Impacto del Entrenamiento de Sprint Resistente en Diferentes Distancias: Revisión Sistemática y Meta-Análisis

Resisted Sprint Training Impact on Sprint across Distances: A Systematic Review and Meta-Analysis

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Abstract

Introduction: Sprint performance is a critical component in many sports, and Resisted Sprint Training (RST) is widely used to enhance acceleration and speed. However, the effectiveness of different RST protocols across various sprint distances remains unclear.
Objective: This systematic review and meta-analysis aimed to evaluate the impact of RST using sleds and load vests on sprint performance over 5, 10, 20, and 30-meter distances. Methodology: The study followed PRISMA guidelines, conducting a comprehensive literature search across 16 electronic databases (e.g., PubMed, Web of Science) in April 2023. Search terms included "sled sprint training," "resisted sprint training," and "heavy sled training." Inclusion criteria targeted randomized clinical trials with pre-post intervention protocols lasting at least four weeks, focusing on both athletes and non-athletes in field, court, and track sports. Studies using elastics or parachutes, or those lacking load or timing data, were excluded. From 311 articles identified, 8 met the inclusion criteria.
Results: The meta-analysis revealed significant improvements in sprint performance, particularly in protocols utilizing sleds, horizontal force application, and load prescriptions of 7.5%-15% of body weight. Performance enhancements were observed across 5-meter and 30-meter distances, with maturational stage playing a role in younger athletes' responses. Discussion: The findings align with previous research emphasizing the benefits of horizontal resistance and optimal load application in sprint training. However, gaps remain in standardizing load classifications and comparing sled versus vest-based protocols. Conclusions: RST interventions can effectively improve sprint performance, but individualized load prescriptions and training adaptations are essential.

Keywords

Athletic Performance; Biomechanics; Exercise Physiology; Resistance Training; Sports Training.

Resumen

Introducción: El rendimiento en sprint es un componente crítico en muchos deportes, y el Entrenamiento de Sprint Resistente (RST) se utiliza ampliamente para mejorar la aceleración y la velocidad. Sin embargo, la efectividad de diferentes protocolos de RST en varias distancias de sprint sigue sin estar clara. Objetivo: Esta revisión sistemática y meta-análisis tuvo como objetivo evaluar el impacto del RST con el uso de trineos y chalecos lastrados en el rendimiento del sprint en distancias de 5, 10, 20 y 30 metros.
Metodología: El estudio siguió las directrices PRISMA, realizando una búsqueda exhaustiva de literatura en 16 bases de datos electrónicas (por ejemplo, PubMed, Web of Science) en abril de 2023. Los términos de búsqueda incluyeron "entrenamiento de sprint con trineo", "entrenamiento de sprint resistido" y "entrenamiento con trineo pesado". Los criterios de inclusión se centraron en ensayos clínicos aleatorizados con protocolos de intervención pre-post de al menos cuatro semanas, dirigidos tanto a atletas como a no atletas en deportes de campo, cancha y pista. Se excluyeron estudios que utilizaran elásticos o paracaídas, o aquellos que carecieran de datos detallados sobre carga o tiempo. De los 311 artículos identificados, 8 cumplieron con los criterios de inclusión.
Resultados: El meta-análisis reveló mejoras significativas en el rendimiento del sprint, particularmente en protocolos que empleaban trineos, aplicación de fuerza horizontal y prescripciones de carga entre el 7.5% y el 15% del peso corporal. Se observaron mejoras en el sprint en distancias de 5 y 30 metros, con una influencia del estado madurativo en la respuesta de los atletas más jóvenes.
Discusión: Los hallazgos coinciden con investigaciones previas que destacan los beneficios de la resistencia horizontal y la aplicación óptima de carga en el entrenamiento de velocidad. No obstante, persisten brechas en la estandarización de la clasificación de cargas y en la comparación entre protocolos basados en trineos y chalecos lastrados.
Conclusiones: Las intervenciones de RST pueden mejorar eficazmente el rendimiento en sprint, pero es esencial una prescripción individualizada de cargas y adaptaciones del entrenamiento.

Palabras clave

Biomecánica; Entrenamiento de resistencia; Entrenamiento deportivo; Fisiología del ejercicio; Rendimiento atlético.

Introduction

Proficient physical preparation, encompassing both anaerobic and aerobic attributes, holds pivotal significance in the realm of sports engagement. Athletes exhibiting heightened power generation and the capacity to exert substantial force at remarkable velocities tend to excel in explosive undertakings (Carlos-Vivas et al., 2020; Maciejczyk et al., 2021; Pareja-Blanco et al., 2019). The domains of both field sports and track and field sports demand a fusion of high- and low-intensity maneuvers, featuring intermittent surges of high intensity and the ability to execute successive bursts of speed. These elements stand as decisive determinants for elevated sports performance (Gonçalves et al., 2021; González-Fernández et al., 2022; Ulupınar et al., 2021). Sports typified by intermittent attributes stand to gain from enhancements in sprint performance.

Particularized training modalities such as "resisted sprint training" (RST) have the potential to confer advantages to athletes by augmenting linear velocity during competitive bouts (Borges et al., 2016), along with rapid changes in direction executed at elevated speeds (Rodríguez-Osorio et al., 2019). The practice of RST, known as "Resisted Sled Sprint Training," entails the incorporation of resistance through the utilization of sleds, apparatuses designed to furnish horizontal opposition during sprint workouts. The primary goal of this method resides in imposing overload to cultivate neuromuscular capabilities that foster horizontal displacement, ultimately ameliorating velocity, strength, and power in this specific direction (Cahill et al., 2020; Luteberget et al., 2015).

Various iterations of RST exist; the sprints can be performed by pulling the load with the assistance of harnesses or by pushing the designated load. Essential considerations encompass the friction generated by the equipment deployed and the variance in running kinetics, as the mechanics of the motion differ contingent upon whether the athlete is dragging or pushing the resistance, as well as the magnitude of the load employed (Cahill et al., 2020; Fitzpatrick et al., 2019; Luteberget et al., 2015).

Literature reveals disparities concerning the threshold of load deemed as heavy (ranging from 20% to 80% of body weight) for prescribing TSR (Lahti et al., 2020; Rodríguez-Osorio et al., 2019). There appears to be a consensus in the literature that lighter and moderately heavy loads correspond with heightened maximum speed, whereas heavier loads correlate with enhanced acceleration (Morris et al., 2021; Rodríguez-Osorio et al., 2019). Excessive load imposition can give rise to mechanical disadvantages during training sessions, exemplified by undue trunk flexion (Lahti et al., 2020). Conversely, training loads proximal to 12.5% of body weight facilitate the maintenance of sprint kinetics in a favorable manner (Luteberget et al., 2015). Consequently, the mechanics of RST prescription ought not to exclusively hinge on the percentage of body weight; incorporating decay speed as a metric for training prescription to attain an optimal equilibrium between load, power, speed, and sustenance of sprint biomechanics appears to be a viable approach (Cahill et al., 2020; Sinclair et al., 2021).

In addition to "sleds," alternative equipment exhibiting analogous mechanics for RST implementation are documented, including elastic bands, parachutes, and load-bearing vests (Cronin et al., 2008; Gil et al., 2018; Hicks et al., 2023; Moya-Ramon et al., 2020; Rodríguez-Osorio et al., 2019). However, this study concentrates on articles pertaining to sleds and load vests. Consequently, the principal aim of this research is to comprehensively survey literature concerning training categorized as RST involving sleds and load vests. This investigation focuses on athletes, whether professional or not, engaged in field, court, and track and field pursuits. The overarching objective is to elucidate the relationship between the four-week duration of the targeted protocol and its ensuing impact on sprint performance.

Method

Study Design

The systematic review adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) model, a recognized framework for comprehensive review synthesis (Page et al., 2021). This article has been registered in PROSPERO under the number CRD42025648467. The scope of this review encompassed original articles emanating from randomized clinical trials, featuring pre-post-intervention protocols, and disseminated within scholarly journals listed in electronic databases. The focal point of the evaluation was training regimens centered around Resisted Sprint Training (RST), characterized by a minimum intervention duration of four weeks. This inquiry concentrated on the impact of RST on the enhancement of linear velocity performance during sprints, specifically targeting individuals engaged in field, court, and track and field disciplines. Inclusive criteria necessitated articles to be in English and include data derived from linear velocity tests conducted over sprint distances of 5, 10, 20, and 30 meters.

Search Strategies

The pursuit of relevant literature commenced within the electronic repository of "Periodic Capes (BRA)" during the period of April 2023, unhampered by constraints pertaining to publication dates. To formulate a robust query, descriptors, and terminology were sourced from Medical Subject Headings (MeSH) via the U.S. National Library of Medicine (NLM) portal and keywords discerned from prior works known to the authors. The amalgamation of these descriptors and terms, complemented by judicious application of Boolean operators, encompassed the following: "sled sprint training" OR "resisted sprint training" OR "resisted sprint" OR "assisted sprint training" OR "assisted sprint" OR "Heavy Sled Training."

The exploration of pertinent databases transpired within the confines of the electronic platform, and included the following repositories: PubMed; Gale Academic One File; Science Citation Index Expanded (Web of Science); Directory of Open Access Journals; PubMed Central; Ovid Kluwer Journals; Springer Link Journals; Taylor & Francis Journals Complete; Elsevier Science Direct Journals; Auto Holdings Journals; Social Sciences Citation Index (Web of Science); Elsevier Clinical Key Journals; Free E-Journals; Wiley Online Library; Wiley Frozen Package; De Gruyter journals; Highwire Press Free; and Sage Premier Journal Collection. This exhaustive foray into databases enabled a comprehensive survey of available literature within the chosen domain.

Inclusion and Exclusion Criteria

In the process of selecting studies for this review, the following rigorous inclusion and exclusion criteria were applied:

Inclusion Criteria:

- Articles comprising a sample of male and/or female participants.
- Articles authored by individuals with expertise in field, court sports, or "track and field" activities.
- Articles that employed the resisted sprint training (RST) method within their test protocols.
- Articles conducting assessments of sprint performance through measurements of maximum linear velocity.
- Articles published in the English language.
- Exclusion Criteria:
- Articles conducting sprint tests without providing details about the equipment used to record sprint performance timings.
- Articles employing a simple clock to time sprints.
- Articles omitting information on load percentages relative to body weight or percentages for speed decay in the context of target training.
- Articles fail to isolate RST from other training methodologies. If parallel training was prescribed, uniformity across all experimental groups was required; otherwise, the study would be excluded.
- Articles not meeting the minimum intervention duration of four weeks.
- Articles incorporating elastic bands and parachutes as intervention tools.
- Articles lacking tabulated pre-post intervention data in written form.

Assessment of Study Quality

The assessment of study quality and the identification of potential bias were conducted independently by two reviewers (Reviewer 1: B.S., Reviewer 2: A.M.). The TESTEX scale (Tool for the assEssment of Study qualiTy and reporting in EXercise), developed by Smart et al. in 2015, was employed for this purpose. In the event of discordant assessments, a constructive dialogue was initiated to reach a consensus on the final evaluation. The evaluation criteria encompassed study description, internal validity, external validity (bias assessment), and sample power. These criteria were evaluated using a binary scoring system: "1" denoted affirmation, and "0" indicated denial. Studies deemed to exhibit a low risk of bias (scoring equal to or greater than 8) were considered for inclusion in this review.

Data Extraction Approach

Upon acquisition of the selected articles, an organized data extraction process was implemented as follows:

a) Comprehensive profiling of the sample, encompassing key aspects such as age, height, weight, duration of experience within the respective sports modality, intervention duration, specific sports discipline, and sample size.

b) Thorough depiction of the executed protocols and the corresponding groups within the randomized clinical trials. This involved specifying intervention durations and the equipment employed during the testing phase.

c) Compilation of mean values from linear velocity tests, accompanied by standard deviations, both pre- and post-protocol, across all groups.

This data extraction procedure was executed using Microsoft Excel™ (Microsoft Corporation, Santa Rosa, CA, USA) for meticulous organization and tabulation. The gathered data, encompassing mean and standard deviation results of sprint performance, in conjunction with corresponding distances, was methodically arranged to facilitate the subsequent meta-analysis.

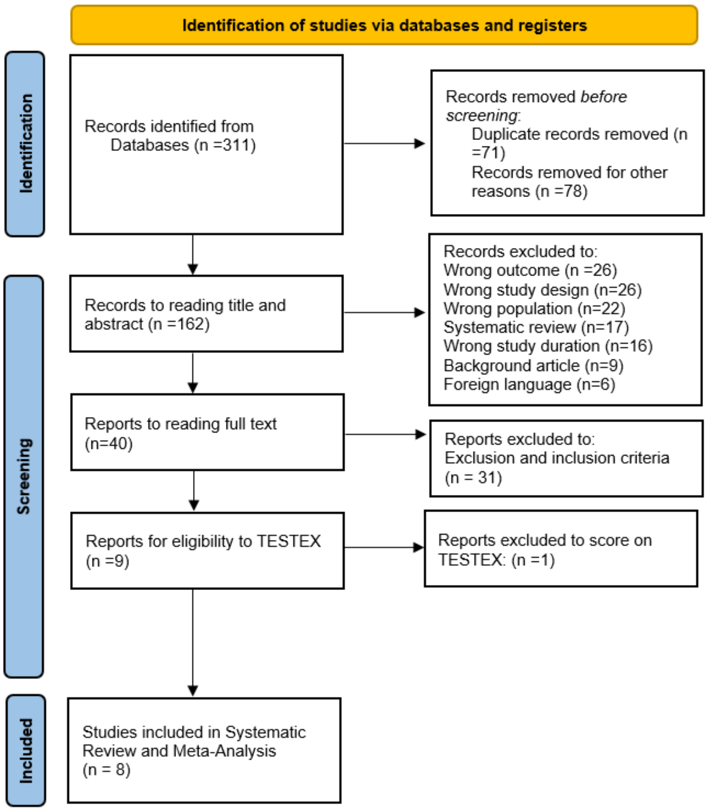
Meta-Analysis Methodology

Following the completion of data extraction, a rigorous statistical analysis was conducted using the Review Manager software, version 5.4.1 (RevMan 5; Cochrane Collaboration, Oxford, United Kingdom). Random effects statistics were employed, with the utilization of the inverse variance for calculating mean difference rates. The effect size (Z) was accompanied by a 95% confidence interval (CI), and a comprehensive assessment of heterogeneity (I^2) was undertaken. The designated significance level for statistical significance (P) was set at <0.05. This meticulous meta-analysis approach enabled a thorough examination of the cumulative data extracted from the various studies under consideration.

Results

The initial search endeavor yielded 311 articles employing the specified keywords and Boolean operators. To streamline the review process, the Rayyan software (a web and mobile app for systematic reviews) was enlisted, following a method devised by Ouzzani et al. (2016). This systematic approach led to the exclusion of 71 duplicate articles and 78 articles that deviated from the thematic focus. This shows the selection of 162 articles for initial screening based on title and abstract. Subsequently, a comprehensive evaluation eliminated 26 articles with inappropriate outcomes, 26 employing incompatible methodologies, 22 involving unsuitable populations, 16 with intervention durations shorter than four weeks, 9 considered as "background" literature, 6 non-English articles, and 17 systematic reviews. The remaining 40 articles were subjected to in-depth scrutiny, leading to the exclusion of 31 articles in alignment with the established inclusion and exclusion criteria. Ultimately, 9 articles qualified for bias assessment using the TESTEX scale (Tool for the assEssment of Study qualiTy and reporting in EXercise) formulated by Smart et al. (2015). Following evaluation, one article was excluded, leaving 8 articles eligible for data extraction and subsequent meta-analysis (refer to Figure 1).

Figure 1. The identification of database pathways and the corresponding phases of the PRISMA Flow Diagram.



For bias assessment, the authors reached a consensus on the assigned scores (detailed in Table 1).

Table 1. Risk of Bias Scoring According to the TESTEX Criteria.

Study	1A	2A	3A	4A	5A	6A	6B	6C	7A	8A	9A	9B	10A	11A	12A	Total
Borges et al. (2016)	1	1	0	1	0	1	1	0	0	1	1	1	0	1	0	10
Morris et al. (2021)	1	0	1	1	0	1	1	1	0	0	1	1	1	1	1	11
Lahti et al. (2020)	1	1	1	1	0	1	0	0	0	1	1	1	1	0	0	11
Sinclair et al. (2021)	1	1	1	1	0	0	1	0	0	1	1	1	1	1	0	10
Rodríguez-Osorio et al. (2019)	1	0	0	1	0	1	0	1	0	1	1	1	1	1	0	12
Cahill et al. (2019)	1	0	1	1	0	0	1	1	0	1	1	1	1	1	0	10
Lutebeget et al. (2015)	1	0	1	0	0	1	0	1	0	1	1	1	1	0	0	9
Spinks et al. (2007)	1	1	1	0	0	1	1	0	0	0	1	1	1	1	0	8
Carlos-Vivas et al. (2020)	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	13

Note. 1) Are the eligibility criteria for participants clearly stated? (2) Was the allocation to groups random? (3) Was the allocation of participants concealed? (4) Were the groups similar at baseline regarding key variables such as demographics or baseline performance measures? (5) Was an intention-to-treat analysis performed? (6) Was blinding conducted for assessors (6a), participants (6b), and trainers or therapists (6c), each earning one point? (7) Was physical activity monitored during the intervention period for both groups? (8) Was exercise attendance during supervised sessions assessed and reported? For Reporting (5 points), the criteria include: (9) Were key outcome measures and their variability (e.g., standard deviation, standard error, or confidence intervals) reported (9a), and were all other outcome measures reported (9b)? (10) Was adherence to the exercise intervention assessed and reported? (11) Were adverse events or reasons for withdrawal from the study reported? (12) Were the details of the exercise program, such as frequency, intensity, time, and type, described with enough clarity for replication? The total score ranges from 0 to 15, with higher scores reflecting better quality and reporting standards in exercise studies.

Articles attaining a score of 8 or above on the TESTEX scale were further considered. These selected articles, which fulfilled the stringent criteria, presented protocols, respective groups undergoing RST training, control groups, or groups employing alternative training methodologies for comparison (detailed in Table 2).

Table 2. Summarized information for each study included in the meta-analysis.

Study	Participants	Intervention	Equipment of running analysis	Outcomes
Borges et al. (2016)	20 male soccer players competing in the São Paulo state championship.	7 sets of sprints with increasing distances (5m, 10m, 20m, 30m). 45-120 seconds rest between sets.	Brower photocell (timing gates, model BR001, Draper, UT, USA)	Resisted sprint induced greater improvements in sprint time than plyometric, amounting to 0–30 m
Cahill et al. (2019)	50 male athletes who practice rugby and lacrosse, characterized by PHV.	1st-4th week: series of sprints (3 per session) at varied speeds (25%, 50%, 75% velocity) over different distances (7.5–22.5 meters) with a 3-minute interval.	Radar device (Model Stalker ATS, Applied Concepts, Dallas, TX, USA)	Improved acceleration and performance consistency under progressive fatigue loads.
Luteberget et al.	18 female semi-professional	10th week: 4 series of 3	Electronic timing (Speed Trap	Increased performance in

(2015)	handball players from a first-division team in Norway.	sprints over 20 meters with 2-minute intervals between sprints and 5 minutes of active recovery. No additional load.	II TC System, Brower)	sprint tests under controlled fatigue conditions.
Carlos-Vivas et al. (2020)	48 male soccer players with previous RST experience, average age of 18 years.	Group URS (n=12) trained with a robotic resistance motion system, following a periodized undulating program. Training included 8 sessions with linear sprints and directional changes, loads varied between 10%, 15%, and 20% body weight.	Microgate's WITTY System (Microgate, Bolzano, Italy)	Linear sprint improvements and adaptations in directional changes. Positive neuromuscular enhancements.
Morris et al. (2021)	73 male soccer players, categorized by maturational stages (pre-PHV, PHV, and post-PHV).	10 sprints (20m each, 90s rest). Sled weight increased every two weeks by 10%, up to 30% body weight.	Brower photocell (timing gates)	There were minimal changes in strength, speed and power for each maturity group across the 6-week intervention
Lahti et al. (2020)	32 professional male rugby players with at least three years of competitive experience.	Performed two 20m sprints at two different intensities. No extra-training intervention.	Stalker ATS radar device	Both heavy resistance subgroups improved significantly all 10–30-m split times. The heavy resisted sled training 50% velocity decrement resistance, improved significantly more compared to CON in 0–10-m split-time and peak power.
Sinclair et al. (2021)	26 male rugby players with minimal three years of competitive experience.	Performed 3x20m sprints with 2 minutes rest. Used a sled at 20% velocity decrement load.	Electronic timing gates (SmartSpeed, Fusion Sport, Australia)	Both groups improved significantly, therewere no statistical differences between the two training methods. Improvements in 505-agility test, and countermovement jump in the sled training group.
Rodriguez-Osorio et al. (2019)	54 male soccer players competing in Spain's third division, with a minimum of six years' playing experience.	3-5 sets of 25m sprints with a 50% bodyweight sled. Direction changes every 5m with a 45° angle.	Microgate photocells (Witty, Bolzano, Italy)	Sprint 10m, and sprint 20m were substantially enhanced in direction changes with 50% of body weight

Notes: *PHV*: Peak Height Velocity (used to determine maturational stages in youth athletes); Sprint protocols are adjusted according to study groups, with specific equipment and methodologies for assessing motor performance; Missing data or absence of specific interventions for Groups 3 and 4 are noted as "None."

The evaluation of the 5-meter sprint performance drew upon 4 articles encompassing a total of 81 evaluations, manifesting uniformity in terms of heterogeneity. Statistical analysis revealed a statistically significant positive difference in performance improvement for the 5-meter sprints post-intervention: Z = 4.65 (P < 0.00001), as indicated in Figure 2 and Figure 3.

Figure 2. Forest plot of 5-meter sprint performance comparing RST training versus the control group.

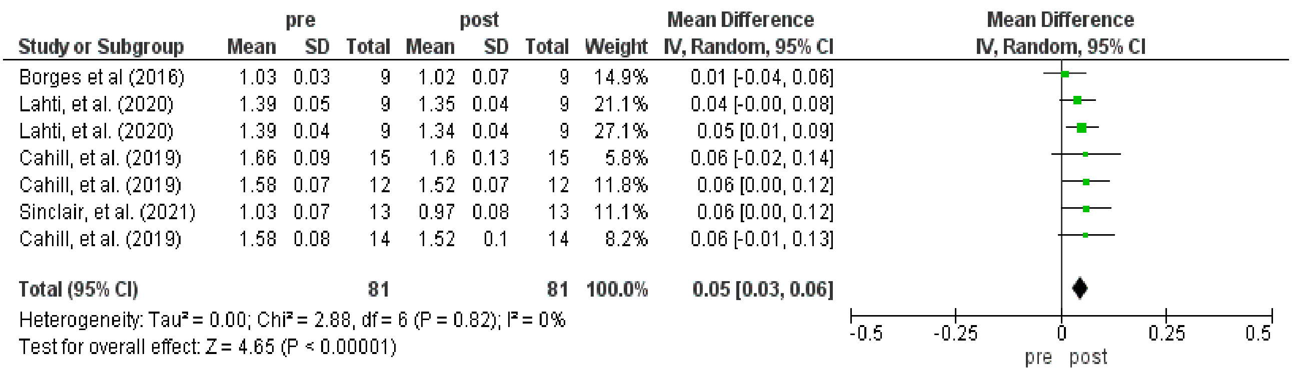
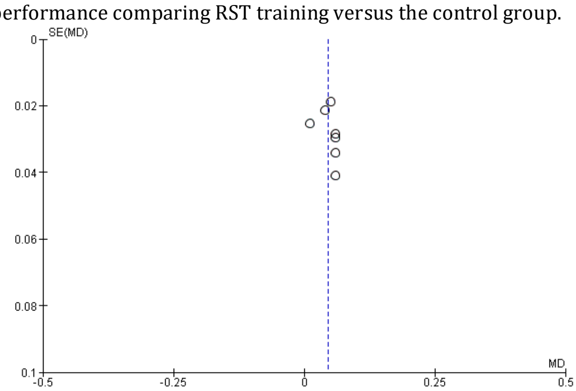


Figure 3. Funil plot of 5-meter sprint performance comparing RST training versus the control group.



In the case of the 10-meter sprint performance, a pool of 7 articles involving a total of 228 evaluations was analyzed. Although the assessment of heterogeneity indicated variations among studies, the effect size pointed to a statistically significant positive difference in the improvement of 10-meter sprint performance post-intervention: Z = 4.60 (P < 0.00001), showcased in Figure 4 and Figure 5.

Figure 4. Forest plot of 10-meter sprint performance comparing RST training versus the control group.

	pre			post				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Rodriguez-Osorio, et al (2019)	3.15	0.12	19	3.1	0.13	19	18.3%	0.05 [-0.03, 0.13]
Rodriguez-Osorio, et al (2019)	3.13	0.22	19	3.08	0.18	19	7.1%	0.05 [-0.08, 0.18]
Sinclair, et al. (2021)	3.01	0.1	13	2.94	0.11	13	17.7%	0.07 [-0.01, 0.15]
Cahill, et al. (2019)	3.76	0.23	14	3.68	0.19	14	4.7%	0.08 [-0.08, 0.24]
Cahill, et al. (2019)	3.88	0.21	15	3.79	0.23	15	4.7%	0.09 [-0.07, 0.25]
Lahti, et al. (2020)	3.45	0.12	9	3.36	0.1	9	11.1%	0.09 [-0.01, 0.19]
Cahill, et al. (2019)	3.76	0.1	12	3.65	0.09	12	20.0%	0.11 [0.03, 0.19]
Lahti, et al. (2020)	3.43	0.08	9	3.32	0.1	9	16.5%	0.11 [0.03, 0.19]
Total (95% CI)			**110**			**110**	**100.0%**	**0.08 [0.05, 0.12]**

Heterogeneity: Tau² = 0.00; Chi² = 1.93, df = 7 (P = 0.96); I² = 0%
Test for overall effect: Z = 4.79 (P < 0.00001)

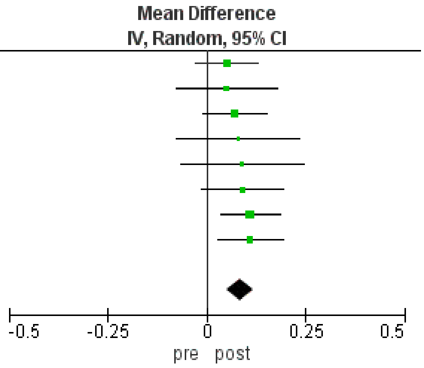
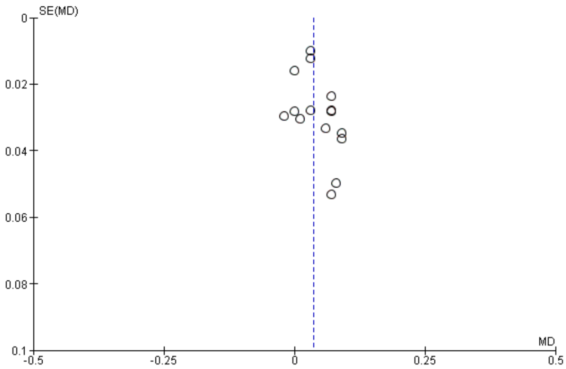
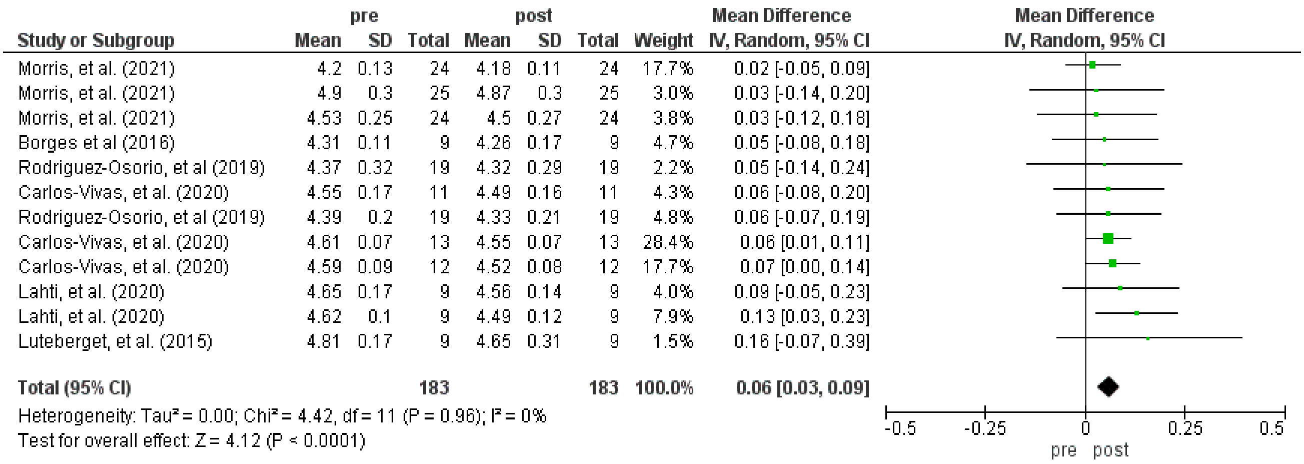


Figure 5. Funil plot of 10-meter sprint performance comparing RST training versus the control group.



Moving to the 20-meter sprint performance, 4 articles accounting for 110 evaluations exhibited consistency in heterogeneity. Similar to previous analyses, the effect size underscored a statistically significant positive difference in 20-meter sprint performance improvement post-intervention: Z = 4.79 (P < 0.00001), elucidated in Figure 6 and Figure 7.

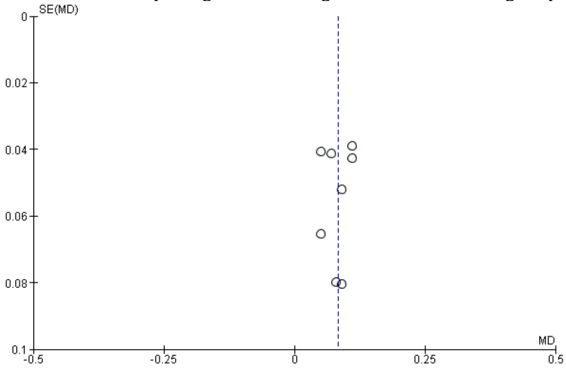
Figure 6. Forest plot of 20-meter sprint performance comparing RST training versus the control group.



Study or Subgroup	pre Mean	pre SD	pre Total	post Mean	post SD	post Total	Weight	Mean Difference IV, Random, 95% CI
Morris, et al. (2021)	4.2	0.13	24	4.18	0.11	24	17.7%	0.02 [-0.05, 0.09]
Morris, et al. (2021)	4.9	0.3	25	4.87	0.3	25	3.0%	0.03 [-0.14, 0.20]
Morris, et al. (2021)	4.53	0.25	24	4.5	0.27	24	3.8%	0.03 [-0.12, 0.18]
Borges et al (2016)	4.31	0.11	9	4.26	0.17	9	4.7%	0.05 [-0.08, 0.18]
Rodriguez-Osorio, et al (2019)	4.37	0.32	19	4.32	0.29	19	2.2%	0.05 [-0.14, 0.24]
Carlos-Vivas, et al. (2020)	4.55	0.17	11	4.49	0.16	11	4.3%	0.06 [-0.08, 0.20]
Rodriguez-Osorio, et al (2019)	4.39	0.2	19	4.33	0.21	19	4.8%	0.06 [-0.07, 0.19]
Carlos-Vivas, et al. (2020)	4.61	0.07	13	4.55	0.07	13	28.4%	0.06 [0.01, 0.11]
Carlos-Vivas, et al. (2020)	4.59	0.09	12	4.52	0.08	12	17.7%	0.07 [0.00, 0.14]
Lahti, et al. (2020)	4.65	0.17	9	4.56	0.14	9	4.0%	0.09 [-0.05, 0.23]
Lahti, et al. (2020)	4.62	0.1	9	4.49	0.12	9	7.9%	0.13 [0.03, 0.23]
Luteberget, et al. (2015)	4.81	0.17	9	4.65	0.31	9	1.5%	0.16 [-0.07, 0.39]
Total (95% CI)			**183**			**183**	**100.0%**	**0.06 [0.03, 0.09]**

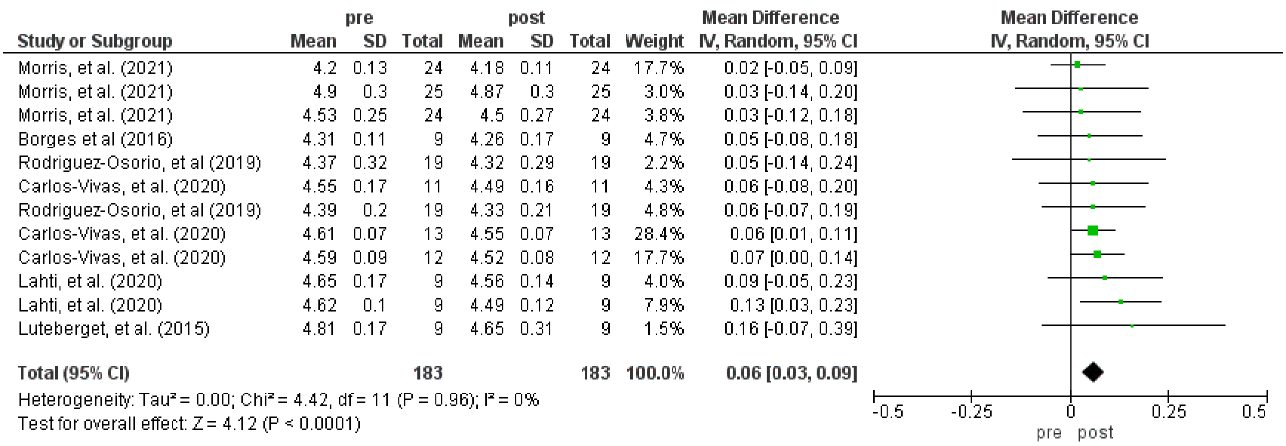
Heterogeneity: Tau² = 0.00; Chi² = 4.42, df = 11 (P = 0.96); I² = 0%
Test for overall effect: Z = 4.12 (P < 0.0001)

Figure 7. Funil plot of 20-meter sprint performance comparing RST training versus the control group.



Lastly, the evaluation of the 30-meter sprint performance hinged on 6 articles involving a total of 183 evaluations, presenting homogeneity in terms of heterogeneity. The effect size yielded a statistically significant positive difference in performance improvement for the 30-meter sprints post-intervention: Z = 4.12 (P < 0.0001), as depicted in Figure 8 and Figure 9.

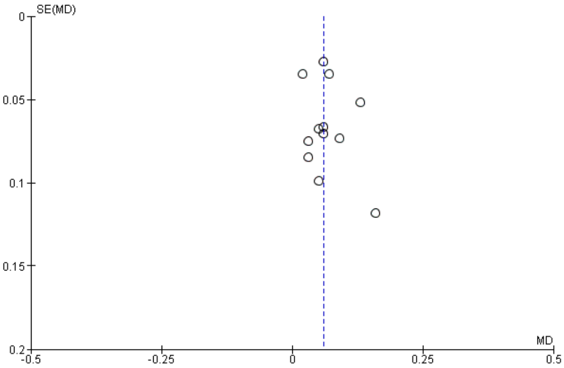
Figure 8. Forest plot of 30-meter sprint performance comparing RST training versus the control group.



Study or Subgroup	pre Mean	pre SD	pre Total	post Mean	post SD	post Total	Weight	Mean Difference IV, Random, 95% CI
Morris, et al. (2021)	4.2	0.13	24	4.18	0.11	24	17.7%	0.02 [-0.05, 0.09]
Morris, et al. (2021)	4.9	0.3	25	4.87	0.3	25	3.0%	0.03 [-0.14, 0.20]
Morris, et al. (2021)	4.53	0.25	24	4.5	0.27	24	3.8%	0.03 [-0.12, 0.18]
Borges et al (2016)	4.31	0.11	9	4.26	0.17	9	4.7%	0.05 [-0.08, 0.18]
Rodriguez-Osorio, et al (2019)	4.37	0.32	19	4.32	0.29	19	2.2%	0.05 [-0.14, 0.24]
Carlos-Vivas, et al. (2020)	4.55	0.17	11	4.49	0.16	11	4.3%	0.06 [-0.08, 0.20]
Rodriguez-Osorio, et al (2019)	4.39	0.2	19	4.33	0.21	19	4.8%	0.06 [-0.07, 0.19]
Carlos-Vivas, et al. (2020)	4.61	0.07	13	4.55	0.07	13	28.4%	0.06 [0.01, 0.11]
Carlos-Vivas, et al. (2020)	4.59	0.09	12	4.52	0.08	12	17.7%	0.07 [0.00, 0.14]
Lahti, et al. (2020)	4.65	0.17	9	4.56	0.14	9	4.0%	0.09 [-0.05, 0.23]
Lahti, et al. (2020)	4.62	0.1	9	4.49	0.12	9	7.9%	0.13 [0.03, 0.23]
Luteberget, et al. (2015)	4.81	0.17	9	4.65	0.31	9	1.5%	0.16 [-0.07, 0.39]
Total (95% CI)			**183**			**183**	**100.0%**	**0.06 [0.03, 0.09]**

Heterogeneity: Tau² = 0.00; Chi² = 4.42, df = 11 (P = 0.96); I² = 0%
Test for overall effect: Z = 4.12 (P < 0.0001)

Figure 9. Funil plot of 30-meter sprint performance comparing RST training versus the control group.



Discussion

The primary objective of this comprehensive study was to methodically scrutinize the existing literature, specifically focused on distinctive Resisted Sprint Training (RST) protocols employing load vests or "sleds." Excluding the utilization of elastics and parachutes, this analysis concentrated on practitioners, athletes, and non-athletes engaged in court, field, and track and field sports. The central analytical premises pertained to the enhancement of sprint performance across 5, 10, 20, and 30-meter distances. The ensuing discourse elucidates the multifaceted outcomes derived from the meticulous meta-analysis conducted using data curated from the collated articles.

The evaluation of 5-meter sprint performance highlighted pivotal contributions from studies proposed by Lahti et al. (2020) and Borges et al. (2016), exerting substantial statistical influence. Lahti et al. (2020) orchestrated a 7-week protocol, involving two weekly sessions comprising 6 to 8 efforts for 31 professional athletes from Finland's premier division (24.1 ± 5.1 years). The experimental groups were bifurcated, each implementing distinct protocols featuring speed decays of 60% and 50% respectively. These protocols garnered statistical weights of 21.1% and 27.1% in the meta-analysis. Notably, the 50% speed decay protocol exhibited a confidence limit (CL) skewed entirely toward the post-protocol phase. On the other hand, Borges et al. (2016) contrasted plyometric and RST protocols among players under 17 years old (16.6 ± 0.6 years) participating in a state championship. The RST group (n = 9) engaged in protocols encompassing 2 to 7 sets of single repetitions across distances of 5, 10, 20, and 30 meters, with rest intervals spanning 45 to 120 seconds, tailored to training demands. Despite variations in load and target speed decay ranging from 10% to 13% of body weight, the meta-analysis yielded a statistical weight of 14.9%. Nonetheless, neither the confidence limit nor the meta-analysis outcome exhibited a pronounced inclination toward the post-protocol phase. It is noteworthy that prescribed loads of approximately 7.5% to 15% of body weight are intertwined with a suitable prescription concerning speed decay (Lahti et al., 2020).

In the context of 10-meter sprint performance, the meta-analysis underscored a heterogeneity value ranging from low to moderate (25%-50%), i.e., I^2 = 38%. This signified possible variations in the proposed protocols across the selected articles, attributing methodology discrepancies as delineated in prior studies (Higgins et al., 2003; Mazin & Martinez, 2009). The inclusivity of studies involving men and/or women without age-group specification could have influenced these outcomes. Morris et al. (2021) delved into the profiles of 73 soccer players, categorized based on their proximity to peak velocity: pre-PHV (n = 25; 12.19 ± 0.51 years), circa-PHV (n = 24; 14.30 ± 0.84 years), and post-PHV (n = 24; 16.34 ± 1.18 years). Remarkably, a uniform intervention protocol was employed across all experimental groups, featuring load prescriptions ranging from 10% to 30% of body weight. Interestingly, the intervention showcased minimal impact across all groups, attributed to synergistic adaptations influenced by maturational age and training effects. This is indicative of the intricate interplay between training timing and maturational stages, resulting in optimized neural plasticity, muscle fiber recruitment, and coordination for superior lengthening-shortening cycle performance (Morris et al., 2021; Radnor et al., 2018). It's essential to acknowledge that lower levels of proteins like succinate dehydrogenase and phosphofructokinase within younger age groups can influence high-intensity training outcomes, as these enzymes are directly linked to energy production pathways such as electron transport chain and glycolysis, respectively (Viru et al., 1999). The initial sprints primarily emphasize neuromuscular factors, while the capacity to sustain performance hinges on metabolic system efficacy (Gonçalves et al., 2021). Directly contrasting the study by Cahill et al. (2019) and the study by Morris et al. (2021), both of which focused on a 10-meter performance test, reveals a significant commonality in their selection of participants within the post-peak height velocity range (16.6 ± 0.8 years and 16.34 ± 1.18 years respectively) as stipulated by Mirwald et al. (2002). The distinctive factor arises in their discerning choices of suitable RST methodologies for these individuals. This particularity can be dissected by juxtaposing the protocols employed by Cahill et al. (2019) and Borges et al. (2016) (16.6 ± 0.6 years) in the context of a 5-meter sprint performance. Intriguingly, Cahill et al. (2019) demonstrated more favorable outcomes, as evidenced by the propensity of the confidence limit (CL) favoring the post-protocol phase.

Luteberget et al. (2015) also yielded contrasting outcomes pertaining to the sprint performance over a 10-meter distance. The study aimed to discern the effects of RST against traditional sprint training (TST), sans additional load, involving 18 semi-professional female handball players from a Norwegian first-division team. The divergence lay in the incorporation of 12.4% of body weight as extra load in the RST group (n = 9), while no discernible statistical difference emerged between the groups. Intriguingly, results indicated that the 10-week RST protocol was inconducive to improvements in the 10-meter sprint performance, unlike the TST protocol, thereby indicating a lack of efficacy for this specific "sled training" format in enhancing short distances, particularly for female handball athletes.

Delving into the meta-analysis outcomes concerning 20-meter sprint performance, two articles, unequivocally tilting the confidence limit towards the post-protocol phase, lend credence to the robustness of the method adopted (Cahill et al., 2020; Lahti et al., 2020). This unequivocal statistical positivity underscores the reliability of the approach employed. Cahill et al. (2019) orchestrated an intervention involving 53 lacrosse and rugby players, grouped into four distinct categories, of which three were experimental and one was a control. The experimental groups predicted upon the speed decay paradigm, delineating decay rates of 25% to 22.5 meters, 50% to 15 meters, and 75% to 7.5 meters per effort. Over a span of 8 weeks, all groups undertook an equivalent number of weekly sprints, exhibiting uniform age ranges (16.6 ± 0.8 years). Among these experimental groups, the 75% decay of speed protocol emerged as the most statistically viable in the meta-analysis for the 20-meter performance. Notably, this method also boasted the highest statistical weight (20%) across all studies within the 20-meter performance domain.

Regarding the 20-meter sprint performance, the study conducted by Lahti et al. (2020) stands out for its robustness in employing a 50% speed decay strategy. This approach exhibited compelling reliability, as evidenced by the overwhelmingly favorable outcome in relation to the confidence limit (CL) post-intervention protocol. A similar trend was also observed in the context of the 30-meter sprint performance.

Concerning the results of the 30-meter performance, the methodologies that displayed CL leaning towards the post-protocol effect, along with the highest statistical weights among the RST methods (28.4% and 17.7%), were delineated in the research by Carlos-Vivas et al. (2020). This study investigated three distinct RST protocols, alongside a control group, encompassing 48 soccer players well-versed in "resisted sled training," with an average age of approximately 18 years (18.2 ± 2.2 years). All groups adhered to equivalent training distance and body load percentage, which varied at 10%, 15%, and 20%. The divergence lay in the implements used across the protocols. One group harnessed a load-bearing vest, while another employed a portable robotic horizontal resistance (1080 Sprint™; 1080 Motion, Lidingö, Sweden), akin to sleds. The third group employed both implements interchangeably. The control group pursued the same training volume sans additional load. This protocol spanned two weekly training sessions over the course of eight weeks. The meta-analysis findings indicated that the groups utilizing robotic resistance (statistical weight = 28.4%) and those employing both implements (statistical weight = 17.7%) emerged as the most effective RST methods for enhancing the 30-meter sprint performance. In contrast, the group employing load-bearing vests demonstrated a lower statistical weight (4.3%). Notably, the groups harnessing robotic resistance and both implements also secured the highest statistical weight for the 10-meter performance (15.7% and 14.0% respectively).

A distinct investigation examined in this review, also employing load-bearing vests, was undertaken by Rodríguez-Osorio et al. (2019). However, their results did not exhibit significant enhancements in post-intervention sprint performance for distances of 10, 20, and 30 meters. The variation in outcomes between RST methods utilizing vests and/or sleds can be rationalized through the lens of dynamic correspondence theory. This theory underscores the necessity for exercises and implements to align

with the vectors of sports practice. In essence, the efficacy of the RST method hinges upon the implementation of implements capable of employing horizontal vectors to enhance linear velocity performance (Carlos-Vivas et al., 2020; Fitzpatrick et al., 2019).
The current study did not categorize the methods based on the differentiation of protocols concerning the prescribed target load for horizontal resistance, expressed as a percentage of body weight, or the rate of velocity decay. Nor did it classify whether the utilized loads were categorized as light or heavy according to established literature benchmarks (Lahti et al., 2020; Morris et al., 2021; Rodríguez-Osorio et al., 2019). Regarding the intervention period, a consensus appears to suggest that the positive effects of the RST can be discerned with an intervention frequency of twice a week spanning a six-week period. Another noteworthy observation pertains to the interplay between the RST method and the maturational age group, indicating potential detriments at younger ages. While it is not feasible to draw conclusive comparisons between studies employing "sleds" versus those utilizing load vests, it is apparent that the primary focus of this article was to ascertain the effect size of the post-protocol RST method. However, a discernible pattern emerges indicating that sprint enhancement is closely linked to methodologies that account for the application of forces aligned with the horizontal vector.

Conclusions

This comprehensive meta-analysis provides robust insights into the efficacy of RST protocols utilizing sleds and load vests to enhance sprint performance across various distances. The findings underscore the critical role of protocol design, particularly in relation to speed decay rates, load prescriptions, and horizontal force application, in determining the success of RST interventions.
The studies reviewed demonstrated varying degrees of efficacy based on sprint distances and participant demographics. Regarding 5-Meter Sprint, the studies highlighted the importance of speed decay strategies and load prescriptions ranging from 7.5% to 15% of body weight, with notable statistical contributions to performance enhancement. Concerning 10-Meter Sprint, while some studies indicated limited impact due to participant maturation and synergistic training effects, others revealed that sled-based RST protocols were more effective when employing horizontal force application. About 20-Meter Sprint, protocols emphasizing speed decay rates of 50% to 75% demonstrated significant efficacy, particularly in studies, underscoring their robustness in enhancing performance over intermediate distances. In 30-Meter Sprint studies, the use of robotic resistance systems and combined implements emerged as the most effective methods, with high statistical weights favoring post-intervention improvements. Key takeaways from the study can be indicated. For instance, methods that align with the horizontal vectors of sports movements, such as sleds and robotic resistance systems, were more effective in improving linear sprint performance compared to load vests. In addition, the efficacy of RST is closely tied to appropriate load prescriptions, with loads around 10% to 15% of body weight appearing optimal for enhancing short-distance sprint performance. RST outcomes are influenced by the maturational stage of participants, with younger athletes exhibiting lower enzymatic capacities for high-intensity training adaptations. A consensus between the studies suggests that twice-weekly RST sessions over a six-week period yield positive performance outcomes.
While the present study reveals valuable patterns, it also identifies gaps in the literature, particularly the lack of standardized classifications for "light" versus "heavy" loads and insufficient differentiation in the impact of sled versus vest-based RST. Future research should focus on optimizing RST protocols by tailoring interventions to individual athlete characteristics, maturational stages, and the specific demands of their sports. By prioritizing horizontal force application and refining training lo ads, RST has the potential to significantly enhance athletic performance across various sprint distances.

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