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Systematic Review

The Effect of Resisted Sprint Training on Acceleration: A Systematic Review and Meta-Analysis

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ABSTRACT

International Journal of Exercise Science 17(6): 986-1002, 2024. Resisted sprint (RS) training, such as sled or parachute towing, is commonly used for sprint training among field sport athletes. While RS training is frequently employed by athletes and coaches, there is little research on its benefits, especially compared to unresisted running (UR) training programs with similar training volumes. This systematic review and meta-analysis compared the effectiveness of RS training on acceleration compared to UR training. Potential sources were limited to peer-reviewed articles published in English prior to June 12, 2022, and gathered from the EBSCOhost, PubMed, and Web of Science online databases identified using combinations of the following terms: *towing*, *sled*, "*resisted sprint*," "*sprint acceleration*," "*sprint performance*," and "*sprint speed*." The search returned 1,159 sources, from which 15 were eligible for inclusion. Fifty effects were used to estimate the impact of RS training on initial sprint speed. Based on the cumulative results from these studies, RS training yielded a small improvement in acceleration but was not different from same volume of UR training (Hedges' d Effect Size=0.11, 95% CI: -0.01 to 0.23; p=0.08). These results do not support the use of RS training over UR training for improving initial sprint speed; however, further research should be conducted.

KEY WORDS: Towing, sled, performance, speed

INTRODUCTION

Sprint ability is a valuable quality for athletes. Sprint performance can be broken into three main phases: acceleration, maximum sprint velocity, and deceleration (14). In most cases, a quick burst of speed can be used by field sport athletes to gain preferential position over an opponent (9). This acceleration phase refers to the initial change in velocity and sprint performance over shorter distances, whereas, maximal speed is commonly observed when sprinting distance exceeds 30 m (29). Even elite 100-m sprinters may take up to 60 m to achieve their maximum speed (18). Deceleration commonly refers to "speed endurance," or the ability of the athlete to maintain their maximum speed without a decline in velocity (14). While maximum speed and deceleration are valuable, the initial break-away speed from acceleration may provide a more important competitive advantage as many athletes rarely cover large distances in sprint efforts during sport competition (29).

Stride length (the distance between successive points of contact of the same foot) and stride frequency (the number of times a stride is taken within a given time or distance) are key components of sprinting velocity, and velocity will improve by increasing one without diminishing the other. Stride length peaks during the latter part of a sprint performance, whereas stride frequency commonly peaks during the earlier portion of a sprint; however improvements in both will result in even greater velocity (17). Coaches, athletes, and strength and conditioning professionals have used resistance training to target the musculature of the hips, quadriceps, and calves to improve stride length. The goal of improving strength is to exert a greater force on the ground to propel one further in a stride (2, 3, 19, 22, 38). Stride frequency is often determined by contact time, the amount of time the foot is on the ground, and flight time, the time between contacts. A low contact time and a shorter flight time (while maintaining stride length) yields higher frequency. Explosive weight training and plyometrics are often used to decrease contact time and thereby increase stride frequency (2, 19, 22, 38). However, these training methods target vertical force, whereas resisted sprinting has been employed to target the horizontal force utilized in sprinting and necessary for acceleration. For example, strength and conditioning professionals have attempted to specifically target horizontal force production using resistance generated by towing a load, wearing a weighted vest, or running with a parachute.

Resisted sprint (RS) training utilizes the theory of overload (19, 22) and specificity (43) to increase force output and favorable adaptations in running (5, 19, 22). This overload may also produce neuromuscular adaptations so that when the resistance is removed, the muscles function at a higher rate (5, 19, 40). By applying specificity, the precise running muscles and neuromuscular pathways are targeted.

Despite the theoretical benefits of RS training, the performance benefits of RS training appear to be inconsistent and may depend on the comparison condition, or lack thereof, used in prior research. While RS training may improve maximum sprinting speed, improvements in acceleration may be negligible, especially compared to traditional unresisted running (UR) training, and acceleration has not been the exclusive focus of prior reviews when limited to studies with an UR comparison group (1, 33). In addition, the acceleration phase is likely more important than maximum speed in many sports because of the time required for an athlete to achieve maximum speed, the short sprint and rapid change in direction required in baseball, soccer, rugby, and American football, as well as the smaller court dimensions in basketball and tennis (18, 29). As such, the purpose of this study is to quantify the effect of RS training compared to UR training on the acceleration phase of sprinting.

METHODS

The review was conducted in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement guidelines (30). Articles published prior to June 12, 2022, were located using searches of EBSCOhost (n=1,173), PubMed (n=1,736), and Web of Science (n=807) online databases using combinations of the terms: *towing*, *sled*, "*resisted sprint*," "*sprint acceleration*," "*sprint performance*," and "*sprint speed*." A total of 3,716 articles were returned with the initial search process, yielding 1,159 sources after duplicates were removed. A manual review of the article references was conducted to identify additional publications not discovered by the database search, however no additional publications resulted from the manual search of references. A flowchart depicting study selection is provided in Figure 1.

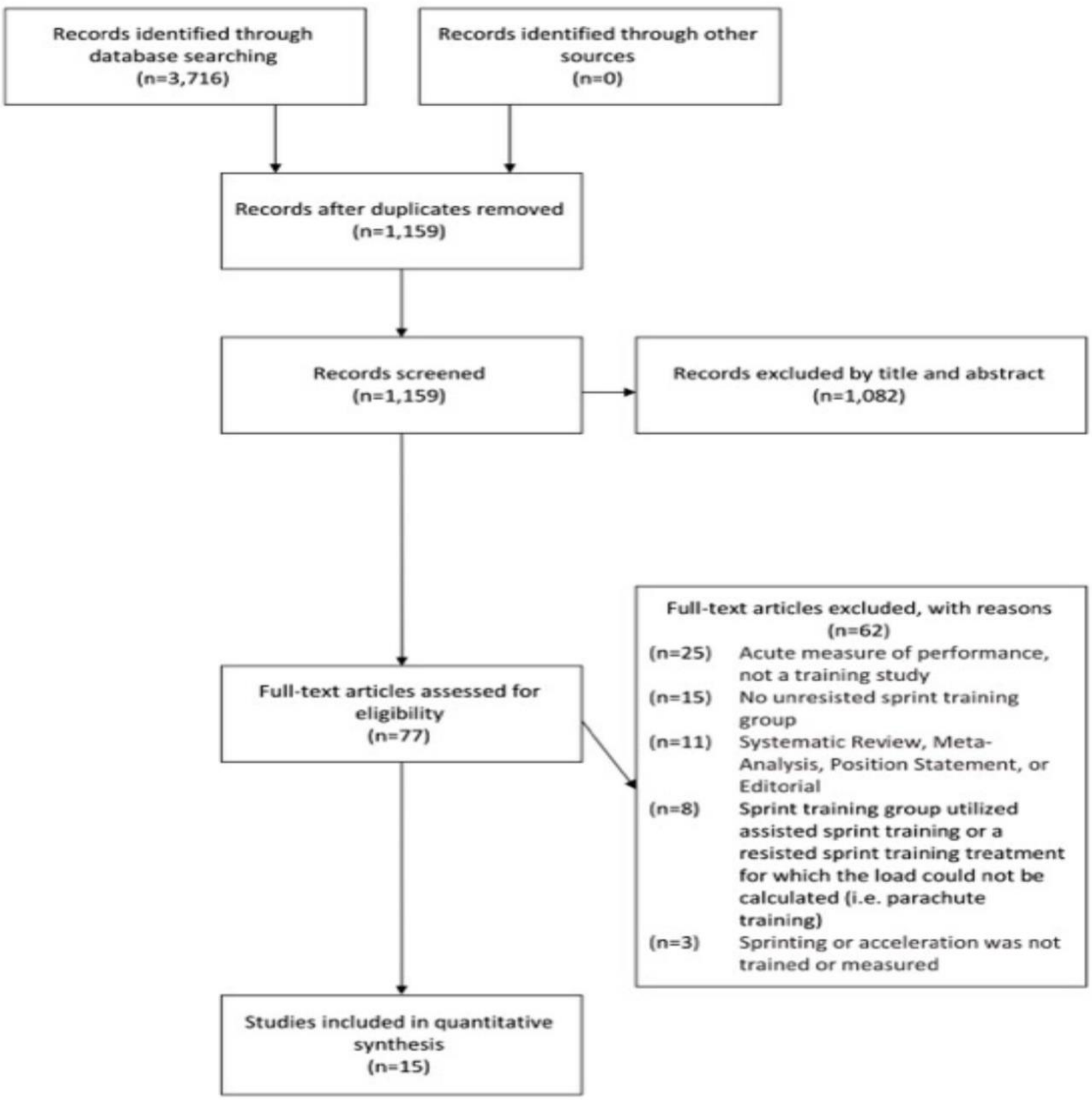

Figure 1 - Flow chart of study selection.

Study Selection
Strict inclusion criteria were used to include articles in the final analysis, and all eligible studies were 1) peer-reviewed publications, 2) available in English, 3) randomized participants to RS training and UR training groups, 4) measured speed or time recorded from 0 m; and 5) utilized measurable resistance loads attached to the torso. Excluded records were 1) not peer reviewed, 2) provided a review or position statement 3) did not measure running sprint outcomes, 4) included youth (< 18 years old) as research participants, or 5) did not isolate linear resisted running as the training variable. All 15 articles reported mean pre-training and post-training times or speed or provided figures from which the mean could be determined. Likewise, the standard deviation was reported, or was able to be calculated from standard error or graphical representations. One study had 19 participants and stated they were evenly distributed between the 3 training groups (20). Since a reply from the author was not received, a conservative estimate of 6 participants per condition was used.

Effect Size Calculation
The effect size (ES) was calculated by subtracting the mean difference of the UR training group from the mean difference of the RS training group and dividing by the pooled standard deviation (SD) (21). It was then adjusted for small sample bias (15, 21). For studies in which the times for intervals were reported (12, 24, 27, 28, 32, 34, 37, 42), the mean change was calculated by subtracting the post-training time from the pre-training time. In the remaining studies (2, 20, 22, 26, 38, 40, 43), speed (m/s) was reported and pre-training speed was subtracted from post-training speed to find the mean change. Each ES was qualitatively described as small, medium or large (ES=0.2, 0.5, and 0.8, respectively) (8). Data were independently extracted by two authors (EKA and KS), with discrepancies resolved by a third reviewer (MVF) prior to aggregating effects. An improvement in sprint performance resulted in a positive ES.

A summary of participant and study characteristics are shown in Tables 1 and 2, respectively, and moderators and study quality are described in Tables 3 and 4.

Table 1. Baseline descriptive characteristics of participants and characteristics of resisted sprint training interventions.

	Minimum	Maximum	Mean	Standard Deviation
Age (yrs)	19	27	23	2
Height (cm)	162.0	186.0	175.3	6.6
Weight (kg)	58.7	90.2	74.4	8.7
Gender (% male)	0	100	74	9
Load (%BM)	6.8	89.1	33.7	26.7
Intervention Length (weeks)	4	10	7	2
Training Frequency (days/week)	1	3	2	1
Session Duration (min)*	30.0	90.0	54.9	18.6
Sprint Distance (m)	4.6	20.0	9.0	4.4

BM, body mass; min, minimum. *only reported in 3 studies.

Table 2. Characteristics of studies examining the effect of resisted sprint training.

Source	N	Gender M/F	Resistance Load	Freq (d/wk)	Dur (wks)	Participants
Alcaraz et al., 2014	22	14/8	7.5% SR	2	4	National track athletes
Escobar Àlvaraz et al., 2021	31	31/0	50% VD	2	8	Rugby: amateur
Kristensen et al., 2006	12	8/4	15 kg	3	6	Competitive students
Lockie et al., 2012	18	18/0	12.6% BM	2	6	Field sport athletes
Luteberget et al., 2015	18	0/18	12.4% BM	2	10	Handball: semi-pro
Makaruk et al., 2013	24	0/24	10% VD	3	9	"Highly fit" college students
McMorrow et al., 2019	13	13/0	30% BM	1-2	6	Soccer: professional
Morin et al., 2017	16	16/0	80% BM	2	8	Soccer: amateur
Pareja-Blanco et al., 2020	28	0/28	40% BM	1	8	Recreational athletes
Rodriquez-Rosell et al., 2020	60	60/0	20% BM 40% BM 60% BM 80% BM	1	8	Recreational athletes
Sinclair et al., 2021	26	26/0	20% VD	2	8	Rugby: professional
Spinks et al., 2007	20	20/0	10% VD	2	8	Rugby/soccer: semi-pro
Upton et al., 2011	19	0/19	12.6% BM	3	4	Soccer: DI NCAA collegiate athlete
West et al., 2013	20	20/0	12.6% BM	2	6	Rugby: professional
Zafeiridis et al., 2005	22		5kg	3	8	Recreational athletes

BM, body mass; DI, division 1; NCAA, National Collegiate Athletic Association; Dur, duration; F, female; Freq, frequency of training; M, male; N, number; semi-pro, semi-professional; VD, velocity decrement; wks, weeks; unknown quantities are left blank

Table 3. Definitions for levels of moderators.

Moderator	Definition
Age	Continuous variable, mean age of the experimental group reported in years
Height	Continuous variable, mean height of the experimental group reported in cm
Weight	Continuous variable, mean body mass of the experimental group reported in kg
Gender	Continuous variable, percentage of self-reported male participants in the experimental group
Load	Continuous variable, resistance load used for the intervention reported as percent body mass*
Intervention Length	Continuous variable, training intervention program length reported in weeks
Training Frequency	Continuous variable, number of training sessions reported in days per week
Session Duration	Continuous variable, intervention training session duration reported in minutes per session
Sprint Distance	Continuous variable, distance of individual sprints during training reported in meters

*the regression formula relating velocity to load: % Load = -1.96 (% velocity) + 188.99, established by Lockie et al. 2003 (28), was used to convert velocity change to percent of body mass; absolute loads were compared to mean mass and expressed as percent body mass.

Table 4. Study quality characteristics of studies examining the effect of resisted sprint training.

	PEDro Scale Question Number											
Source	1	2	3	4	5	6	7	8	9	10	11	Total
Alcaraz et al., 2014	1	1	0	1	0	0	0	0	0	1	1	4
Escobar Àlvaraz et al., 2021	1	1	0	0	0	0	0	1	1	1	1	5
Kristensen et al., 2006	1	0	0	1	0	0	0	1	1	1	1	5
Lockie et al., 2012	1	1	0	1	0	0	0	1	0	1	1	5
Luteberget et al., 2015	1	0	0	1	0	0	0	0	0	1	1	3
Makaruk et al., 2013	1	1	0	1	0	0	0	1	1	1	1	6
McMorrow et al., 2019	1	1	0	1	0	0	0	0	0	1	1	4
Morin et al., 2017	1	1	0	1	0	0	0	0	0	1	1	4
Pareja-Blanco et al., 2020	1	1	0	1	0	0	0	1	1	1	1	6
Rodriquez-Rosell et al., 2020	1	1	0	1	0	0	0	1	1	1	1	6
Sinclair et al., 2021	1	1	0	1	0	0	0	1	0	1	1	5
Spinks et al., 2007	1	1	0	1	0	0	0	1	1	1	1	6
Upton et al., 2011	1	1	0	1	0	0	0	1	1	1	1	6
West et al., 2013	1	0	0	1	0	0	0	1	1	1	1	5
Zafeiridis et al., 2005	1	0	0	1	0	0	0	0	0	1	1	3

Note: Points were awarded when a criterion was clearly satisfied. Scale question number 1 was not used to calculate the total score reported, yielding total possible scores ranging from 0–10 points.

Two-way (effects × raters) intraclass correlation coefficients with absolute agreement were calculated to examine interrater reliability (EA and KS), with initial ICC values ranging from 0.36 to 1.00 for each individual variable assessed across the 50 effects. Upon further examination, the poor agreement between raters was observed for the sample descriptive characteristic Height variable due to different units of measure reported across studies (i.e. meters vs. centimeters). Intraclass correlation increased to 100% agreement after adjusting for discrepancies between reviewers for each ES calculation and moderator used in the subsequent analyses.

Study Quality Assessment

The methodological quality of each study was assessed using the PEDro scale, which serves as an 11-item scale, where higher scores indicated better methodological study quality (25). The first scale item was not used to calculate the total score, and as a result possible scores ranged from 0-10. Study quality was categorically described as "poor," "fair," "good," and "excellent" using the thresholds of <4 points, 4 to 5 points, 6 to 8 points, and >9 points, respectively.

Statistical Analysis

All statistical analyses were performed using the "metafor" package in R (v 4.2.1; R Core Team, https://www.r-project.org/) (41). Random effects models were used to aggregate a mean ES and 95% confidence interval using a 3-level meta-analysis model structure to adjust for between-study variance and the correlation between effects nested within studies (4, 7). This was required as multiple effects were gathered from studies involving repeated measures. Individual effects were weighted by the inverse variance and aggregated using restricted maximum likelihood estimation. Heterogeneity was indicated if Q total reached a significance level of $p<.05$ and was assessed by examination of the I^2 statistic (15, 16). An I^2 value was categorized as low, moderate, or high based on calculations equal to 25%, 50%, or 75%, respectively.

In the event of significant heterogeneity, an attempt to explain the observed heterogeneity was performed using a similar 3-level meta-regression analysis with robust variance estimation based on a number of independent variables chosen *a priori* due to their influence on training adaptations. Data available for study and participant characteristics are presented as M±SD.

RESULTS

The cumulative results from 15 studies published between 2005 and 2022 indicated that RS training did not yield greater improvements in sprint performance when compared to UR training (ES=0.1085, 95% CI: -0.0129 to 0.2300; z=1.7521; p=0.0798) (Figures 2 and 3).

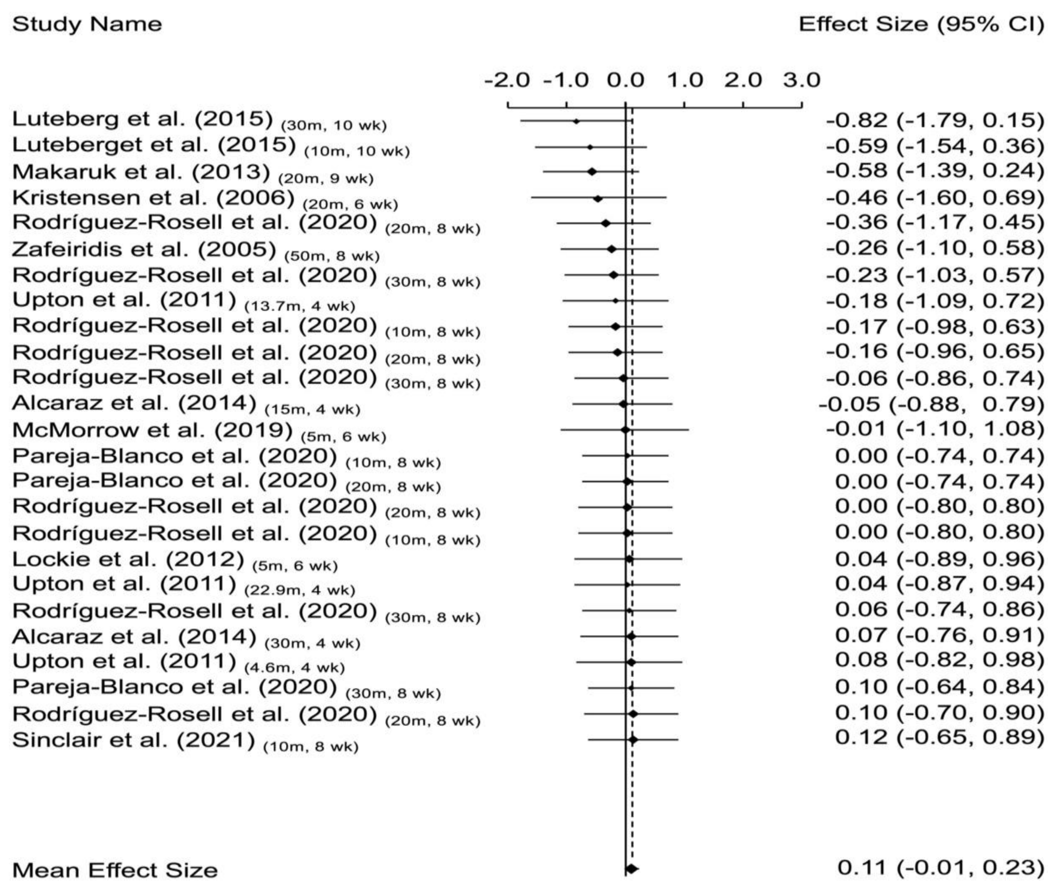

Figure 2 - Forest plot of Hedges' d effect sizes. The aggregated Hedges' d is the random effects mean effect size for Resisted Sprint training on Acceleration weighted by the Inverse Variance.

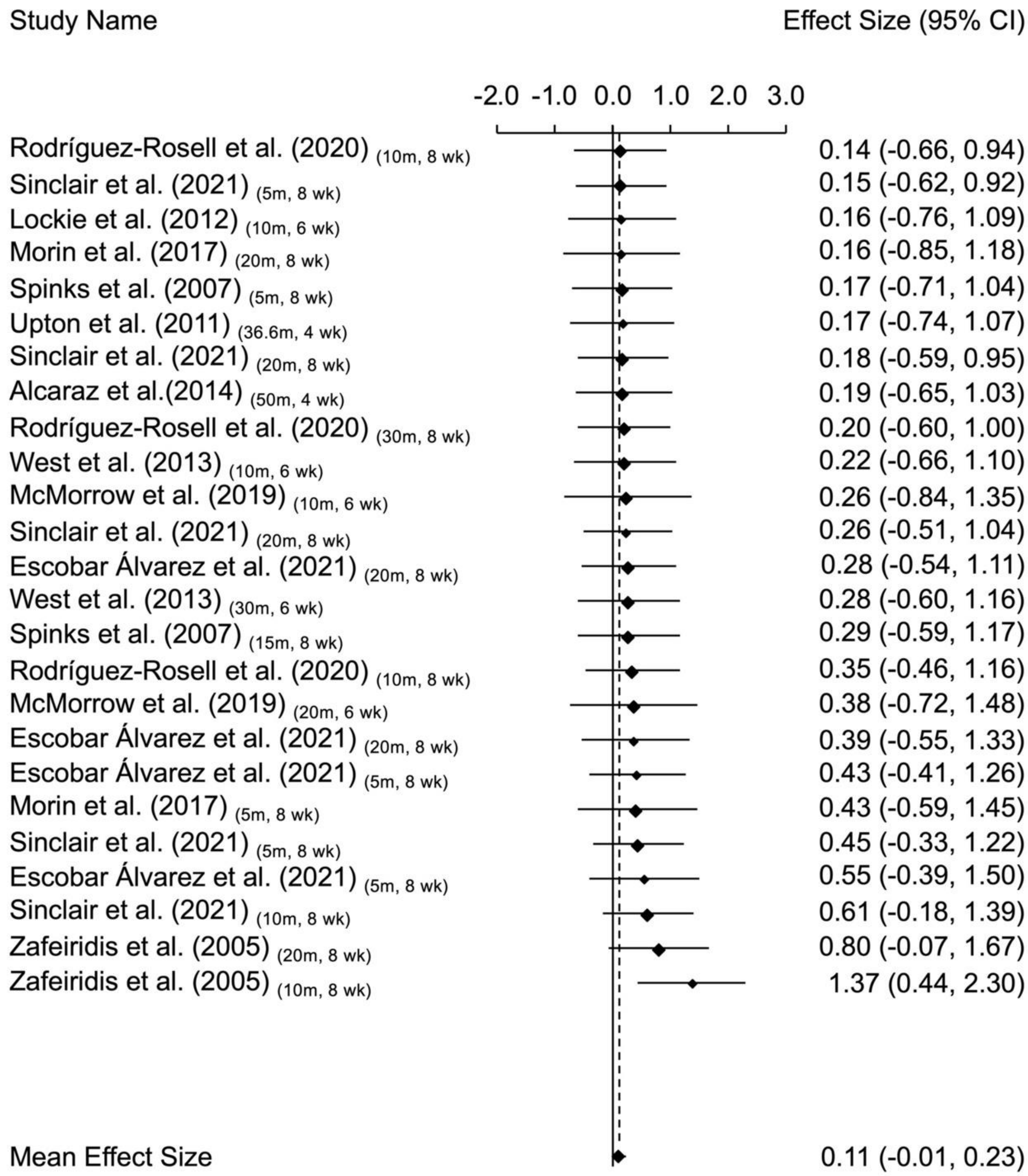

Figure 3 - Forest plot of Hedges' d effect sizes. The aggregated Hedges' d is the random effects mean effect size for Resisted Sprint training on Acceleration weighted by the Inverse Variance.

The majority of effects (k=37 effects, 74.0%) were larger than zero, with observed effects ranging from -0.8189 to 1.3656. In addition, only two studies in this review of 15 found improvements following UR training when no improvements in the RS groups.

Published data from 15 studies utilized in this review yielded 50 effects, with between 1 and 12 effects (3.3±2.7 effects) per study. Data were collected from 352 participants with complete pre- and post- training times or speed. Samples ranged from 6 to 14 participants (10.3±2.3 participants) per treatment group. The number of training sessions ranged from 8 to 24 sessions (14.7±5.3 sessions) over spans of 4 to 10 weeks (7±1 weeks). Resistance loads varied greatly from an estimated 6.8% to 89.1% body mass (34.3±28.9% body mass). While some studies consisted exclusively of men (n=7, 47%) (22, 27, 28, 34, 37, 38, 42), or women (n=5, 33%) (12, 24, 26, 32, 40), other samples were mixed (n=2, 13%) (2, 20). One study (n=1, 7%) did not report biological sex of the participants included in their sample (43). Athletic experience and sport participation also varied greatly, with multiple studies (n=5, 33%) involving college physical education students or recreational athletes (20, 26, 32, 34, 43), and others including professional athletes (n=3, 20%) (27, 37, 42). Additional descriptive characteristics of the studies included in the current analysis are detailed in Table 2.

Study Quality Assessment

Total study quality scores ranged from 3 to 6 points, with the majority (n=13, 86.7%) of studies included in this analysis categorized as “good” or “fair” quality. Regarding each specific assessment item, all studies (n=15, 100%) included a clear description of the study samples and exclusion criteria. In addition, nearly all studies (n=14, 93.3%) included training groups who were similar at baseline regarding most important characteristics. The one exception was a study of 31 rugby athletes who were allocated to a RS or UR group (12). However, the two experimental RS groups were stratified by player position including forwards and backs, whereas the UR group included a combined sample of players from both position groups (12). Lastly, most studies (n=11, 73.3%) specifically mentioned that participants were randomized or block-randomized to ensure that participants were equally distributed across treatment groups. Additional study characteristics can be found in Table 4.

Homogeneity of Results

In addition to the small non-significant improvement in sprint performance following RS training, low heterogeneity was observed between effects (Q_{49}=29.4179, p=0.9880, I^2= 0%). Based on a non-significant Q statistic and an I^2 indicating low heterogeneity, the variability in effects was not greater than would have occurred naturally based on chance or random study sampling error. The null hypothesis for homogeneous distribution was accepted, and post-hoc analyses were not warranted. Additionally, a fail-safe N was not computed since the overall mean ES analysis yielded a null result.

Assessment of Bias and Sensitivity Analysis

A funnel plot was created as an exploratory assessment to address potential bias (Figure 4), and potential publication bias was also addressed using Egger's test (11).

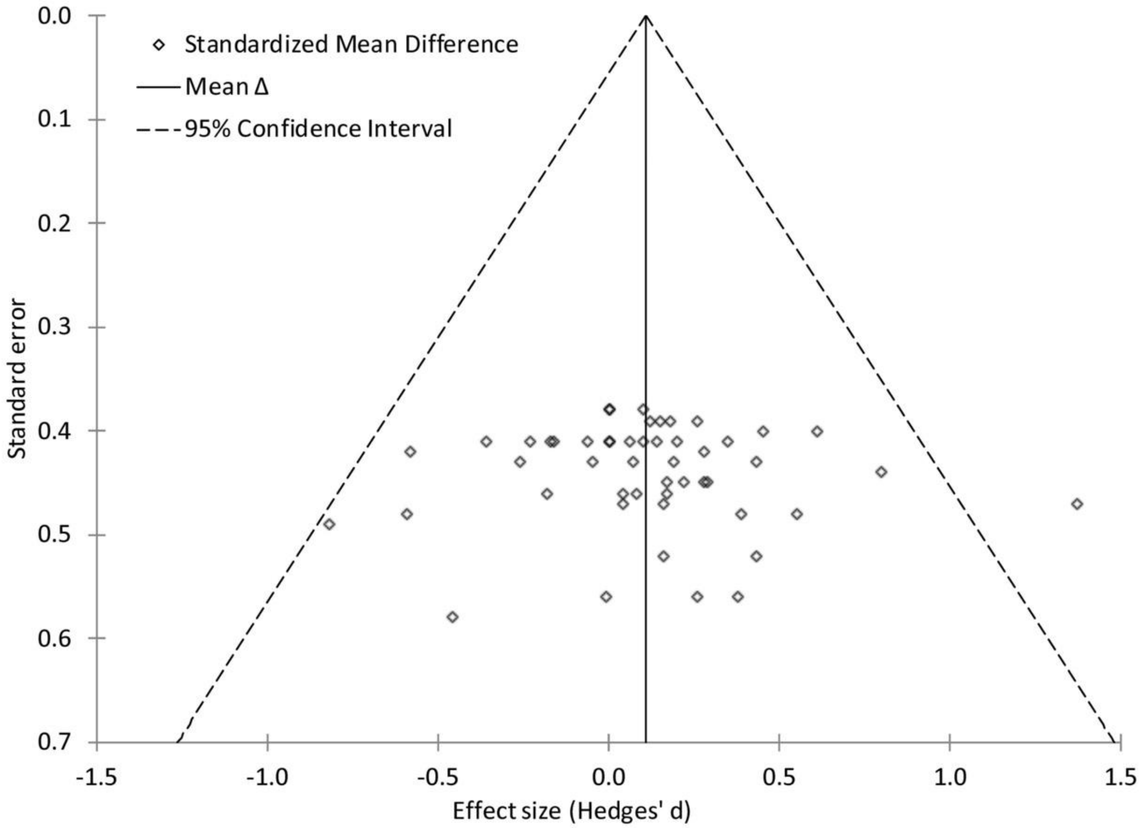

Figure 4 - Funnel plot of Hedges' d effect size versus study standard error. The aggregated Hedges' d is the random effects mean effect size for Resisted Sprint training on Acceleration weighted by the Inverse Variance.

The intercept of the regression model indicated that the funnel plot was symmetrical and was not subject to potential bias (b=0.2232, p=0.8370). After visually inspecting the funnel plot, a sensitivity analysis was performed removing 1 of the 50 effects as a potential outlier outside of the 95% confidence interval. Removing this effect slightly decreased the mean effect (ES=0.0874, 95% CI: -0.0342 to 0.2090, p=0.1589) for the remaining 49 effects.

DISCUSSION

Coaches, athletes, and strength and conditioning professionals commonly use RS training to improve sprint performance, however without observed heterogeneity, these small nonsignificant changes appear to be consistent regardless of the sprint distance, resistance load utilized, or demographic characteristics of the athlete. For most athletes, these results indicate that RS training provides little additional improvement in sprint acceleration beyond what would occur following UR training. However, if these small improvements occur following RS, the observed changes would improve performance by 0.08 s and 0.10 s (men and women, respectively) in the 2020 Olympic 100-m finals, which represents the difference between a gold or silver medal, or finishing completely outside of the top three (13).

Some prior reviews suggested that RS can effectively improve acceleration and sprint speed when examining pre-post changes within a single group intervention, with the magnitude of the observed changes ranging from moderate to large (1, 33, 36). However, the results of the current study are consistent with other previous reviews which found similar small, but not statistically significant, improvements in sprint velocity during the acceleration phase in experimental groups performing RS compared to control groups performing UR (1, 33). As a result, the within-group pre-post changes may serve little practical utility. These previous reviews of sprint training found improvements related to RS training but could not conclusively state that RS training was more effective than UR training on the acceleration phase because of the variety of study designs, the various training modes, and the different performance measures used (1, 33, 36).

One reason for the conflicting results found in other reviews examining the effect of RS training is because these did not directly compare RS to UR training as in the present study. Rumpf et al. examined multiple sprint training methods in men and found RS, UR, and assisted sprint training improved speed across all test distances (0–10, 0–20, 0–30, and 30+ m) (ES=-1.10) (36). The RS group exhibited improvements with large effect sizes across all distances, with the greatest improvements observed over the 0–20m distance (ES=-1.39) (36). Similarly, Petrakos et al. reviewed 11 studies and concluded that moderate to heavy loads of RS training yielded improvements in acceleration for strength trained athletes (33). As mentioned previously, not all the studies included in these prior reviews included an UR training comparison group. In those which did, the results were equivocal comparing the efficacy of RS to UR training. In fact, in all but one of the 15 studies in this review, there were improvements in the UR groups as well.

Although the benefits of RS over UR training may be unclear, there are other considerations to address when evaluating RS training. However, in the absence of significant heterogeneity, these differences may be spurious and could explain inconsistent conclusions drawn across previous research. For example, performance values beginning beyond the 0-m mark have been used to examine the effect of RS training on maximum or “flying” speed, whereas the present review only analyzed performance from 0 m (33). Differences in these results also may be due to sport specific factors and previous exposure to sprint training (22-24, 38, 40, 42). A biological sex difference may also exist as the effects of load have been primarily tested on male participants (32), as female athletes often have lower absolute strength levels and less skeletal muscle mass than male athletes (6). Concurrent strength training may also play a role in the effectiveness of RS training. In studies of well-trained field athletes, those that showed improvements in both RS and UR training assessed participants who were concurrently engaged in strength training programs (22, 38, 42). Furthermore, the training status of the participant may not be of critical importance, as participants have included university students, recreational athletes, and elite-level athletes (2, 20, 26, 43). While it stands to reason that smaller improvements should be observed in elite-level athletes who are likely closer to their physiological peak capacity, this was not apparent in the current results. With proper coaching in place, improved technique and proper sprint form can improve performance even among participants without prior sprint training, and may be observed in beginner and novice-level athletes following the addition of one sprint training session a week (39). Again, the current results were consistent regardless of the sprint distance, resistance load utilized, or demographic characteristics of the athlete, and these potential factors should be considered with caution.

Some evidence suggested that heavier loads also might elicit greater adaptations. Bachero-Mena and Gonzalez-Badillo (5) studied the effects of resistance equal to 5%, 12.5%, and 20% body mass, on male sports science students. All three groups improved their 0–40-m time, but the heavy load group also improved time in the 0–20-m and 0–30-m distances. The authors concluded that a heavier load produced greater improvements for initial sprint speed; however a UR control group was not used for comparison (5). Although kinematics change with larger loads (i.e. shorter stride length, greater body lean, etc.), the results of the current analysis would question whether these changes eventually yield greater adaptations (3). As such, performance improvements should be prioritized over kinematic changes, and without a UR comparison group, benefits of using heavier loads should be interpreted with caution (33). More recent studies have used heavier loads ranging from 20% to over 90% body mass, and they also included an UR comparison group, but no differences between groups were observed (27, 37).

Among recreationally active male athletes performing RS with loads ranging from 20% to 80% body mass, velocity improvements occurred at 40% and 60% body mass, but improvements were not observed with training loads equal to 80% body mass (34). As recreational athletes may not have a strong sprint training background, improvements are likely with any form of sprint training and a load of 80% may be too much for an athlete without sprint training experience.

In contrast to research in recreationally active adults, trained athletes may experience some benefit from RS training with higher loads. Escobar-Álvarez et al. (12) studied loads of between 80% and 90% body mass in female rugby backs and forwards. In 5-m and 20-m sprints, the UR and both RS groups showed improvement; however, only a small improvement was observed in the UR group compared to a moderate improvement in the RS groups. Both RS groups improved more than the UR group, but RS groups were not different from one another (12). Morin et al. (28) also sought to train at a velocity of 50% maximum and utilized an 80% body mass load (due to homogeneity of participants) with in-season, amateur, male soccer players.

Similar to the results observed by Escobar-Álvarez, only a small improvement was observed in the UR group whereas a moderate improvement was observed in the RS groups, with no statistically significant difference observed between groups after 8 weeks of training (28). Examining the interaction between training load and the athlete status of an individual (i.e., athlete vs. recreationally active vs. sedentary adults) was not possible due to the lack of heterogeneity in the current review, however this offers an opportunity for future research.

The training prescription also varied by study, and additional characteristics of study duration and weekly frequency of study training are listed in Table 3. In the 15 articles reviewed, both RS and UR groups participated in the same training regimen. Although the same distance was covered, the RS groups completed more work by moving an additional load. The difference in workload could have impacted the results; depending on the protocol, it is possible that UR training load was insufficient elicit an adaptation, or RS training volume was excessive and resulted in overtraining. Additionally, given the wide range of training status among the participants and the fact that some participants engaged in concurrent training, different training prescriptions would be appropriate.

Strengths and Limitations

The current meta-analysis used a 3-level model structure to adjust for between-study variance and the correlation between effects nested within studies. While the magnitude of the overall change was small and comparable to other reviews of this topic, the 95%CI were smaller and approached statistical significance. Five additional studies were included in the current analysis that were published since the most recent prior review in 2018. Aspects of training program design often yield adaptations along a continuum, and the magnitude of the improvement is important to consider. Small improvements in performance may be practically meaningful for athletes to gain a competitive edge and may offer a great opportunity for researchers to continue in this area. While it was beyond the scope of the current review, the potential impact of coaching technique alongside RS or UR training also provides an opportunity for future research. Proper technique is critical for sprint performance; however few studies have examined how to best target key technical elements and improve athlete performance (e.g., verbal cueing, selection of practice drills, providing feedback). Although a thorough description of the technique-specific coaching many of the participants in our studies received was not provided by the authors, it stands to reason that samples of physically active college students and recreationally trained adults did not receive the same quantity or quality of coaching as the samples of collegiate- and elite-level athletes, if any additional coaching was received at all. Despite this limitation, it is unclear how coaching, or lack thereof, may have impacted these results.

The electronic database search identified 100% of the publications included in the final analysis. Including multiple databases with a variety of possible keyword combinations is recommended as part of a systematic review strategy, and to the authors' knowledge this approach successfully identified all relevant publications in the current review (31). A manual search of references is recommended for all systematic reviews and meta-analyses in order to perform an exhaustive search of the literature. Although a keyword search of multiple electronic databases and manual search of references were used in the current study, it is possible that additional studies were not included in this review because they were not identified during either literature search. The authors did not provide a fail-safe N due to the non-significant mean effect. Normally, the fail-safe N is used to estimate the number of effects that would diminish the significance of the observed ES to a non-significant level (35). There may be no way to truly know the number of unpublished studies that exist in the "file drawer." However, conservative estimates suggest that, for the 15 published studies identified in the current review, over 75 unpublished and undiscovered studies may still be filed away.

The authors also included only studies that included RS and UR training interventions that were published in peer-reviewed journals. Excluding studies without a UR training group likely influenced the overall conclusions of our analyses. However, the authors believed this decision provided more practical utility by comparing alternative training programs where UR training served as a "treatment as usual" or "standard care" approach, rather than simple pre-post contrasts compared to no other treatments.

In addition, the authors elected not to perform a moderator or subgroup analysis in the absence of any observed heterogeneity. Prior results indicated that greater improvements in acceleration were observed for males, for recreationally active and moderately trained athletes, and for programs that trained participants more than two days per week, whereas smaller improvements were observed for females, highly trained participants, and lower training frequencies (1). Performing multiple post-hoc analyses without "low" or statistically significant heterogeneity can be a form of "data dredging" and increase the likelihood of committing a Type 1 error, in which the observed relationships may be misleading and false (10). As such, we felt it was more prudent to take a conservative approach to the current subgroup and moderator analysis.

Lastly, the Study Quality Assessments indicated that most of the research in this area could be described as "good" or "fair" quality. The main limitations were related to two areas, blinding and loss to follow-up. It may prove difficult to blind participants to their group allocation during RS training since athletes can feel the difference between RS and UR training. However, it may be possible to blind participants to the true purpose of the study. Furthermore, loss to follow-up is a potential issue in experimental research. The majority of the loss appeared to be due to 1) athlete injuries sustained during their normal competitive season and outside of the training intervention, 2) failure to adhere to the training protocol, or because 3) athletes were transferred to another team during the season. Although the use of an intent-to-treat analysis may decrease the anticipated treatment effect for adherent participants, it will also reduce the likelihood of potential bias.

CONCLUSION

A small improvement in acceleration was observed following RS training when compared to UR training, with little heterogeneity observed among effects, indicating the results were consistent across the distance measured, resistance load utilized, and numerous other participant characteristics. Training experience and concurrent sport training should also be considered when researching and prescribing RS training. Research should continue to examine the difference between RS and UR training in different populations and further assess increased loads and volume prescription.

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