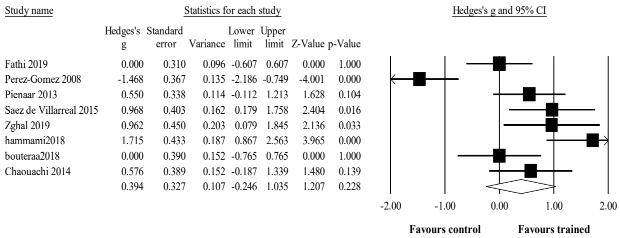

Figure 2. 5m. Forest plot of changes in 5-m sprint performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall result.

Eighteen studies provided data for 10-m sprint performance, involving 23 experimental and 21 CG (pooled n = 595). Results showed a moderate effect of trained participants on 10-m sprint performance (ES = 0.67; 95% CI = 0.37 to 0.97; p < 0.001; I^2 = 66.6%; Figure 3 when compared to controls.

Results were not analysed as per athlete's involvement in specific-active or traditional-active CG, as only one study included specific-active control condition.

No significant moderator effect was noted for training combination-type (p = 0.682), with an ES = 0.61 after PL training combined with an additional training method (12 data points; I^2 = 72.9) and an ES = 0.73 after PL training combined with two or more training methods (11 data points; I^2 = 60.1%).

No significant moderator effect was noted for training combination-type (p = 0.263), with an ES = 1.01 after PL training combined with speed training (5 data points; I^2 = 60.0), an ES = 0.32 after PL training combined with RT (7 data points; I^2 = 73.7%), and an ES = 0.73 after PL training combined with 2 or more training methods (11 data points; I^2 = 60.1%).

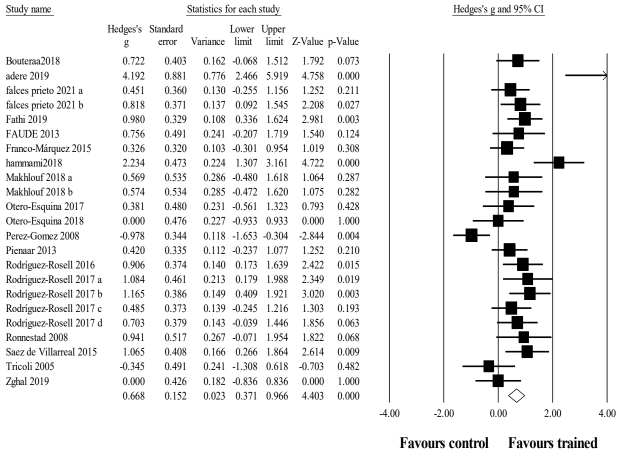

Figure 3. Forest plot of changes in 10-m sprint performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall result.

Twelve studies provided data for 20-m sprint performance, involving 18 experimental and 16 CG (pooled n = 464). Results showed a small effect of trained participants on 20-m sprint performance (ES = 0.45; 95% CI = 0.21 to 0.70; $p < 0.001$; $I^2 = 43.3\%$; Figure 4) when compared to controls.

Results were not analysed as per athlete's involvement in specific-active or traditional-active CG, as no study included specific-active control condition.

No significant moderator effect was noted for training combination-type (p = 0.139), with an ES = 0.25 after PL combined with an additional training method (9 data points; $I^2 = 59.9$) and an ES = 0.63 after PL combined with two or more training methods (9 data points; $I^2 = 0.0\%$).

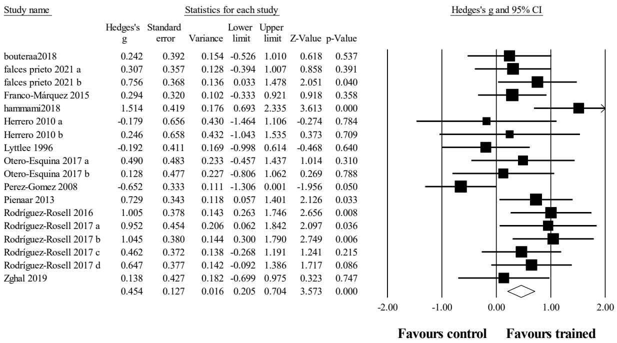

Figure 4. 20m. Forest plot of changes in 20-m sprint performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall result.

Ten studies provided data for 30-m sprint performance, involving 15 experimental and 12 CG (pooled n = 437). Results showed a small effect of trained participants on 30-m sprint performance (ES = 0.46; 95% CI = 0.20 to 0.71; $p < 0.001$; $I^2 = 25.9\%$; Figure 5) when compared to controls.

Results were not analysed as per athlete's involvement in specific-active or traditional-active CG, as no study included specific-active control condition.

A significant moderator effect was noted for training combination-type (p = 0.010), with an ES = 1.03 after PL training combined with speed training (4 data points; $I^2 = 11.8$) and an ES = 0.22 after PL training combined with RT (9 data points; $I^2 = 0.0\%$).

Fifteen studies provided data for maximal squat performance, involving 21 experimental and 19 CG (pooled n = 547). Results showed a large effect of trained participants on maximal squat performance (ES = 1.53; 95% CI = 0.98 to 2.07; $p < 0.001$; $I^2 = 85.2\%$; Figure 6) when compared to controls.

Results were not analysed as per athlete's involvement in specific-active or traditional-active CG, as only 2 studies included specific-active control conditions. A significant moderator effect was noted for training combination-type (p = 0.013), with an ES = 2.02 after PL training combined with RT (15 data points; $I^2 = 89.2$) and an ES = 0.90 after PL training combined with two or more training methods (6 data points; $I^2 = 0.0\%$).

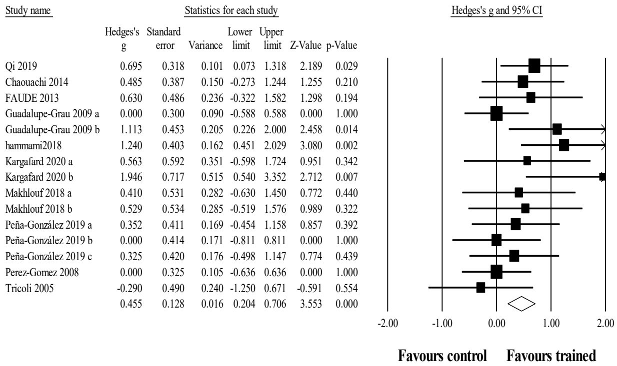

Figure 5. 30m. Forest plot of changes in 30-m sprint performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall result

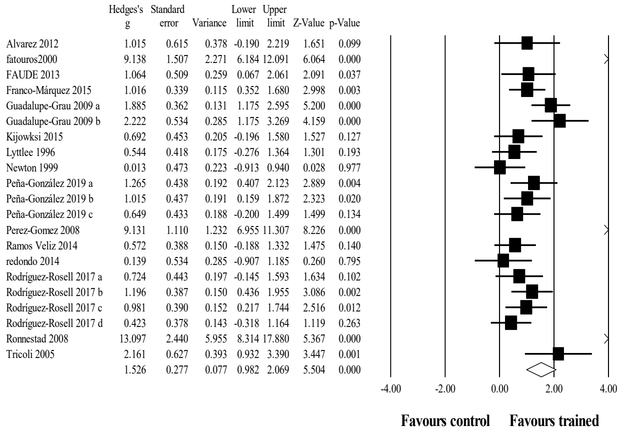

Figure 6. Squat. Forest plot of changes in maximal squat performance, in athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall result.

Discussion

The purpose of this meta-analysis was to determine the effects of CT in comparison to control conditions on speed and strength performance. We found that CT can be employed to improve performance in sprint time and Lower body 1RM (squat). In addition, we aimed to identify training characteristics that may have a greater moderating effect. The main findings indicate that there were statistically significant differences between CT and CG. CT had positive moderate effects on 10m sprint ES=0.67; small effects on 20m sprint ES=0.45; small effects on 30m sprint ES=0.46; and large effects on 1RM squat ES=1.53 compared to control conditions. This implies CT does significantly affect performance in healthy and sport population.

When results were analysed as per athletes' involvement in PL training combined with one compared with two or more training methods no significant moderator effects were found in 10m and 20m. Also, no significant moderator effects were found in 10m when results were compared between PL combined with speed training or PL combined with RT or PL combined with 2 or more training methods, this result suggests that sport scientists and strength and conditioning professionals may use either combination method to achieve positive adaptations on neuromuscular performance variables in sport and healthy population. Interestingly, significant improvements in sprinting performance (30m) were observed after combining PL with speed compared PL with RT, it is plausible that higher volumes or changes in sprint stimulus are needed to elicit adaptations on athletes and healthy participants over the studies that did not have a sprint stimulus (Hammami et al., 2019; Makhlouf et al., 2018; Prieto et al., 2021; Saez de Villarreal et al., 2015). The same results occurs in 1RM squat where significant moderator effects after combining PL with RT (Alvarez et al., 2012; Fatouros et al., 2000; Guadalupe-Grau et al., 2009; Peña-González et al., 2019; Ronnestad et al., 2008; Tricoli et al., 2005) were observed compared with PL combined with two or more methods. These findings suggest training specificity plays a key role in the improvement of speed and strength. Although indirectly, improvements in speed were obtained in the groups that worked PL plus RT (Bouteraa et al., 2020; Fathi et al., 2019; Perez-Gomez et al., 2008; Pienaar & Coetzee, 2013; Ronnestad et al., 2008) and improvements in strength in the groups that trained PL plus two or more methodologies (Faude et al., 2013; Franco-Márquez et al., 2015; Rodriguez-Rosell et al., 2016, 2017). The improvements were greater for the groups that worked this quality specifically. This supports the hypothesis that the combination of different methods within the same session could be an important solution to work on all the qualities and be able to develop them in an optimal way. The results of this meta-analysis provides confirmation to previous narrative reviews (Bauer et al., 2019; Cormier et al., 2020; Thapa et al., 2021) on the effects of PL training combined with RT training for the improvement of strength and speed.

The improvements obtained in strength and speed performance after the application of a CT program may be due to both mechanical and physiological adaptations similar to those obtained with a PL or RT program, but these improvements may be enhanced if they are combined in the same training (Carter & Greenwood, 2014; Robbins, 2005; Sale, 2002). Within these adaptations, we can find them at the hormonal level (e.g., testosterone increase) (Ali et al., 2019; Beaven et al., 2011) and cellular adaptations favourable to strength-power generation. In addition, at the level of structural adaptations, it has been reported that after 19 weeks of RT alone, the number of type IIx fibers was reduced (Stasinaki et al., 2015), type IIx fibers are the fibers that contract at higher speed and therefore they are capable of generating higher levels of power and therefore important during maximal-intensity and short-duration actions (e.g., acceleration and sprint) (Bottinelli et al., 1996; Fry et al., 2003; Harridge et al., 1996; Macaluso et al., 2012). Against it was seen that after a program that includes CT these are preserved compared to a RT program (Stasinaki et al., 2015). Other studies that have included PT or CT obtained similar results (Grgic et al., 2021; Macaluso et al., 2012, 2014). A greater recruitment of fast-twitch muscle fibers was also seen during CT, possibly due to the combination of high loads at low speed with low loads at high speed (Gołaś et al., 2016). In addition, CT can help to produce a better coordination and synchronization of the muscle groups that are developing the action to improve and enhance motor skills, this can be seen by a better transfer of energy in the concentric and eccentric phase of muscle movement (Cronin et al., 2001; Robbins, 2005). The improvements of these adaptations will therefore improve speed, jumping and agility (Cavaco et al., 2014; García-Pinillos et al., 2014). From another point of view, CT can lead to optimize the strength-velocity curve of the athlete due to the fact that low loads (i.e., PL) are combined with high loads (i.e., RT) (Cormie et al., 2011a). In this way, when prescribing this training, the coach ensures that the athlete has worked on the two broad components of the continuum. Due to the importance of the force-velocity spectrum parameters (Jiménez-Reyes et al., 2022), it can be thought that these performance improvements obtained after CT can be understandably believed to be due to an optimization of the force-velocity spectrum. The results from our meta-analysis may offer a positive finding amongst a wider population of athletes.

Some limitations are acknowledged. First, a high heterogeneity was observed in the studies included in this analysis as they had different populations and training characteristics. Secondly, the findings of our systematic review suggest the absence of CT studies involving female, only two studies (Bouteraa et al., 2020; Guadalupe-Grau et al., 2009). Therefore, current findings should not be simply extrapolated to female athletes. Future CT research should involve females to overcome this shortcoming in literature. Another major shortcoming noted in this systematic review is there was a greater amount of plyometric combined strength studies included compared with plyometric combined with other methodologies (e.g., speed, COD, three or more methods combined).

Our results substantiate our hypothesis that PL training combined enhances Strength and Speed compared to CG. Although the heterogeneity observed among the studies was high. However, three of four speeds tests and strength test improve significantly after the combined interventions. From an applied perspective, CT may be used to achieve positive adaptations on neuromuscular performance variables in athletes. This may be of interest for coaches and athletes seeking a more time-efficient way to incorporate lower-load and higher-load exercises in their training program (Bauer et al., 2019; Cormier et al., 2020).

Conclusion

Combined strength training is effective to improve sprint time and strength on healthy participants and athletes. Likewise, compared to PL combined with RT, the combination of PL with speed training is more effective to improve sprinting performance (30m). Further, combining PL with strength training appears to provide greater improvements in maximal strength (1RM squat) compared to PL combined with other (two or more) training methodologies not focused on strength gains. However, the role of potential moderator variables such as frequency, duration, or total number of sessions, and the specific dose-response relationships following combined training, particularly in the long term, are unclear at present.

Acknowledgments

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