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Systematic Review

Are We Able to Match Non Sport-Specific Strength Training with Endurance Sports? A Systematic Review and Meta-Analysis to Plan the Best Training Programs for Endurance Athletes

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Abstract: Non-sport-specific strength training is a way to increase endurance performance; however, which kind of exercise (maximal, plyometric, explosive or resistance strength training) gives the best results is still under debate. Scientific publications were analyzed according to the PRISMA checklist and statement. The initial search yielded 500 studies, 17 of which were included in this review using the PEDro Scale. Maximal strength training boosted the ability to express strength particularly in cross-country skiing and cycling, increasing endurance performance, measured as a decrease of the endurance performance tests. In running, explosive strength training did not generate advantages, whereas plyometric strength training led to an improvement in the endurance performance tests and work economy. In running it was possible to compare different types of non sport-specific strength training and the plyometric one resulted the best training methodology to enhance performance. However, studies on other sports only investigated the effects of maximal strength training. It resulted more effective in cross-country skiing (although only one study was eligible according to the inclusion criteria) and in the cycling component of the triathlon and, by contrast, induced modest effects on cyclists' performance, suggesting different type of strength would probably be more effective. In conclusion, each sport might optimize performance by using appropriate non sport-specific strength training, which, however, should be studied individually.

Keywords: concurrent training; work economy; strength training; nonspecific strength training

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1. Introduction

Endurance training leads to vascular and muscular adaptions, favoring the improvement of endurance performance. [1]. More recently, it has been shown that exercise economy is one of the factors determining performance in endurance sports [2]. Exercise economy is defined as the oxygen uptake required at a given submaximal speed [1] and this concept is frequently associated with the work economy that is expressed as aerobic metabolic rate or oxygen uptake at a given speed [3].

Many sports require a combination of strength and endurance training for successful performance and it is known that the inclusion of strength training in an endurance season training period can represent the key strategy to enhance the endurance performance [4]. Strength training increases muscle strength and power. Indeed, in well-trained athletes, the capacity to sustain a high intensity in endurance performances, without the influence of aerobic capacity, could be associated to the strength development [3]. The effectiveness of concurrent training—such as endurance and strength training in the same training program—has long been recognized, in fact, expert trainers believe that the addition of non sport-specific strength training (NST) to sports-specific training improves sports performance [4]. NST is every strength exercise with non-specific sport movements (i.e., squat, deadlift, leg press, leg extension machine, etc.).

Several studies showed that sport-specific strength training improves endurance performance. For example, the running economy increased when incorporating uphill-sprint interval training in the endurance training programs [5]. However, the inclusion of NST in workout sessions leads to similar results: for example, maximal strength exercise (i.e., squatting with maximal external load) before cycling endurance performance improves the subsequent 20 km time trial testing with a better cycling economy [6]. The effect of NST on endurance performance [1,7–9] highlighted that a strength training per se could help endurance athletes to be more economical, in terms of submaximal forces developed during performance (stride during running or pedal during cycling) [1]. For a better yield, strength-training load should be of mixed intensity, frequency and volume [8] and exercises should have kinetics and patterns (rate of force development—RFD, peak force, acceleration, etc.) similar to the athletic requirements [9] (i.e., high exercise speed during squat, lunge and calf if the sport needs lower body fast movements).

Although there is evidence that NST improves endurance performance, it is still not clear which type of NST (maximal, plyometric, explosive or resistance strength training) is the most effective for specific endurance sport disciplines. Training strength with different types of load movement—dynamic or isometric, maximal or resistance, explosive or plyometric—might be more effective for some sports, but several opinions appear controversial. Some studies on swimming provided evidence in favor of plyometric strength training [10,11], others in favor of maximal strength training [12]. In running disciplines explosive strength training seems to work better, as it decreases the muscle activation time, while heavy strength training resulted less efficient [13].

Given this background, the purpose of this review and meta-analysis was to assess which type of NST intervention has proven more efficient to improve the performance, in four different endurance sports: running, cycling, triathlon and cross-country skiing.

2. Materials and Methods

2.1. Search Strategy

This review was conducted according to the PRISMA checklist and the PRISMA statement [14]. The studies included in this review were identified through a database search in PubMed, Google Scholar and Science Direct. The following search terms were used in combination with the Boolean operator: Strength training AND Endurance Performance, Strength training AND triathlon endurance, Strength training AND Running economy, Strength training AND Cycling economy, Strength training AND work economy, Strength training AND Cross-Country Skiing.

2.2. Eligibility Criteria

Studies meeting the following criteria were included or excluded to this review.

2.3. Inclusion

Studies from 1 January 2009 to 31 December 2020;

- Original research papers published on international scientific journals;
- Athletes involved had a VO_2max: Female > 50 mL/min/kg; Male > 55 mL/min/kg or well experience training level;
- Athletes had >6 months' endurance training;
- Strength intervention > 4 weeks in duration;
- Presence of control group(s) (only aerobic training).

2.4. Exclusion

- Reviews and Ph.D. theses;

- Specific strength training interventions (i.e., strength exercises directly related to a specific sport activity);
- Studies evaluating only one physiological or biomechanical parameter (i.e., VO_2max, Lactate, WE, time trial (TT) or time trial to exhaustion (TTE)), to exclude the accidental effects that could improve the endurance performance;
- Non-athlete subjects recruited.

2.5. Quality Assessment

The selected studies were rated using the Physiotherapy Evidence Database (PEDro) Scale. The PEDro scale accounts for the internal validity and interpretability of experimental trials. The scale scores internal validity through aspects of study design, such as randomization, allocation, similarity of key measures at baseline, and blinding of subjects, therapists, and assessors. Additionally, the scale measures the interpretability of research by examining between-group statistics, descriptions of point measures, and measures of variability. The 11-item scale (Table 1) yields a maximum score of 10 points if all criteria are satisfied. Only papers reaching a minimum cut-off of 5 points on the PEDro scale were finally included in the analysis.

Table 1. Studies value by items in the PEDro scale.

PEDro Scale	Eligibility Criteria Were Specified	Subjects Were Randomly Allocated to Groups	Allocation Was Concealed	The Groups Were Similar at Baseline Regarding the Most Important Prognostic Indicators	Blinding of All Subjects	Blinding of All Therapists Who Administered the Therapy	Blinding of All Assessors Who Measured at Least 1 Key Outcome	Measures of 1 Key Outcome Were Obtained from 85% of Subjects Initially Allocated to Groups	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 1 Key Outcome Were Analysed by "Intention to Treat"	The Results of between-Group Statistical Comparisons Are Reported for at Least 1 Key Outcome	The Study Provides both Point Measures and Measures of Variability for at Least 1 Key Outcome	Total
N.Berryman et al., 2010 [15]	Yes	1	0	1	0	0	0	1	1	1	1	6
J. Mikkola et al., 2011 [16]	Yes	1	0	1	0	0	0	1	1	1	1	6
M. Piacentini et al., 2013 [17]	Yes	1	0	1	0	0	0	1	1	1	1	6
S. Sedano et al., 2013 [18]	Yes	1	0	1	0	0	0	1	1	1	1	6
R. Ramirez-Campillo et al., 2014 [19]	Yes	1	0	1	0	0	0	1	1	1	1	6
O. Vikmoen et al., 2016 [20]	Yes	1	0	1	0	0	0	1	1	1	1	6
B. R. Rønnestad et al., 2010 [21]	Yes	0	0	1	0	0	0	1	1	1	1	5
A. Sunde et al., 2010 [22]	Yes	1	0	0	0	0	0	1	1	1	1	5
P. Aagaard et al., 2010 [23]	Yes	1	0	1	0	0	0	1	1	1	1	6
B. R. Rønnestad et al., 2011 [24]	Yes	1	0	0	0	0	0	1	1	1	1	5
E. A. Hansen et al., 2012 [25]	Yes	1	0	0	0	0	0	1	1	1	1	5
B. R. Rønnestad et al., 2014 [26]	Yes	1	0	1	0	0	0	1	1	1	1	6
O. Vikmoen et al., 2015 [27]	Yes	1	0	1	0	0	0	1	1	1	1	6
B. R. Rønnestad et al., 2017 [28]	Yes	1	0	1	0	0	0	1	1	1	1	6

Table 1. *Cont.*

PEDro Scale	Eligibility Criteria Were Specified	Subjects Were Randomly Allocated to Groups	Allocation Was Concealed	The Groups Were Similar at Baseline Regarding the Most Important Prognostic Indicators	Blinding of All Subjects	Blinding of All Therapists Who Administered the Therapy	Blinding of All Assessors Who Measured at Least 1 Key Outcome	Measures of 1 Key Outcome Were Obtained from 85% of Subjects Initially Allocated to Groups	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 1 Key Outcome Were Analysed by "Intention to Treat"	The Results of between-Group Statistical Comparisons Are Reported for at Least 1 Key Outcome	The Study Provides both Point Measures and Measures of Variability for at Least 1 Key Outcome	Total
C. Hausswirth et al., 2009 [29]	Yes	1	0	1	0	0	0	1	1	1	1	6
O. Vikmoen et al., 2017 [30]	Yes	1	0	1	0	0	0	1	1	1	1	6
T. Losnegard et al., 2011 [31]	Yes	0	0	1	0	0	0	1	1	1	1	5

Linked table footnotes: Items in the PEDro scale. 1 = eligibility criteria were specified; 2 = subjects were randomly allocated to groups; 3 = allocation was concealed; 4 = the groups were similar at baseline regarding the most important prognostic indicators; 5 = blinding of all subjects; 6 = blinding of all therapists who administered the therapy; 7 = blinding of all assessors who measured at least 1 key outcome; 8 = measures of 1 key outcome were obtained from 85% of subjects initially allocated to groups; 9 = 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 1 key outcome were analysed by "intention to treat"; 10 = the results of between-group statistical comparisons are reported for at least 1 key outcome; 11 = the study provides both point measures and measures of variability for at least 1 key outcome.

2.6. Statistical Analysis

We conducted two meta-analyses using Statsdirect v3.3 (Statsdirect, Birkenhead, UK) with the aim to find which type of non-specific strength training improved better the endurance ability, thus the performance. Our primary outcome included the economy of gesture, assessed as WE; in a secondary outcome we assessed the endurance performance through the tests TT or TTE. The studies included in the meta-analyses were screened for inconsistency by using the I2 statistic, and pooled estimates of the effect of non-specific strength training (NST) on the endurance ability were obtained by DerSimonian–Laird's method in a random-effect model. The results of Vikmoen et al. (2017) [30] about work economy were duplicated in order to describe the impact of NST in running and cycling separately. Egger's test was used to assess the presence of publication bias.

3. Results

3.1. Included Studies

The initial search yielded 500 publications. Duplicated studies were excluded (n = 348). Studies considered to be potentially relevant after reading the abstract (n = 152) were reviewed, reading the full text. Among those, more papers were excluded because they were not relevant (n = 26) or dealt with generic topics (n = 33) or reviews (n = 19). Of the remaining 74 articles, 57 papers were excluded they did not meet the inclusion criteria (21 = year of publication, 7 = Ph.D. theses, 15 = subjects training level and background level, 4 = strength intervention duration, 10 = strength intervention type). In the end, 17 studies were included in this review (Figure 1), focused on the following endurance sports: cross-country skiing (n = 1), triathlon (n = 2), cycling (n = 8) and running (n = 6).

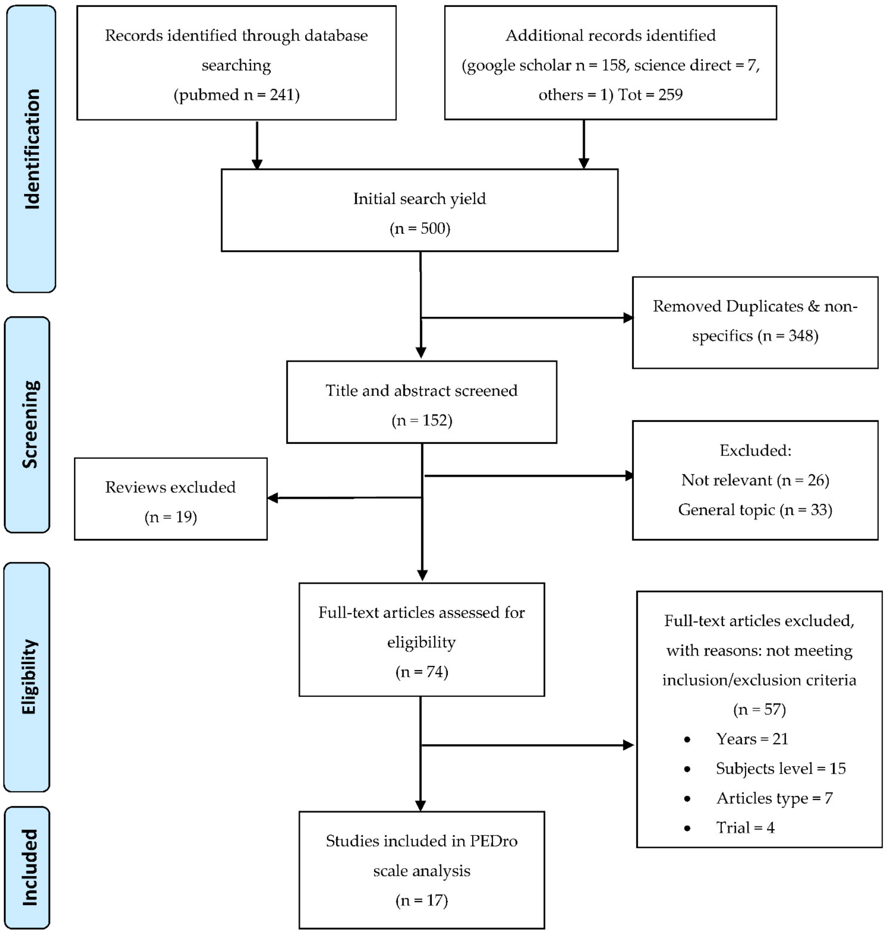

Figure 1. PRISMA flow diagram. The selection process and the inclusion and exclusion criteria used in the systematic review.

3.2. Data Extraction and Outcome Measures

Data from the selected studies were extracted and summarized in three main tables as follows:

3.2.1. Study Characteristics

All the study details, including purpose, athletes, research design and quality assessment, are shown in Table 2: author name and year of publication, characteristics of athletes (number, gender, mean age, mean VO_2max, experience and reported endurance training), research design (type of research and athletes assignment to a study groups) and quality assessment by the PEDro Scale. Among the 17 included studies, a total of 334 national and international athletes (n = 244 male, n = 90 female), with a mean age of 27.75 + 6.76 and a VO_2max range between 52.4 and 80 mL/kg/min, were distributed in a specific group as follows: 10 studies used the randomized controlled trial (RCT) model [15,17–20,23,26,28–30], randomly allocating the participants into the control or intervention groups; four non-randomized studies stratified participants for gender, age and VO_2max [16,22,25,27]; three studies [21,24,31] used the self-choice method to allocate the subjects in the groups. All subjects were "Highly trained" or "High level" athletes following usual endurance training ("ET declared"), performed in specific heart rate (HR) zones in nine studies [18,20,21,24–28,30].

3.2.2. Study Protocols

The main characteristics of strength intervention protocols are reported in Table 3: type of strength training (Maximal, Explosive, Plyometric and Resistance), type of exercises (multi-joint movement, open or closed kinetic chain), volume (sets and repetitions), frequency (times per week), time (number of weeks) and periodization (when the study was performed according to the sport Season). In detail, the types of strength intervention were: maximal strength training (MST) [16,17,19–31]; resistance strength training (RST) [17,18]; plyometric strength training (PST) [15,17,18]; explosive strength training (EST) [15,16]; or combinations of these types [15–18]. All studies used at least one multi-joint, closed kinetic chain exercise (squat, leg press, lunge, squat jump—SJ, counter movement jump—CMJ, drop jump—DJ, etc.); two studies used resistance machine exercise only [23,29], whereas all other studies used free weights, bodyweight resistance or a combination of machines and free weights. Strength interventions ranged from 5 to 25 weeks, with a preference for 10–12 weeks [18,20,21,24,25,27,28,30,31] and only one study used a 5-week program [29] or a 25-week program [26]. Subjects trained 2 times/week in almost all studies; only three studies [22,23,29] reported a 3 times/week training, and only in one study did subjects train once/week [15]. MST volume ranged typically by 3–4 sets of 4–6 repetitions per exercise. RST and PST (maximal reactive speed against gravity, with DJ, skip, CMJ) similarly ranged from 1 to 6 sets of 6–10 repetitions. EST training volume was more variable.

3.2.3. Effect of NST on Sport Performance

Table 4 summarizes the tests used to measure the effects of NST on endurance ability and other targets (body composition, body mass, muscle fibers composition and cross-sectional Area—CSA). Endurance ability was defined as follows: aerobic capacity (VO_2max or peak and maximal aerobic speed—MAS), power output (Po), work economy (WE), time trial (TT) and time-trial to exhaustion (TTE). Twelve studies showed a range of improvement from 3.6% to 45% on 1RM or ISO 1RM [16,17,20–22,24–27,29–31]. Seven studies also showed an increase of Po [22–24,26–28,31]. The remaining studies did not report a direct increase in Po. Eight studies also showed an improvement in neuromuscular activity as RFD, Electromyography (EMG), jump, stiffness [16–20,22,23,28]. Endurance ability was considered in terms of efficacy related to each kind of strength training (maximal, resistance, plyometric and explosive), as detailed below.

Table 2. Study characteristics.

Study		Athletes						Research Design			Quality Assessment
Authors	**Purpose**	**N°**	**Gender**	**Age Mean**	**Vo_2max Mean**	**Experience**	**Endurance Training**	**Subjects Assignment**	**Intervention Group(s) (n°)**	**Control Group (n°)**	**PEDro SCALE**
Running											
N. Berryman et al., 2010 [15]	To compare the effects of 2 strength training methods on the energy cost of running (Cr).	28	M	28	56.9	Well trained	Yes	RCT	11 Reactive 12 Explosive	5	6
J. Mikkola et al., 2011 [16]	To assess the effects of heavy resistance, explosive resistance, and muscle endurance training on neuromuscular, endurance, and high-intensity running performance.	27	M	35.5	n.d.	Well trained	n.d.	Matched	10 Heavy 11 Explosive	6	6
M. Piacentini et al., 2013 [17]	To evaluate the effects of 2 different strength training protocols on RE and strength parameters.	16	12 M 4 F	44.05	n.d.	Master	Yes	RCT	6 Maximal 5 Resistance	5	6
S. Sedano et al., 2013 [18]	To determine which mode of concurrent strength-endurance training might be the most effective at improving running performance in highly trained runners.	18	M	23.7	>65	Well trained	Yes, HR Zones (1) 75/85%, (2) 85/95%, (3) 95/100%	RCT	6 Resistance + Plyometric 6 Strength <40%	6	6
R. Ramirez-Campillo et al., 2014 [19]	To examine the effect of a short-term plyometric training program on explosive strength and endurance performance in highly competitive middle- and long-distance runners.	36	22 M 14 F	22.1	n.d.	National + International	n.d.	RCT	18	18	6
O. Vikmoen et al., 2016 [20]	To investigate the effects of adding strength training to normal endurance training on running performance and running economy in well-trained female athletes.	19	F	n.d.	53	5.8 h × week	Yes, HR Zones (1) 60/82%, (2) 83/87%, (3) 88/100%	RCT	11	8	6
Cycling											

Table 2. *Cont.*

Study		Athletes						Research Design			Quality Assessment
Authors	**Purpose**	**N°**	**Gender**	**Age Mean**	**Vo_2max Mean**	**Experience**	**Endurance Training**	**Subjects Assignment**	**Intervention Group(s) (n°)**	**Control Group (n°)**	**PEDro SCALE**
B. R. Rønnestad et al., 2010 [21]	To investigate the effect of heavy strength training on thigh muscle cross-sectional area (CSA), determinants of cycling performance, and cycling performance in well-trained cyclists.	20	18 M 2 F	28.5	66.35	National	Yes, HR Zones (1) 60/72% (2) 73/82%, (3) 83/87%, (4) 88/92%, (5) 93/100% (5) 93/100%	Self-Ch.	11	9	5
A. Sunde et al., 2010 [22]	To investigate the effect of maximal strength training on CE.	13	10 M 3 F	32.85	61.05	Well trained	Yes	Matched	8	5	5
P. Aagaard et al., 2011 [23]	To examine the effect of concurrent strength and endurance training (SE) on muscle morphology and long/short-term endurance performance.	14	M	19.5	72.5	National + International	Yes	RCT	7	7	6
B. R. Rønnestad et al., 2011 [24]	To investigate how adding heavy strength training to usual endurance training for 12 weeks affects the mean power output during a 5-min all-out trial performed following 185 min of submaximal cycling.	20	18 M 2 F	28.5	66.35	Well Trained	Yes, HR Zones (1) 60/72% (2) 73/82%, (3) 83/87%, (4) 88/92%, (5) 93/100%	Self-Ch.	11	9	5
E. A. Hansen et al., 2012 [25]	To investigate whether enhanced cycling performance after strength training was accompanied by an improved pattern of crank-torque application, reflecting improved pedalling efficacy.	18	16 M 2 F	28.5	52.4	National	Yes, HR Zones (1) 60/72% (2) 73/82%, (3) 83/87%, (4) 88/92%, (5) 93/100%	Matched	10	8	5

Table 2. *Cont.*

Study		Athletes						Research Design			Quality Assessment
Authors	**Purpose**	**N°**	**Gender**	**Age Mean**	**Vo_2max Mean**	**Experience**	**Endurance Training**	**Subjects Assignment**	**Intervention Group(s) (n°)**	**Control Group (n°)**	**PEDro SCALE**
B. R. Rønnestad et al., 2014 [26]	To investigate the hypothesis that a 10-week strength development period would increase lower body muscle strength, and that this adaptation would be maintained by a subsequent 15-week.	16	M	19.6	76.15	National + International	Yes, HR Zones (1) 60–72% (2) 73–87% (3) 88–100%	RCT	9	7	6
O. Vikmoen et al., 2015 [27]	To investigate the effects of 11 weeks of heavy strength training on 40-min all-out performance in trained female cyclist.	19	F	33.2	54.05	Well trained	Yes, HR Zones 1) 60–72%, (2) 73–87%, (3) 88-100%	Matched	11	8	6
B. R. Rønnestad et al., 2017 [28]	To investigate the effect of 10-week heavy strength training on lean lower-body mass, leg strength, determinants of cycling performance and cycling performance in elite cyclists.	20	16 M 4 F	19.5	72–80 63–65	National + International	Yes, HR Zones (1) 60–82%, (2) 83–87%, (3) 88–100%	RCT	12	8	6
Triathlon											
C. Hausswirth et al., 2009 [29]	This study investigated the effects of a combined endurance and strength training on the physiological and neuromuscular parameters during a 2-h cycling test.	14	M	31.3	69.2	17.3 h × week	Yes	RCT	7	7	6
O. Vikmoen et al., 2017 [30]	Investigate the effects of 11 weeks of heavy strength training on 5-min all-out performance after separate trials of prolonged submaximal work in both running and cycling and on physiological responses during the prolonged work.	19	F	n.d.	54 Bike 53 Run	Duathletes	Yes, HR Zones (1) 60–82%, (2) 83–87%, (3) 88–100%	RCT	11	8	6

Table 2. *Cont.*

Study		Athletes					Research Design				Quality Assessment
Authors	**Purpose**	**N°**	**Gender**	**Age Mean**	**Vo_2max Mean**	**Experience**	**Endurance Training**	**Subjects Assignment**	**Intervention Group(s) (n°)**	**Control Group (n°)**	**PEDro SCALE**
					Cross Country Skiing						
T. Losnegard et al., 2011 [31]	The aims of this study were to examine the effect of supplementing high-volume endurance training with strength training	19	11 M 8 F	21.5	64.7	International	n.d.	Self-Ch.	9	10	5

General notes, abbreviations and their definitions: Authors, Purpose (aim of the study), RE (running economy), CE (cycling economy); Athletes data synthesis: number, gender (M: male, F: female), age (mean), VO_2max (mean), experience (level of competition); Research data synthesis: subjects assignment (type of methods used from authors: RCT (randomized controlled trial), Self Ch. (self-choice group), matched (mixed to VO_2max, age or others parameters), divided (separated from authors)], endurance training (endurance training declared in the study), intervention n° (number of subjects in the intervention strength group), control n° (number of subjects in the control aerobic group), PEDro scale (score in the PEDro assessment). n.d.: not declared.

Table 3. Study protocols.

Authors	Type of Strength Training	Type of Exercises	Volume (Sets and Repetitions)	Frequency	Time	Periodization
			Running			
N. Berryman et al., 2010 [15]	Plyometric Explosive	Drop Jump Squat Jump	3 sets × 8 reps 6 sets × 8 reps	1 × w	8 w	n.d.
J. Mikkola et al., 2011 [16]	Explosive Maximal	Squat Smith Machine, Leg Press, Calf, Core ex., Bench Press, Pull Down	3 sets × 6 reps + 2 sets × 5 reps—1st to 4th w 3 sets × 6 reps + 3 sets × 5 reps + 2 sets × 5 reps rest 2/3 min—5th to 8th w 3 sets × 4 reps rest 2/3 min	2 × w	8 w	Pre-season
M. Piacentini et al., 2013 [17]	Maximal Resistance	Half Squat and Lunges with arm weights, Calf raises (Leg Press), Eccentric Quad., Leg Press (MST and RST), Bench Press, Lat Machine, Pulldown Machine, Cable machine, Triceps extension, Dumbbell biceps curl, (MST and RST) Seated Calf raises (RST); Core strength, Push up (RST)	4 sets × 3/4 reps 85/90% 1RM rest 3/4 min 5 sets × 10 reps 70% 1RM rest 2/3 min	2 × w	6 w	Pre-season

Table 3. *Cont.*

Authors	Type of Strength Training	Type of Exercises	Volume (Sets and Repetitions)	Frequency	Time	Periodization
S. Sedano et al., 2013 [18]	Resistance/Plyometric Endurance <40%1RM	Barbell Squat + Vertical Jump (40cm), Lying Leg Curl + Horizontal Jumps, Seated Calf raises + Vertical Jump, Leg Extension + Horizontal Jump Barbell Squat, Lying Leg curl, Seated Calf raises, Leg Extension	3 sets × 7 reps 70% 1RM + 10 reps rest 5 min 3 sets × 20 reps 40% 1RM rest 1 min	2 × w	12 w	Pre-season
R. Ramirez-Campillo et al., 2014 [19]	Plyometric	Drop box Jump	60 reps (2 sets × 10 reps of 20 cm, 2 sets × 10 reps of 40 cm, 2 sets × 10 reps of 60 cm)	2 × w	6 w	n.d.
O. Vikmoen et al., 2016 [20]	Maximal	Half Squat Smith Machine, 1 Leg press, 1 Leg Hip flexion, calf smith machine	3 sets × exercises 10/6 RM—1st to 3rd w 8/5 RM—4th to 6th w 6/4 RM—7th to 12th w	2 × w	11 w	In season
			Cycling			
B. R. Rønnestad et al., 2010 [21]	Maximal	Half Squat, 1 Leg press, 1 Leg Hip flexion, Ankle plantar flexion	3 sets × exercises 10/6 RM—1st to 3rd w 8/5 RM—4th to 6th w 6/4 RM—7th to 12th w	2 × w	12 w	Pre-season
A. Sunde et al., 2010 [22]	Maximal	Half Squat Smith Machine	4 sets × 4 reps	3 × w	8 w	Pre-season
P. Aagaard et al., 2011 [23]	Maximal	Leg Extension, Leg Press, Leg Curl, Calf raises	3sets × 12 reps—1st week 3 sets × 10 reps—2/3th weeks 3 sets × 8 reps—4/5th weeks 2/3sets × 6 reps—6th to 16th weeks	2/3 × w	16 w	/
B. R. Rønnestad et al., 2011 [24]	Maximal	Half Squat, 1 Leg press, 1 Leg Hip flexion, Ankle plantar flexion	3 sets × exercises 10/6 RM—1st to 3rd w 8/5 RM—4th to 6th w 6/4 RM—7th to 12th w	2 × w	12 w	Pre-season
E. A. Hansen et al., 2012 [25]	Maximal	Half Squat, 1 Leg press, 1 Leg Hip flexion, Ankle plantar flexion	3 sets × exercises 10/6 RM—1st to 3rd w 8/5 RM—4th to 6th w 6/4 RM—7th to 12th w	2 × w	12 w	Pre-season
B. R. Rønnestad et al., 2014 [26]	Maximal	Half Squat, 1 Leg Press, 1 Leg Deadlift, Calf raises	Pre-season 3 sets × (10—6—6 reps)—1/2/3rd w 3 sets (8—5—5 reps)—4/5/6th w 3 sets (6—4—4 reps)—7/8/9/10th w In season 3 sets × 5 Reps (8/10 RM)—11th to 25th w	2 × w pre-season 1 × w in season	25 w	Pre-season 10 w In season 15 w

Table 3. *Cont.*

Authors	Type of Strength Training	Type of Exercises	Volume (Sets and Repetitions)		Frequency	Time	Periodization
O. Vikmoen et al., 2015 [27]	Maximal	Half Squat, 1 Leg Press, 1 Leg Hip Flexion, Ankle plantar flexion	3 sets × exercises	10/6RM—1st to 3rd w 8/5RM—4th to 6th w 6/4RM—7th to 12th w	2 × w	11 w	Pre-season
B. R. Rønnestad et al., 2017 [28]	Maximal	Half Squat, 1 Leg Press, 1 Leg Hip Flexion, Ankle plantar flexion	3 sets × exercises	10/6RM—1st to 3rd w 8/5RM—4th to 6th w 6/4RM—7th to 12th w	2 × w	10 w (20 sessions)	Off-season
Triathlon							
C. Hausswirth et al., 2009 [29]	Maximal	Leg curl, Leg press, Leg Extension, Calf raises	3/5 sets × 3/5 reps		3 × w	5 w	Pre-season
O. Vikmoen et al., 2017 [30]	Maximal	Half Squat Smith Machine, 1 Leg Press, 1 Leg Deadlift, Calf raises	3sets (10—6—6 reps)—1st to 3rd w 3 sets (8—5—5 reps)—4th to 6th w 3 sets (6—4—4 reps)—7th to 11th w		2 × w	11 w	In season
Cross Country Skiing							
T. Losnegard et al., 2011 [31]	Maximal	Half Squat, Seated pull-down, standing pull down and Triceps press	1st day 3 sets × 6 reps/ 2nd day 3 sets × 10 reps—1st to 3rd w 1st day 3 sets × 5 reps/ 2nd day 3 sets × 8 reps—4th w 1st day 4 sets × 8 reps—5th to 8th w 1st day 3 sets × 4 reps/ 2nd day 3 sets × 6 reps—9th to 12th w		2 × w (45′)	12 w	Pre-season

General notes, abbreviations and their definitions: Intervention methods: Authors, type of strength intervention, type of intervention protocol, type of exercises, frequency (times × week), time (total weeks), periodization (period of season). W: weeks; 1st to 4th w: from the first week to the fourth week; RM: repetition maximal; n.d.: not declared.

Table 4. Effect of NST on sport performance.

Authors	Tests	VO_2max/Peak	MAS	Strength	Power Output (Po)	WE	Time Trial (TT)	Time Trial Exhaustion (TTE)	Other Targets (Body Composition, Body Mass, Muscle Fibers, CSA)
				Running					
N. Berryman et al., 2010 [15]	VO_2max, MAV, RE, PP, TT 3 km	=	n.d.	n.d.	↑ PP ** EST	↑ RE: +7% PST +4% ** EST	↑↑ TT 3 km: * EST +4% PST +5% Control +3%	n.d.	=
J. Mikkola et al., 2011 [16]	Body mass, Jump test, 1 RM, EMG, MART, VO_2max, LT, Endurance test	=	↑ MART: +2.6 ± 2.7% * MST	↑ 1 RM Leg Press: +3.6% r MST * EST ** ↑ r EMG activation: +16.2% * MST +9% ** EST ↑ Jump test: +6.1% ** MST	n.d.	↑ Speed at 7 mmol/L LT: +2.6 ± 2.5% * MST	n.d.	n.d.	n.d.
M. Piacentini et al., 2013 [17]	1RM, SJ, CMJ, Stiffness, RPE, VO_2, RE, Anthropometric	n.d.	n.d.	↑ 1 RM: +17% * MST ↑ Stiffness: +13% * RST	n.d.	↑ RE: (marathon pace) +6.17% * MST	n.d.	n.d.	=
S. Sedano et al., 2013 [18]	CMJ, Hopping test, 1RM, RE, VO_2max, HRmax, Peak, RPE, TT 3 km	=	n.d.	↑ CMJ: +9.1% *** ↑ Hopping test: +3.7% *** PST	↑ Peak Velocity: +4.4% *** MST	↑ RE: VO_2 16 km/h * PST	↑↑ TT 3 km PST **	n.d.	↓ RPE: MST ***
R. Ramirez-Campillo et al., 2014 [19]	CMJ, DJ, 20 m sprint, TT 2.4 km	n.d.	n.d.	↑ CMJ: +8.9% ↑ DJ 20 cm: +12.7% r ↑ DJ 40 cm: (r = −0.82) +16.7% ***	n.d.	↑↑ r 20 m sprint test: +2.3% **	r ↑↑ TT 2.4 km: +3.9% ** ↑↑ r 20 m sprint test: +2.3% **	n.d.	↑ BMI: **

Table 4. *Cont.*

Authors	Tests	VO_2max/Peak	MAS	Strength	Power Output (Po)	WE	Time Trial (TT)	Time Trial Exhaustion (TTE)	Other Targets (Body Composition, Body Mass, Muscle Fibers, CSA)
O. Vikmoen et al., 2016 [20]	Muscle sample, 1RM one leg press and half squat, VO_2max, SJ, CMJ, TT 40′ all out	=	n.d.	↑ 1RM 40%: ** SJ and CMJ: +8.9% and +5.9% *	n.d.	=	=	n.d.	↑ CSA: vastus lateralis **
				Cycling					
B. R. Rønnestad et al., 2010 [21]	Thigh muscle CSA, Isometric (ISO) Half Squat, Cycling incremental test, Wingate Test, TT 40′ all out	=	n.d.	↑ ISO Half squat: +21.2 ± 4.9% **	↑ W max: +4.3 ± 1.1% * ↑ Wmax at 2mmol/L: +3.6% * ↑ r Wingate test: +9.4 ± 2.9%**	=	↑↑ TT 40-min all out trial: +6.0 ± 1.7% **	n.d.	↑ rr Lean Body mass: +1 ± 0.5% ** ↑ r Thigh muscle knee extensors CSA: +4.6 ± 0.5% ** (r = 0.47)
A. Sunde et al., 2010 [22]	1RM Squat Smith Machine, RFD, WE 70% VO_2max, TTE, VO_2max, LT	=	n.d.	↑ 1RM squat: +14.2% ↑ r RFD squat: +16.2% *	↑ Pm at VO_2max 70%: +6.9% *	↑ r WE: (70%VO_2max) +4.7% (r = 0.58) *	n.d.	↑ r TTE: +17.2% (r = 0.64) *	=
P. Aagaard et al., 2011 [23]	MCV Leg Extension Isometric, RFD, TT 45 min	=	n.d.	↑ MCV Isom: +12% * ↑ RFD: +20% **	n.d.	=	↑↑ TT 45 min: +8% *	n.d.	↑ Type IIA fibers 26–34% * ↓ Type IIX 0.5–0.6% *
B. R. Rønnestad et al., 2011 [24]	1RM Half Squat, Cycling incremental test, TT 5 min all out trial after 185 min at 44% of Wmax, RPE	↓ VO_2max during 185 min: −2.2 ± 0.6% *	n.d.	↑ r 1RM Half squat: +26% **	↑ r Pm at TT 5 min all out: +7.2 % ± 2 **	↓ VO_2max during 185 min: -2.2 ± 0.6% *	↑ r Pm at TT 5 min all out: +7.2% ± 2 **	n.d.	↑ Lean Body mass: +1.2% * ↓ RPE: *

Table 4. *Cont.*

Authors	Tests	VO_2max/Peak	MAS	Strength	Power Output (Po)	WE	Time Trial (TT)	Time Trial Exhaustion (TTE)	Other Targets (Body Composition, Body Mass, Muscle Fibers, CSA)
E. A. Hansen et al., 2012 [25]	1RM Half Squat, Cycling incremental test, 5 min all out trial after 185 min at 44% of W max, Crank torque	=	n.d.	↑ 1RM Half squat: +18.9% ***	↑↑ ^{r} Pm TT 5 min all out: +7 % **	↑ ^{r} Peak positive crank torque: +3% ** ↓ Peak negative crank torque	↑↑ ^{r} Pm TT 5 min all out: +6.8% **	n.d.	=
B. R. Rønnestad et al., 2014 [26]	FFM, PP-40 min, VO_2max, WE, PP, PP-30″ (Wingate test), PP 4mmol/L	=	n.d.	↑ ISO half squat: +20% ±12 **	↑ ^{r} W max: +3% ± 3 * (r = 0.69) ↑ ^{rr} Pm 4mmol/L: +3.2% ± 3.5 * ↑ ^{r} Pm TT 40 min: +6.5% ± 5.7 **	↑ Peak torque in pedal stroke: * ^{r}(r = −0.63) ^{rr} (r = −0.50)	↑ ^{r} Pm TT 40 min: ±6.5% ± 5.7 **	n.d.	↑ Lean body mass: +2% ± 1*
O. Vikmoen et al., 2015 [27]	Thigh muscle CSA, 1RM Half Squat, Cycling incremental test, Wingate, TT 40′ all out	=	n.d.	↑ 1RM Leg Press: +38.6 ± 19.0% **	↑ PP Wingate test: +12.7 ± 12.6% ** ↑ Pm Wingate test: +3.4 ± 4.3% * ↑ ^{rr} TT 40-min all-out Pm output: +6.4 ± 7.9% ** ^{r} (r = 0.67)	= (testo)	↑ ^{rr} TT 40-min all-out Pm output: +6.4 ± 7.9% ** ^{r} (r = 0.67)	n.d.	↑ ^{r} (r = 0.59) ↑ ^{rr} CSA of m. Quadriceps Femoris: +7.4 ± 5.3% ** (r = 0.73) ↑ ^{rr} Type IIA Fibers 39–50% ** (r = 0.63)
B. R. Rønnestad et al., 2017 [28]	Lower body mass, SJ, 1RM Half Squat, Cycling incremental test, Wingate, TT 40′ all out	=	n.d.	↑ Isom Half Squat: +20% *** ↑ SJ: +8% **	↑ Pm Wingate test: +2 ± 3% *	=	=	n.d.	=

Table 4. *Cont.*

Authors	Tests	VO_2max/Peak	MAS	Strength	Power Output (Po)	WE	Time Trial (TT)	Time Trial Exhaustion (TTE)	Other Targets (Body Composition, Body Mass, Muscle Fibers, CSA)
				Triathlon					
C. Hausswirth et al., 2009 [29]	1RM Leg Press, MCV Leg Extension Isometric after 2 h bike test. BIKE: VO_2max, MAV	=	n.d.	↑ 1RM Leg Press: +6.6% **	n.d.	=	n.d.	n.d.	n.d.

Table 4. *Cont.*

Authors	Tests	VO_2max/Peak	MAS	Strength	Power Output (Po)	WE	Time Trial (TT)	Time Trial Exhaustion (TTE)	Other Targets (Body Composition, Body Mass, Muscle Fibers, CSA)
O. Vikmoen et al., 2017 [30]	VO_2max, 1RM Half Squat, Pm 5 min all out	=	n.d.	↑ 1RM Half squat: +45% **	↑ Pm Bike 5 min all out: +7 ± 4.5% * ↑ Pm Run 5 min all out: +4.7 ± 6% *	↑ Pm Bike 5 min all out: +7 ± 4.5% * ↑ Pm Run 5 min all out: +4.7 ± 6% *	n.d.	n.d.	↑ Lean Body mass: +3.1% *
				Cross Country Skiing					
T. Losnegard et al., 2011 [31]	1RM Half Squat + Seat pull down, CMJ, VO_2max, TT 5 min double poling	↑ VO_2max on skate-roller skiing performance test: +7 ± 1% **	n.d.	↑ 1RM Half Squat: +12% ↑ Pull down: +19% **	↑ Pm +5 min double poling *	↑ 5 min Double poling: +7.4% ± 2.6 *	↑↑ Upper body 1.1 km TT: +7% ± 1 *	n.d.	↑ CSA triceps: +5.5% **

General notes, abbreviations and their definitions: Authors reference, test applied, results on aerobic parameters (VO_2max or peak and MAS), results on strength, results on power output "Po" (power mean "Pm", peak power "PP"), results on work economy (WE), results on endurance performance (TT and TTE), results on Other targets (rating perception exertion "RPE", body composition, body mass, fibers composition, cross-sectional area "CSA", fat-free mass "FFM"). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; =: no change; r: "r" Pearson correlation; RM: repetition maximal; EMG: electromyography; CMJ: counter movement jump; SJ: squat jump; DJ: drop jump; MART: maximal aerobic resistance test; MAS: maximal aerobic speed; MCV: maximal contraction voluntary; RFD: rate of force development; MAV: maximal aerobic velocity; W: watt; ↑: increase value; ↓: decrease value; ↑↑: improvement test; ↓↓: worsening test; n.d.: not declared.

WE, TE and TTE were considered the main parameters associated to the endurance performance and therefore, they were used in meta-analysis and forest plots construction.

3.3. Aerobic Capacity and Work Economy

The aerobic capacity was evaluated by VO_2max/peak or maximal aerobic speed (MAS). Two studies showed an increase of aerobic capacity [16,31] and one a decrease [24], whereas the others did not report a direct improvement in VO_2max or MAS. In general, the VO_2max or aerobic capacity parameters were not correlated to the improvement in WE. Of note, almost all studies assessed the increase of WE after NST (Table 4). Those studying running showed a significant increase of running economy (RE) (7%) [13] or speed (from 2.3% to 6.17%) [16–19,30], as well as in studies on cycling was reported a significant increase of cycling economy (CE) (4.7%) [22] or VO_2 value consumed during cycling test (−2.2%) [24] or speed at specific power outputs [30]. Similarly, the study on cross-country skiing showed a significant increase of double poling economy (+7.4%) [31]. By contrast, seven studies instead did not report any change on WE [20,21,23,27–29]. Because WE represent one of the major parameters associated to endurance performance, we considered its modulation in response to each type of NST in the different sport disciplines, as detailed below.

3.3.1. Maximal Strength Training (MST)

The running studies using a MST protocol showed an increase in maximal strength ability, assessed by 1RM test, correlated to the improvement in the work economy in running (running economy—RE, measured as running speed (speed at 7 mmol/L + 2.6%, $p = 0.049$ [16]), or as running pace race (marathon pace +6.17%, $p < 0.05$ [17]) or as performance on "5′ min all-out" in the triathlon study (+4.7%, $p < 0.05$ [30]). In the cycling studies four studies did not report the results or changing about work economy (cycling economy—CE) [21,23,27,28], while the others were in agreement with the running studies, as they showed an improvement in CE after MST, evaluated as percentage of VO_2 expression, correlated to the gain in RFD Squat test (70% of VO_2max +4.7%, $p < 0.05$, r = 0.58 [23]), or as peak torque pedal stroke ($p = 0.007$ [25,26]) or as performance on "5′ min all-out" (+7%, $p < 0.05$ [30] in the triathlon study), or evaluated as VO_2 during the test, correlated to the gain in the 1RM half squat test (VO_2 during cycling test −2.2%, $p < 0.05$ [24]). According to data from running or cycling studies, also in the cross-country skiing study [31] MST increased WE, measured with 5 min of double poling test (+7.4%, $p < 0.05$) (cf. with Figure 2). However, even if MST positively affected WE in all the sports considered, it was also associated with an increase of both strength ability, as expected, and muscles' cross-section area (CSA) in running [20], cycling [21,24,26,30] and cross-country skiing [31], as detailed in Table 4.

3.3.2. Explosive Strength Training (EST)

The EST in running studies [15,16] did not show a substantial improvement in RE. Indeed, by using EMG, Mikkola and coworkers [16] demonstrated that explosive performance was higher in athletes trained for maximal strength (see study groups in Tables 3 and 4) than explosive strength.

3.3.3. Plyometric Strength Training (PST)

The studies using the PST protocols showed an increase in RE (+7%, $p < 0.01$ [15]), also measured as running speed (VO_2 at 16 km/h [18]) or sprinting performance correlated to the gain in DJ 40 cm test (20 m sprint test +2.3%, $p < 0.01$ [19]), as demonstrated with specific tests such as CMJ, DJ, hopping test and EMG (CMJ +9.1% $p = 0.001$ and hopping test +3.7%, $p = 0.007$ [18]; CMJ +8.9% and DJ +12.7 to 16.7%, $p < 0.001$ [19]). The positive effect of PST in running was higher than other tested NST, especially when compared to EST [15] (cf. with Figure 2).

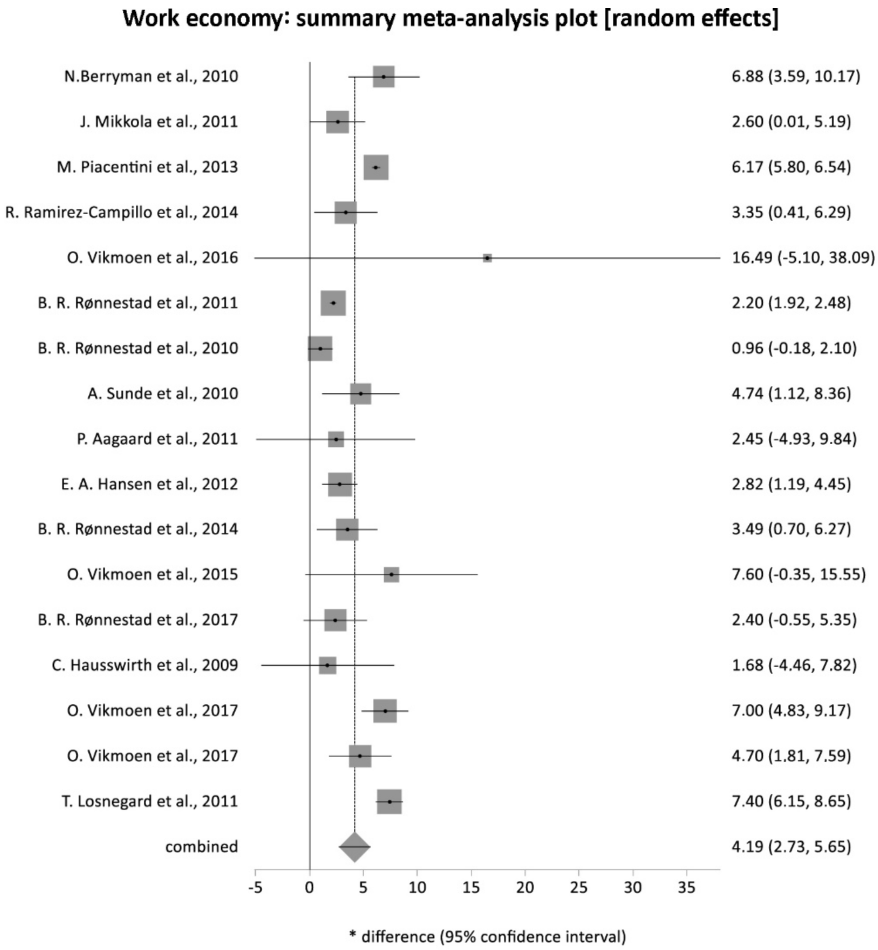

Figure 2. Forest plot of the studies included in the meta-analysis for work economy: forest plot with effects size and 95% confidence interval of every study included in the statistical analysis and combined effect size, representing the effect of intervention protocol (non-sport-specific strength training) on the economy of gesture (work economy). Cochran Q = 352.5 (df = 16) $p < 0.0001$; moment-based estimate of between studies variance = 6.6; I2 (inconsistency) = 95.5% (95% CI = 94.3% to 96.3%); random effects (Der Simonian–Laird); Pooled * difference = 4.19 (95% CI = 2.7 to 5.6); Z (test * Difference) = 5.6$p < 0.0001$.

3.3.4. Resistance Strength Training (RST)

The RST was limited to running and always combined to other kind of strength training. Piacentini and colleagues [17] applied a protocol of RST and MST, whereas Sedano and colleagues [18] (data not shown in the meta-analysis) associated RST to PST, obtaining in both conditions an amelioration of the RE. The results on the effect of NST on our primary outcome (economy of gesture, assessed as WE) are detailed and summarized in Figure 2.

3.4. Endurance Performance Tests

The endurance performance was assessed by three main tests (time trial—TT, time trial to exhaustion—TTE and power output—Po), as described above, and detailed below and summarized in Figure 3. Ten studies out of 17 reported improvements in TT or TTE and Po (Table 4). Different types of NST were able to increase several endurance performance parameters, indeed, TT arose from 3.9% to 8% [15,18,19,21,23–27,31] and TTE ameliorated about 17.2% [22]. Power peak (PP) expressed during the Wingate test increased from 3% to 12.7% [15,18,21,26,27] and power mean (Pm) expressed during TT test increased from 3.4% to 8% [22,24,26–31].

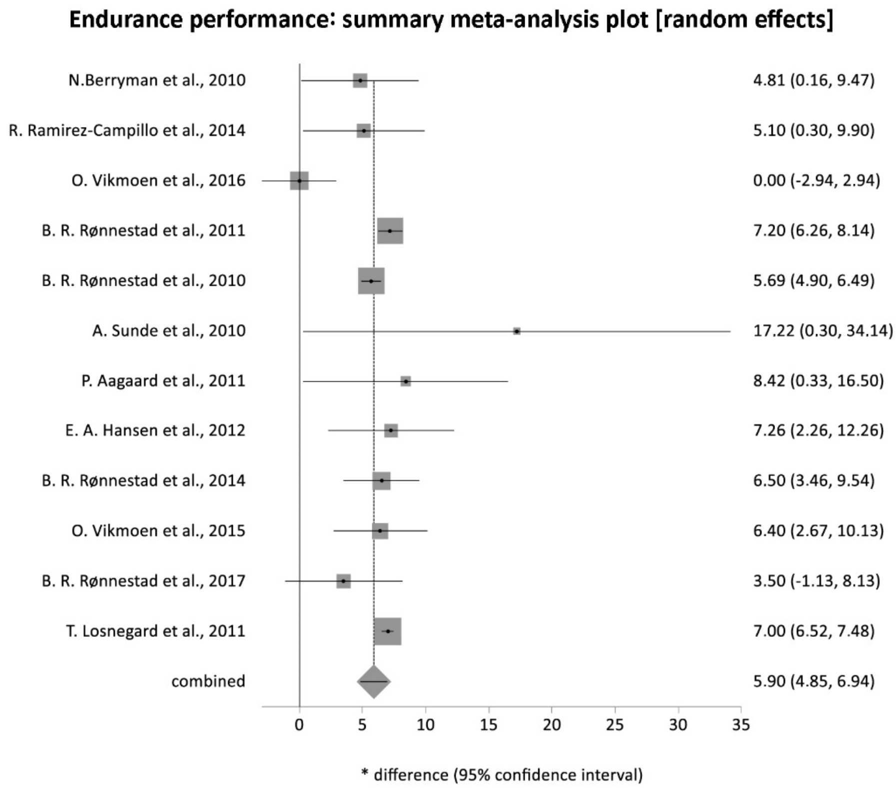

Figure 3. Forest plot of the studies included in the meta-analysis for endurance performance: forest plot with effects size and 95% confidence interval of every study included in the statistical analysis and combined effect size, representing the effect of the intervention protocol (nonspecific strength training) on the endurance performance (time trial or time trial to exhaustion). Cochran Q = 33.1 (df = 11) $p = 0.0005$; moment-based estimate of between studies variance = 1.3; I2 (inconsistency) = 66.7% (95% CI = 28.1% to 80.4%); random effects (Der Simonian–Laird) pooled * difference = 5.9 (95% CI = 4.8 to 6.9); Z (test * difference) = 11 $p < 0.0001$.

As reported about WE, the results from endurance performance tests were analyzed in response to each type of NST in the different sport disciplines, as detailed below.

MST: Among running studies, only Vikmoen et al. (2016) [20] assessed MST alone, namely without any comparisons with other types of NST, but the authors did not report any significant improvement, whereas in cycling studies, MST improved both TT or TTE in almost all studies (Figure 3), as well as the Po test. The higher strength expression (1RM test) was correlated to the improvement in the TT "5 min all-out" (+7.2%, $p < 0.01$ [24]; +7%, $p = 0.007$ [25]) and in the "45 min TT" (+8%, $p < 0.05$ [23]) as well as the increased strength (RFD +16.2%) was associated to TTE amelioration (+17.2%, r = 0.64 [22]). Accordingly, the cycling-specific strength expression (peak pedal torque) was related to the increase in Po efficacy, measured with the specific Wingate test [26] but also in the Pm expression during TT test [25].

In agreement with the cycling studies, cross-country skiing study reported a gain in maximal strength that consequently led to an improvement in TT performance (upper body 1.1 km TT +7%, $p < 0.05$ [31]).

As described above, MST led to an increase in CSA (muscles knee extensor +4.6%, $p < 0.01$ [24] and muscle Quadriceps Femoris +7.4%, $p = 0.0004$ [27]) and the switch of muscle type fibers from IIx to IIa (Type IIa +39–50%, $p = 0.002$ [27]; Type IIa +26–34%, $p < 0.05$ [23]) were correlated to an improvement of power (Wingate test +9.4%, $p < 0.01$, r = 0.47 [21]; TT Power mean +6.4%, $p = 0.002$, r = 0.63 fibers, r = 0.73 CSA [27]) and strength (maximal contraction voluntary—MCV, +12%, $p < 0.05$ [24]).

PST, EST and RST. PST could be also associated to different kinds of strength training. Indeed, it was considered as the principal protocol [19] or it was compared to EST [15] or to both RST and endurance training [18]. In both cases PST reported positive results on TT and TTE performance in the running studies, leading to an improvement in endurance performance [15,18,19]. Indeed, in the study of Ramirez-Campillo and colleagues [19] the improvement in the TT was correlated to the reduction in time spent in both 2.4 km and 20 m sprint performance tests.

4. Discussion

The purpose of this systematic review and meta-analysis was to understand whether different non sport-specific strength training, namely strength exercises that do not recall the sport-specific movements, could be related to best performances in specific endurance sports (running, cycling, triathlon and cross-country skiing).

In general, the aerobic parameters (VO_2max or MAS) did not change from pre- to post-intervention, while the endurance performance increased. The gain in endurance performance, therefore, could only be linked to mechanical factors and these—as expected—were different in the different sports. In agreement with these findings, Authors [32,33] showed that aerobic capacity was not inhibited by concurrent training (endurance and strength training). Rather, a better neuromuscular coordination delaying the onset of fatigue after strength intervention and a skeletal muscles changes in fiber composition might be the mechanism responsible for the increase of aerobic performance [34–36]. Therefore, we looked across literature for the type(s) of non-sport-specific strength training (MST, PST, EST and RST) reported as more efficient in increasing endurance ability, focusing on WE (running economy, cycling economy, double poling economy) (Figure 2) and endurance performance tests (TT, TTE and Po) (Figure 3). Even if different study designs and methodologies could possibly influence the results, the quality of the studies considered was acceptable, considering the PEDro score. In these studies, all NST intervention types impacted on performance (cf. with Figures 2 and 3, positive combined effect size), improving several physiological parameters relevant for endurance athletes. However, considering the aforementioned 4 endurance sports, we found data on the comparison between different types of NST only for running, whereas for the other disciplines only MST was considered. Indeed, maximal strength training is the most studied type of exercise among non-sport-specific strength training across the plentiful literature, while scarce data is available on plyometric, explosive or resistance strength training. Therefore, the data reported in this meta-analysis could help in prompting new studies on endurance sports.

As reported in Figure 2, the work economy was positively affected by MST in general, which in running resulted more efficient than explosive [16] or resistance [17] training. However, when it was compared to plyometric [15] training, MST showed less efficacy in ameliorating running economy. This scarce effect of MST was evident also in cycling, as in all the studies reporting cycling economy values most of those resulted smaller than the overall effect [21,23–26,28]. Therefore, it is reasonable to hypothesize that non-sport-specific strength training other than MST might be considered to improve work economy in cycling. By contrast, when cycling is considered as the component of triathlon discipline, its work economy seems positively affected by MST [30], as well as the running component [30]. Even if only one study on cross-country skiing was included in this meta-analysis, the MST was clearly able to improve work economy [31], suggesting that this type of non-sport-specific strength training might be effective in cross-country skiing athletes.

As shown in Figure 3, the non-sport-specific strength training effects on endurance performance were variable. Among studies on running, only three reported data on endurance performance [15,19,20], considering plyometric or maximal strength training. MST resulted ineffective on endurance performance in running [20] as well as PST. This result of PST in endurance performance in running might be due to the low frequency [15] or time [19] of training protocols (see Table 3).

Significant improvements in endurance performance were obtained by MST in cycling [22–27]; however, the variability of these results reinforces the idea that different types of non-sport-specific strength training might be preferable in this discipline. Unfortunately, the lack of data on endurance performance in the triathlon did not allow us to speculate on running and cycling components.

Summarizing, in running the better non-sport-specific strength training seems to be PST, even if MST could induce some improvements. By contrast, EST might be inappropriate for best performance in running. Although MST was the only non-sport-specific strength training studied in cycling, our analysis suggests that other types of exercises might be more effective. Indeed, as we found in running, we can speculate that PST or other strength trainings might be preferable in cycling. By contrast, for both triathlon and cross-country skiing, MST can be recommended.

In conclusion, the results of our meta-analysis support the hypothesis that appropriate non-sport-specific strength training can optimize performances in specific endurance sport disciplines.

5. Limitations

Only studies on running compared different types of non-sport-specific strength training, and all the other sport disciplines were investigated according to MST exclusively. Only two publications concerned triathlon and just one was focused on cross-country skiing. Therefore, further research is needed to obtain more data for all the types of non-sport-specific strength training included in this review. Some of the studies that matched the items of the PEDro scale, did not report data on the investigated outcomes, therefore they were not included in the meta-analysis, that could be also influenced by different methodologies and assessment tests of the relevant parameters among studies.

6. Perspective

Although the literature on NST is increasing, the idea of looking at NST in terms of sport-specificity is innovative. Consequently, to the best of our knowledge this is the first meta-analysis assessing which type of NST is more efficient to achieve a better performance in endurance sports. Our findings indicate that MST is the most studied type of NST applied to endurance sports, even if it may not be the best. Indeed, for instance, best running performances were obtained by PST. Therefore, it is more than plausible that future optimal matching of NST with sport disciplines will boost athletic performance. These results are of primary importance for coaches focused on planning the best training programs for elite endurance athletes. Our approach, however, also highlights how additional studies are necessary to reach a full understanding of this topic in view of its relevant practical applications.

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Conflicts of Interest: The authors declare no conflict of interest.

Glossary: Explosive strength—the ability to exert maximal forces in minimal time; maximum strength—the maximum force a muscle can exert in a single maximal voluntary contraction; plyometric strength—the explosive movements in which a concentric muscle action is enhanced by a previous eccentric contraction; resistance strength—the contraction ability against an opposing force.

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