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Methodological characteristics, physiological and physical effects, and future directions for velocity-based training in soccer: A systematic review

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Abstract

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Keywords

football, athletic performance, strength training, resistance training, velocity-based training

Cover Page Footnote

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Review

Methodological characteristics, physiological and physical effects, and future directions for velocity-based training in soccer: A systematic review

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Abstract: Introduction. This systematic review was conducted to (1) characterize the main elements of studies of velocity-based training (VBT) (e.g., training protocols) conducted in soccer, (2) summarize the main physiological and physical effects of VBT on soccer players, and (3) provide future directions for research. Methods: A systematic review of Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus, and Web of Science databases was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Results: The database search initially identified 127 titles. Of those, five articles were deemed eligible for the systematic review, two studies used a traditional strength training approach, and the other remaining three used sprint training with either resisted sprints or combined resisted and unresisted sprints. All studies addressed strength and power and sprint outcomes, three measured jump performance improvements, and only one study addressed spatiotemporal and kinematics or aerobic measures regarding adaptations to VBT interventions. Only one study addressed acute responses to VBT training regarding spatiotemporal variables and kinematics. Conclusions: Acute responses to VBT training were as follows: when sprint time decreases by at least 50–60%, sprint kinematics are immediately affected, but spatiotemporal variables are only significantly affected when velocity loss (v.loss) reaches at least 60%. For long-term adaptations, it seems that for strength increases using the squat, higher or lower velocity loss due to in-set fatigue accumulation does not make a difference, although it does affect jump performance, favoring the low v.loss groups (15%). The same applies to sprint, as low v.loss accumulation due to fatigue along sets seems to be detrimental to sprint performance adaptations. Moreover, high v.loss during sprints due to external load can improve sprint performance without harming the running technique as was previously thought.

Keywords: football; athletic performance; strength training; resistance training; velocity-based training.

1. Introduction

Velocity-based training (VBT) is a modern, precise, and objective method for prescribing resistance training programs, and it provides a way to access training intensity and volume [1]. Traditional methods for prescribing training intensity were done through a percentage of one repetition maximum (%1RM) [2], a type of auto-perception like the rate of perceived exertion (RPE) [3] or reps in reserve (RIR) [4], or even a combination of these. However, there are some issues with the methods presented above. For example, %1RM does not take into account weekly strength fluctuations [5], improvements in strength during the mesocycle [6], readiness [7], or individual differences for some exercises such as the squat [8]. In a study by Pareja-Blanco [7], players endured 18 RT sessions across six weeks, and an "unstable" theoretical 1RM was observed (mainly in the VL15 group), specifically from sessions 1 to 10.

Probably, considering RPE alongside %1RM based training increases autoregulation, but it still has its flaws. RPE accounts for the perception of an individual at a given time that can be negatively or positively affected by many factors, such as music, caffeine consumption, personality, and temperature, affecting the athlete's judgment [9]. RPE can also be lower when an athlete is further from failure [10], such as after speed and power training, leading to less accurate exertion gauges and, therefore, monitoring. For example, Hackett [10] showed that when actual repetitions to failure (ARF) or estimated repetitions to failure (ERF) were above 3 and/or <5, respectively, accuracy progressively decreased. Furthermore, in a meta-analysis including 202 studies, Doherty [11] accounted for the effects that caffeine had during and after exercise on RPE, concluding that caffeine improves exercise performance; it was also found that that RPE accounted for 29% of the variation in increased performance by increasing the capacity to tolerate discomfort.

In the majority of sports, powerful and explosive athletes have a competitive advantage [12]. Specifically, in soccer, explosive actions can determine the outcome of a game [13, 14]; therefore, it is important that coaching staff improve players' explosive abilities through a well-designed strength and conditioning program that uses different targets in the force-velocity curve, from low-velocity high-force movements, such as heavy squats, to moderate-force and moderate-velocity movements, like weighted jump squats with various weights, up to high-speed low-force movements, such as plyometric jumps and sprints. It is also important that the training plan is individualized to each athlete's abilities and readiness, and it can better control the fatigue experienced during this type of session. Primarily during the season, when, due to congested schedules, athletes are already exposed to frequent games. However, to implement this in a large team (such as a soccer team) with limited coaching staff to control every athlete set, and with all the caveats associated with %based training RPE or repetitions in reserve (RIR), as well as individual differences, VBT may better account for all these issues. It provides objective data that can easily be individualized by applying the precise measures related to which part of the strength curve the user wants to simulate and can be auto-regulated according to the one's readiness [15] and the level of fatigue imposed (proximity to failure/individual minimum velocity threshold (MVT), and/or velocity drop (V.Drop)) [1]. It can also improve athletes' motivation [16, 17] and track progression in a more objective way than the RPE/RiR due to the above factors.

In a study by Weakley [17], athletes were exposed to the same protocol twice, which comprised a set of 10 repetitions of back squats, all of which were measured by GymAware. The group that had feedback had an almost certainly greater mean concentric velocity than the other group when considering all repetitions. Another study [18] led to the same conclusions using a similar test setup (10 repetitions of each trial including either verbal or visual kinematic or verbal encouragement feedback). There were no significant differences between groups that received feedback, but all groups that received feedback performed better than the control group, which had no feedback.

VBT effects were also studied in soccer, such as different velocity loss (15% (VL15) vs. 30% (VL30)) in trained soccer players, and it was observed that the outcomes, such as

1RM, countermovement jump (CMJ), Yo-Yo Intermittent Recovery Test (YYIRT), and 30-sprint, led to greater improvements for the VL15 group in CMJ and a likely positive effect in the 1RM [7]. Loturco [19] studied the effects of increasing bar velocity (IGV) or reducing (RGV) (20% for each group) during six sets of six repetitions of squat jumps, finding that the RGV group experienced better results in the leg press 1RM, but the IGV group had more favorable increases in the zig-zag change of direction speed test and 20-m sprint speed test for all distances (5, 10 and 20 m), whereas the RGV group had improvements at 20 m, leaving CMJ with no significant differences in changes between groups.

Considering the growing number of VBT studies conducted in soccer and their practical relevance, there is a need for a systematic review that may help to characterize the experimental VBT protocols in soccer players and provide a general overview of the physiological and physical effects on the players. A scoping review may help to present an overview of the possible applications of VBT in soccer and help to define future research and intervention directions. Therefore, the aim of this scoping review was threefold: (1) to characterize the main elements of VBT studies (e.g., training protocols) conducted in soccer; (2) to summarize the main physiological and physical effects of VBT on soccer players; and (3) to provide directions for future research.

2. Materials and Methods

This systematic review followed the Cochrane Collaboration guidelines [20]. The scoping review strategy was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines [21].

2.1. Eligibility Criteria

The P.I.C.O.S. (Population or problem; Intervention or exposure; Comparison; Outcome; Study design) is: P (healthy soccer players of any age or sex); I (VBT training protocols); C (preferably, comparator groups using non-VBT based training, but not mandatory); O (acute and/or chronic responses: biochemical, physiological and physical); S (multiarm, either randomized or non-randomized).

The inclusion and exclusion criteria based on PICOS can be found in Table 1.

Table 1. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Population	Healthy soccer players of any age, sex or competitive level	Sports other than soccer; players with injuries, illness or disabilities
Intervention	Intervention/exposure using VBT.	Non-VBT based training.
Comparator	Controls performing field-based soccer training, with or without additional non-VBT physical training. Alternatively, controls performing VBT with different velocity losses.	No control groups.
Outcome	At least one pre-post acute and/or a chronic outcome (acute response: immediate response of a physical or physiological variable in response to the exercise; chronic response: adaptations promoted by the training intervention, consisting in permanent changes in physical or physiological variables) related to physiological (e.g., heart rate responses, blood lactate concentrations, oxygen uptake, rate of perceived exertion) and physical (e.g., strength and power, speed, change-of-direction, aerobic capacity) measures	No pre-post data related to acute and/or chronic physiological and physical measures

	Inclusion criteria	Exclusion criteria
Study design	Multi-arm designs (randomized or non-randomized).	Descriptive studies or observational analytic.
Additional criteria	Only original and full-text studies written in English, Portuguese, Spanish, Italian and French.	

2.2. Information Sources

Electronic databases (Cochrane Library, EBSCO, PubMed, Scielo, Scopus, SPORTDiscus and Web of Science) were searched for relevant publications on April 13, 2021 An additional search within the reference lists of the included records was conducted to retrieve additional relevant studies. An external expert was contacted in order to verify the final list of references included in this systematic review, in order to understand if there was any study that was not detected through our research. Possible errata for the included articles were considered.

2.3. Search Strategy

Free text terms were entered in various combinations in the title or abstract: ("Soccer" OR "Football") AND ("velocity-based" OR "VBT"). In EBSCO and Scielo, the combination of title and abstract is not available. Instead of conducting multiple searches, the search was expanded to "all fields".

2.4. Selection Process

The screening of the title, abstract and reference list of each study to locate potentially relevant studies was independently performed by the two authors (FMC and JA). Additionally, they reviewed the full version of the included papers in detail to identify articles that met the selection criteria. A discussion was made in the cases of discrepancies regarding the selection process with a third author (JR).

2.5. Data Collection Process

A data extraction was prepared in Microsoft Excel sheet (Microsoft Corporation, Readmon, WA, USA) in accordance with the Cochrane Consumers and Communication Review Group's data extraction template [22]. The Excel sheet was used to assess inclusion requirements and subsequently tested for all selected studies. The process was independently conducted by the two authors (FMC and JA). Any disagreement regarding study eligibility was resolved in a discussion. Full text articles excluded, with reasons, were recorded. All the records were stored in the sheet.

2.6. Data Items

The main outcomes defined for data extraction were: (i) acute or immediate effects related to VBT exposure (internal load, external load, hormonal responses and strength and power); and (ii) adaptations related to VBT interventions (pre-post differences in strength and power, muscle architecture, aerobic performance, sprinting, jumping, change-of-direction [COD] and repeated sprint ability [RSA]). The acute or immediate effects are related to immediate and transitory effects of VBT in internal load (e.g., psychophysiological responses [23], e.g., heart rate, rate of perceived exertion [RPE], blood lactate), external load (e.g., physical demands related to the exercise [23], e.g., distances covered at different speed thresholds, accelerations, decelerations), hormonal responses (e.g., testosterone, growth hormone) and strength and power (e.g., vertical jump height using tests as squat, countermovement or drop jumps). The adaptations represent a structural change in fitness status in which the following measures were extracted: (i) strength and power (e.g., repetition maximum); (ii) muscle architecture (e.g., changes in fascicle angle, muscle thickness); (iii) aerobic performance (e.g., maximal oxygen uptake, distance in field-based tests); (iv) sprinting (e.g., time in specific distances, as 10-, 20-, 30-meters); (v) jumping (e.g., vertical jump in testes as squat, countermovement or drop jump, horizontal jumps); (vi) COD (e.g., time in tests as 5-0-5, pro-agility, T-test); and (vii) RSA (e.g., time or fatigue index in tests of repeated-sprints in different distances).

In addition to the main outcomes, the following information was extracted: (i) type of study design, number of participants (n), age-group (youth, adults or both), sex (men, women or both), competitive level (if available), and type of original articles included (study design).

2.7. Study Risk of Bias Assessment

The version 2 of the Cochrane risk-of-bias tool for randomized trials (RoB2) [24] was used to assess the risk of bias in the included randomized-controlled trials. Five dimensions are inspected in this assessment tool: (i) bias arising from the randomization process; (ii) bias due to deviations from intended interventions; (iii) bias due to missing outcome data; (iv) bias in measurement of the outcome; and (v) bias in selection of the reported result. Using RoB2 a qualitative synthesis was performed. Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

The Cochrane risk of bias in non-randomized studies of interventions (ROBINS-I) was used to assess the risk of bias in included non-randomized intervention studies [25]. Three domains are analyzed in this assessment tool: (i) pre-intervention (bias due to confounding; bias in selection of participants into the study); (ii) at intervention (bias in classification of interventions); and (iii) post-intervention (bias due to deviations from intended interventions; bias due to missing data; bias in measurement of outcomes; bias in selection of the reported results). Two of the authors (JA and HS) independently assessed the risk of bias. Any disagreement in the rating was resolved through discussion and by a third author (FMC).

2.8. Effect Measures

Mean and standard deviation of the absolute and relative measures will be collected and represented in summary tables.

3. Results

3.1. Study selection

The searching of databases identified a total of 127 titles. These studies were then exported to reference manager software (EndNoteTM 20.0.1, Clarivate Analytics, Philadelphia, PA, USA). Duplicates (77 references) were subsequently removed either automatically or manually. The remaining 50 articles were screened for their relevance based on titles and abstracts, resulting in the removal of a further 42 studies. Following the screening procedure, 8 articles were selected for in depth reading and analysis. After reading full texts, a further 4 studies were excluded due to not meeting the eligibility criteria regarding intervention [26, 27] or comparators [28, 29]. Four studies were deemed eligible for qualitative analysis: three randomized studies [7, 30, 31] and one non-randomized study [32]. A manual search within their reference list suggested four titles of interest, of which three were excluded upon analysis of the abstracts [33–35], but one randomized study was included in the final sample [36]. Due to the small number of studies and their heterogeneity, meta-analysis was not performed.

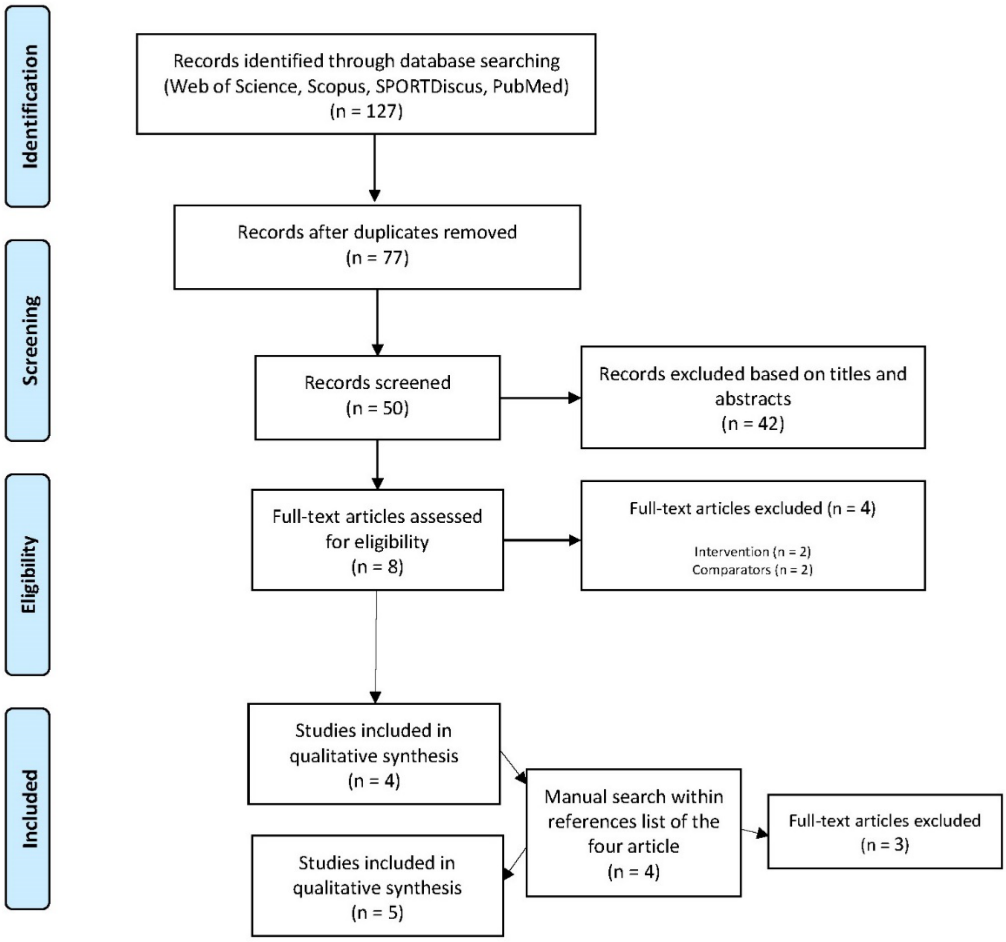

Fig. 1. PRISMA flow diagram highlighting the selection process for the studies included in the current systematic review.

3.2. Study characteristics and training protocols

The characteristics of the included studies can be found in Table 2. All the studies included in this review [7, 30–32, 36] were made in a young adult population and athletes chronic response, varying on the competitive level at which they played. Loturco [31] and Grazioli [30] sample was from professional Brazilian players, being the first in elite. Other two [7, 32] samples were from Finland Premier League and highly trained soccer players respectively. Finally, Morin [36] intervention was in a group of amateur players.

Table 2. Characteristics of the included studies.

Study	SDes	N	Age (y)	Sex/ Competitive level	Design	Outcomes	Tests used in the original studies	Measure extracted from the tests in the original studies
[31]	Rand.	32	VEL = 19.18+-0.72 years INT= 19.11 +-0.7 years	Masculine Brazilian elite soccer players	Soccer players were split in two groups (IN and VEL). Training protocol divided by common 3-week strength program followed by a 3-week power-oriented program, were, VEL increased velocity INT decreased	Strength and power, jump and sprint performance	Squat 1RM Mean Power Squat Mean Power Jump Squat Squat Jump Countermovement jump 10-m Sprint 30-m Sprint	Maximal strength (kg) Mean Power w/ moderate loads (w) Mean Power w/ light loads (w) Mean propulsive power w/light loads (w) Jump height (cm) Sprint Speed (s)
[30]	Rand.	17	25.8 +-4.3 years	Male Brazilian professional soccer players	Soccer players were split in two groups according to their velocity loss during the sled	Isokinetic, jump and sprint performance	20-m Sprint Squat Jump Countermovement Jump	Sprint speed (s) Jump height (cm) Quadriceps peak torque (N), rate of

Study	SDes	N	Age (y)	Sex/ Competitive level	Design	Outcomes	Tests used in the original studies	Measure extracted from the tests in the original studies
					resisted sprints (10% velocity loss G10 and 20% velocity loss G20).		Maximal isometric torque Maximal isokinetic torque Isometric rate of torque development	torque development N/s) and maximal rate of torque development (N/s) Hamstring peak torque (N), rate of torque development N/s) and maximal rate of torque development (N/s)
[7]	Rand.	16	23.8 ±3.4	Highly trained male soccer players	The players were split in two groups VL15 and VL30, where they would stop the squat set when a 15% and 30%, respectively, of velocity was loss.	Strength and power, sprint and jump performance, aerobic	30-m Sprint Countermovement Jump Isoinertial squat loading Yo-Yo Intermittent Recovery Test Level 1	1RM Squat (kg) Sprint speed (s) Jump height (cm) Average mean propulsive velocity (m/s) YYIRTL1 (m)
[36]	Rand.	16	26.3 ±4.0	Amateur male soccer players	Players were divided in two groups, control and VHS. Control group performed only unresisted sprints whereas VHS performed a mix of resisted and unresisted sprints.	Sprint performance	30-m Sprint Force-velocity profile	Maximal theorical running velocity (m/s) Maximal theorical horizontal force (N/kg) Maximal power output (W/kg) Maximal rate of force Decrease in ratio of force (%) Sprint speed (s)
[32]	NRand.	32	24.1 ±5.1	Premier Male Finland soccer division	One control group and two intervention groups HS50% and HS60%. Intervention groups endure in a resisted sled sprints where the goal was to reduce sprint time by 50% (HS50%) and 60% (HS60%).	Sprint performance	30-m Sprint Force-velocity profile Spatiotemporal and Kinematics	Sprint speed (s) Theorical maximal force (N/kg) Velocity (m/s) Maximal power (w/kg) Maximal ratio of forces (%) Average rate of force (%) Contact time (s) Step Rate (Hz) Step length (m/body length) CM distance (m/body length) CM angle (°) Hip-angle ipsilateral and contralateral (°) Trunk angle (°) CM angle relative to horizontal (°) CM distance to toe (m/body length)

SDes: study design; Rand.: randomized; NRand.: non-randomized

The details of the interventions and training protocols can be found in Table 3. All the studies [7, 30–32, 36] included some form of velocity-based training. Loturco [31] and Lathi [32] used velocity-based training as a form of evaluation the correct weight to prescribe the jump squat. Lathi [32] also has a mean to prescribe, but if adjustments were made during training, the intervention was not described by the authors. All others [7, 30, 36] used VBT both for prescription and auto-regulation during the intervention.

Three studies [30, 32, 36] included resisted sprints as their exercise intervention, of which two [32, 36] combined these with unresisted sprints. All of them focused on sprint speed outcomes, varying different splits ranging from 5–30 m. Pareja-Blanco and Loturco [7, 31] used the back squat and jump squat to assess changes in jump and sprint performance and cardiovascular adaptations. Intervention training frequency varied from 1x/week (with the longest duration of 11 weeks) [30] to 3x/week (Pareja-Blanco) [7] (with the shortest duration of six weeks, which was also the case in Loturco's study [31]).

Table 3. Characteristics of the training protocols using velocity-based training.

Study	Duration (w)	d/w	Total sessions (VBT interventions) (n)	Exercises included in the intervention	Sets x Rep	Intensity	Recovery (min)
[31]	6 weeks	2×/week	0*	Back Squat Jump Squat	Strength oriented 4×8 Power oriented 4×4-6	Strength-oriented 50-80% 1RM Power-oriented 30-60% 1RM	2’
[30]	11 weeks	1×/week	10	Resisted Sprints	Total reps G10- 33.75± 9.22 Total Reps G20- 48.76± 7.50	45-65% Body weight	ND
[7]	6 weeks	3x/week	18	Back Squat	According to velocity loss.	50-70% 1RM or 1.13–0.82 m/s	4’
[36]	8 weeks	2x/week	16	Resisted and unresisted Sprints	2x 2 x 5	0 or 80% Body weight	2’ between reps 5’ between blocks
+[32]	9 weeks	Almost 2x/week	ND	Resisted and unresisted sprints	6-8 x 1	Load was chosen to elicit 50 or 60% velocity loss	3’

*w: weeks; d/w: days per week; VBT: velocity-based training; Rep: repetitions; min: minutes; ND: not defined. *%1RM based to prescribe load. ** Half of the training program performed 2 unresisted sprints, the other half only performed one.*

3.3. Risk of bias in studies

The randomized studies were assessed using RoB 2 instrument (Table 4). Among the included studies, three were scored with some concerns [7,30,31] and one with risk of bias [36]. The dimensions of randomization process and selection of the reported result were the items with great concerns.

Table 4. Assessment of the risk randomized studies included with RoB 2.

Study	D1	D2	D3	D4	D5	Overall
[31]	!	+	+	+	!	!
[30]	+	+	+	+	!	!
[7]	!	+	+	+	!	!
[36]	!	-	-	!	!	-

D1: randomization process; D2: deviations from intended interventions (ITT); D3: missing outcome data; D4: measurement of the outcome; D5: selection of the reported result; Green- low risk; Yellow: some concerns; red: high risk of bias

The non-randomized study [32] was assessed using the ROBINS-I (Table 5). The article was scored with critical risk of bias in the items: (D1) reaching risk of bias judgements for bias due to confounding; (D5) reaching risk of bias judgements for bias due to missing data; and (D6): reaching risk of bias judgements for bias in measurement of outcomes.

Table 5. Assessment of risk of bias in non-randomized trails included with ROBINS-I.

Study	D1	D2	D3	D4	D5	D6	D7	Overall
[32]	-	+	+	+	-	-	!	-

D1: reaching risk of bias judgements for bias due to confounding; D2: reaching risk of bias judgments in selection of participants into the study; D3: reaching risk of bias judgments for bias in classification of interventions; D4: reaching risk of bias judgments for bias due to deviations from intended interventions; D5: reaching risk of bias judgements for bias due to missing data; D6: reaching risk of bias judgements for bias in measurement of outcomes; D7: reaching risk of bias judgments for bias in selection of the reported result; Green: low risk; Yellow: moderate/serious risk; Red: critical risk

3.4. Results of individual studies: Acute (immediate) effects

The results related to the acute effects of VBT in kinematics and spatiotemporal variables can be found in Table 6. Only one study [32] followed the immediate response of different velocity losses due to resisted sprints. Both intervention groups showed significant changes in their kinematics, but only the HS60% group also experienced significantly changed spatiotemporal values (contact time, step rate, and step length). The results regarding acute variables are inserted in the same table as the chronic variables; due to the small number of variables and studies, they are referred to as "Immediate" on the spatiotemporal and kinematic tab.

3.5. Results of individual studies: Chronic (adaptation) response

The synthesis of the results regarding the effects of VBT on chronic adaptation (i.e., strength and power, sprint, jump, aerobic performance) can be found in Table 6. All the randomized studies [7, 30–32, 36] measured strength and power outcomes. Two of them [7, 31] involved squat movement patterns, attaining Squat 1RM in both studies; in the study by Loturco [31], no significant differences in changes between groups were found, whereas Pareja-Blanco [7] reported a slightly higher tendency for the low-velocity loss group to improve Squat 1RM and average mean propulsive velocity (AMPV). Loturco [31] also looked at power metrics and found no difference in changes between groups regarding back squat mean power (BS-MP) and squat jump mean power (SJ-MP). The other three studies [30, 36] used sprints, either resisted (sled) or unresisted, and strength outcomes were used, such as isometric peak torque in Grazioli's study [30], where there was a decrease in both groups with no significant difference between them, but not in Morin and Lahti's work [32, 36], where maximal theoretical force (F0) and maximal theoretical effectiveness of directing force forwards in the first step (RFmax) increased. Only in Lahti's [32] study did velocity (v0) increase in one of the groups.

Sprint performance was assessed in all the included studies [7, 30–32, 36]. Morin [36] observed positive effects on 5-m sprint time, as did Lahti [32], but only in the HS50% group, with the caveat that this could be due to weekly performance fluctuations and measurement error not surpassing the minimal detectable threshold. Regarding the 10-m sprints, all three studies [30–32] revealed positive effects, with a tendency for the lower-velocity loss group to have a better outcome [30, 32]. The 20-m sprints followed the same trend, with the three studies [30, 32, 36] showing positive adaptations in the intervention groups, as Grazioli [30] indicated a tendency for better improvements in lower velocity loss groups (G10). For the 30-m distance, only one study [32] had positive outcomes, in contrast with Pareja-Blanco and Loturco [7, 31].

When it comes to jump performance, three studies were included [7, 30, 31]. Two of them [7, 31] showed positive effects, but only VL15 improved CMJ in Pareja-Blanco [7]. In contrast, Grazioli [30] found decrements in jump performance in both intervention groups.

Only one study [7] addressed the aerobic component of performance, with significant improvements found pre-to-post, with no difference between intervention groups.

Finally, one study [32] accessed the impact of different velocity losses in sprints on kinematics and spatiotemporal variables, finding pre-to-post differences only in HS60% but not in HS50%.

Table 6. Qualitative synthesis and summary measures considering the chronic effects of VBT methods.

Study	Strength & Power	Sprint	Jump	Aerobic	Sprint Kinematics & Spatiotemporal
[31]	Significant changes pre-to-posttest Squat 1RM (kg) (VEL: 19,8%; INT:22.1%). No significant differences in changes between groups Squat 1RM (kg). Significant changes pre-to-posttest Back Squat mean power (W) (VEL: 18.5%; INT: 20.4%) No significant differences in changes between groups Squat Mean Power (W). Significant changes pre-to-posttest Squat Jump mean propulsive power (W) (VEL: 29.1%; INT: 31.0%). No significant differences in changes between groups Squat Jump mean propulsive power (W).	Significant changes pre-to-posttest in 10-m sprint time (s) (VEL: -4.3%; INT: -1.6%). No significant differences in changes between groups 10-m sprint times No significant changes pre-to-posttest in 30-m sprint time (s) (VEL: -0.8%; INT: -0.1%).	Significant changes pre-to-posttest Jump Squat height (cm) (VEL: 7.1%; INT: 4.5%) and CMJ height (cm) (VEL: 6.7%; INT: 6.9%). No significant differences in changes between groups in Jump Squat height (cm) and CMJ height (cm).		
[30]	Significant decreases in Quads Iso Peak Torque (N) in G20 (-14.4+-12.5%) and G10 (-1.7 +-6.7%) no difference between groups. No additional significant effects. No additional significant effects.	Greater improvement G10 in 10-m sprint time (s) (-5.5+- 3.3% vs -1.74+-5.94%) 20-m sprint time (s) (-2.5+- 2.1% vs 1.4 +-3.76) than G20. No additional significant effects.	Significant decreases in CMJ height (cm) G20 (-7.1+-4.7%) and G10 (-1.7 +-6.7%). No additional significant effects.		
[7]	VL15 significant improvement Squat 1RM (P<0.01). VL15 likely positive effect Squat 1RM (kg) (101.3 ±18.1 to 110.3 ±14) vs VL30 possibly a positive effect Squat 1RM (kg) (100.2 ±20.3 to 106.5 ±28.5) VL15 possibly positive effect AMPV (m/s) (1.19 ±0.12 to 1.23 ±0.09) vs VL30 unclear effect AMPV (ms) (1.16 ±0.11 to 1.18 ±0.13)	No significant differences between pre-to-post-test in both groups.	VL15 significant greater improvement CMJ height (cm) (P<0.05). VL30 no significant CMJ improvements. Possibly negative effects CMJ performance VL30 groups	Significant difference pre-to-post-test in YYIRT (m) in both groups (P<0.01). No significant difference in changes between groups.	

Study	Strength & Power	Sprint	Jump	Aerobic	Sprint Kinematics & Spatiotemporal
[36]	VHS F0 (N/kg) pre-to post-test moderate effect (ES= 0.080 ±0.61). VHS RFmax (%) pre-to-posttest moderate effect (ES= 0.85 ±0.66) CON F0(N/kg) and RFmax (%) pre-to-posttest unclear effect (ES= 0.20 ± 0.53; ES=-0.11 ±0.54). VHS v0 (m/s) trivial effect (ES=-0.16+-0.30). VHS DRF ability moderate negative effect (ES=-0.61+-0.52).	5-m sprint (s) VHS moderate positive effect (ES=-0.68 ±0.59) vs CON small positive effect (ES=-0.23 ±0.27). 20-m sprint (s) VHS small positive effect (ES=-0.40 ±0.44) vs CON trivial positive effect (ES=-0.12 ±0.13).			
[32]	Significant F0 (N/kg) improvements HS60% (p=0.02) and HS50% (p=0.02). Significant Mean RFmax (%) improvements HS60% p=0.013; ES=0.80) and HS50% (p<0.001 ES=1.14). Significant Maximum Power (W/kg) improvements HS60% p=0.011) and HS50% (p<0.001). Significant improvements in velocity (m/s) in HS50% (p=0.04; 3.08% change). Velocity (m/s) HS60% (p=1.00; 1.79% change). Pmax (W/kg) improved significantly more in HS50% vs Control Group.	Significant improvements 10-m sprint (s) HS60% (p=0.001; d=-0.96) and HS50% (p<0.001; d=-1.25). Significant improvements 20-m sprint (s) HS60% (p=0.008; d=-0.77) and HS50% (p<0.001; d=-1.15). Significant improvements 30-m sprint (s) HS60% (p=0.02; d=-0.62) and HS50% (p<0.001; d=-1.18). 10-m sprints (s) improved significantly more in HS50% vs Control Group.			*Immediate significant change HS60% in contact time (s) (p=0.002) step rate (p=0.004) and step length (p=0.008). *Immediate significant decrease CM touchdown distance (m/body length) HS60% (p=0.003) and HS50% (p=0.003). Significant decrease CM angle at touchdown (º) HS60% (p=0.005) and HS50% (p=0.005). Pre-to-posttest significant decrease in contralateral hip angle at touchdown (º) HS60% (-4,01%; p=0.004) CON (-3.13%; p=0.006).
[30]	Significant decreases in Quads Iso Peak Torque (N) in G20 (-14.4 ±12.5%) and G10 (-1.7±6.7%) no difference between groups. No additional significant effects. No additional significant effects.	Greater improvement G10 in 10-m sprint time (s) (-5.5 ±3.3% vs -1.74±5.94%) 20-m sprint time (s) (-2.5±2.1% vs 1.4±3.76) than G20. No additional significant effects.	Significant decreases in CMJ height (cm) G20 (-7.1±4.7%) and G10 (-1.7 ±6.7%). No additional significant effects.		
[7]	VL15 significant improvement Squat 1RM (P<0.01). VL15 likely positive effect Squat 1RM (kg) (101.3 ±18.1 to 110.3 ±14) vs VL30 possibly a positive effect Squat 1RM (kg) (100.2 ±20.3 to 106.5 ±28.5) VL15 possibly positive effect AMPV (m/s) (1.19 ±0.12 to 1.23 ±0.09) vs VL30 unclear effect AMPV (ms) (1.16 ±0.11 to 1.18 ±0.13)	No significant differences between pre-to-post-test in both groups.	VL15 significant greater improvement CMJ height (cm) (P<0.05). VL30 no significant CMJ improvements. Possibly negative effects CMJ performance VL30 groups	Significant difference pre-to-post-test in YYIRT (m) in both groups (P<0.01). No significant difference in changes between groups.	

Study	Strength & Power	Sprint	Jump	Aerobic	Sprint Kinematics & Spatiotemporal
[36]	VHS F0 (N/kg) pre-to post-test moderate effect (ES= 0.080 ±0.61). VHS RFmax (%) pre-to-posttest moderate effect (ES= 0.85 ±0.66) CON F0(N/kg) and RFmax (%) pre-to-posttest unclear effect (ES= 0.20 ±0.53; ES=-0.11±0.54). VHS v0 (m/s) trivial effect (ES=-0.16 ±0.30). VHS DRF ability moderate negative effect (ES=-0.61 ±0.52).	5-m sprint (s) VHS moderate positive effect (ES=-0.68 ±0.59) vs CON small positive effect (ES=-0.23 ±0.27). 20-m sprint (s) VHS small positive effect (ES=-0.40 ±0.44) vs CON trivial positive effect (ES=-0.12 ±0.13).			
[32]	Significant F0 (N/kg) improvements HS60% (p=0.02) and HS50% (p=0.02). Significant Mean RFmax (%) improvements HS60% p=0.013; ES=0.80) and HS50% (p<0.001 ES=1.14). Significant Maximum Power (W/kg) improvements HS60% p=0.011) and HS50% (p<0.001). Significant improvements in velocity (m/s) in HS50% (p=0.04; 3.08% change). Velocity (m/s) HS60% (p=1.00; 1.79% change). Pmax (W/kg) improved significantly more in HS50% vs Control Group.	Significant improvements 10-m sprint (s) HS60% (p=0.001; d=-0.96) and HS50% (p<0.001; d=-1.25). Significant improvements 20-m sprint (s) HS60% (p=0.008; d=-0.77) and HS50% (p<0.001; d=-1.15). Significant improvements 30-m sprint (s) HS60% (p=0.02; d=-0.62) and HS50% (p<0.001; d=-1.18). 10-m sprints (s) improved significantly more in HS50% vs Control Group.			*Immediate significant change HS60% in contact time (s) (p=0.002) step rate (p=0.004) and step length (p=0.008). *Immediate significant decrease CM touchdown distance (m/body length) HS60% (p=0.003) and HS50% (p=0.003). Significant decrease CM angle at touchdown (º) HS60% (p=0.005) and HS50% (p=0.005). Pre-to-posttest significant decrease in contralateral hip angle at touchdown (º) HS60% (-4,01%; p=0.004) CON (-3.13%; p=0.006).
[30]	Significant decreases in Quads Iso Peak Torque (N) in G20 (-14.4 ±12.5%) and G10 (-1.7 ±6.7%) no difference between groups. No additional significant effects. No additional significant effects.	Greater improvement G10 in 10-m sprint time (s) (-5.5 ±3.3% vs -1.74 ±5.94%) 20-m sprint time (s) (-2.5 ±2.1% vs 1.4 ±3.76) than G20. No additional significant effects.	Significant decreases in CMJ height (cm) G20 (-7.1 ±4.7%) and G10 (-1.7 ±6.7%). No additional significant effects.		
[7]	VL15 significant improvement Squat 1RM (P<0.01). VL15 likely positive effect Squat 1RM (kg) (101.3 ±18.1 to 110.3 ±14) vs VL30 possibly a positive effect Squat 1RM (kg) (100.2 ±20.3 to 106.5 ±28.5) VL15 possibly positive effect AMPV (m/s) (1.19 ±0.12 to 1.23 ±0.09) vs VL30 unclear effect AMPV (ms) (1.16 ±0.11 to 1.18 ±0.13)	No significant differences between pre-to-post-test in both groups.	VL15 significant greater improvement CMJ height (cm) (P<0.05). VL30 no significant CMJ improvements. Possibly negative effects CMJ performance VL30 groups	Significant difference pre-to-post-test in YYIRT (m) in both groups (P<0.01). No significant difference in changes between groups.	

**Acute responses*

A conceptual overview elaborated by the authors of this scoping review can be seen in Figure 2. This overview aims to systematize the complexity of the field and present it in an intelligible manner.

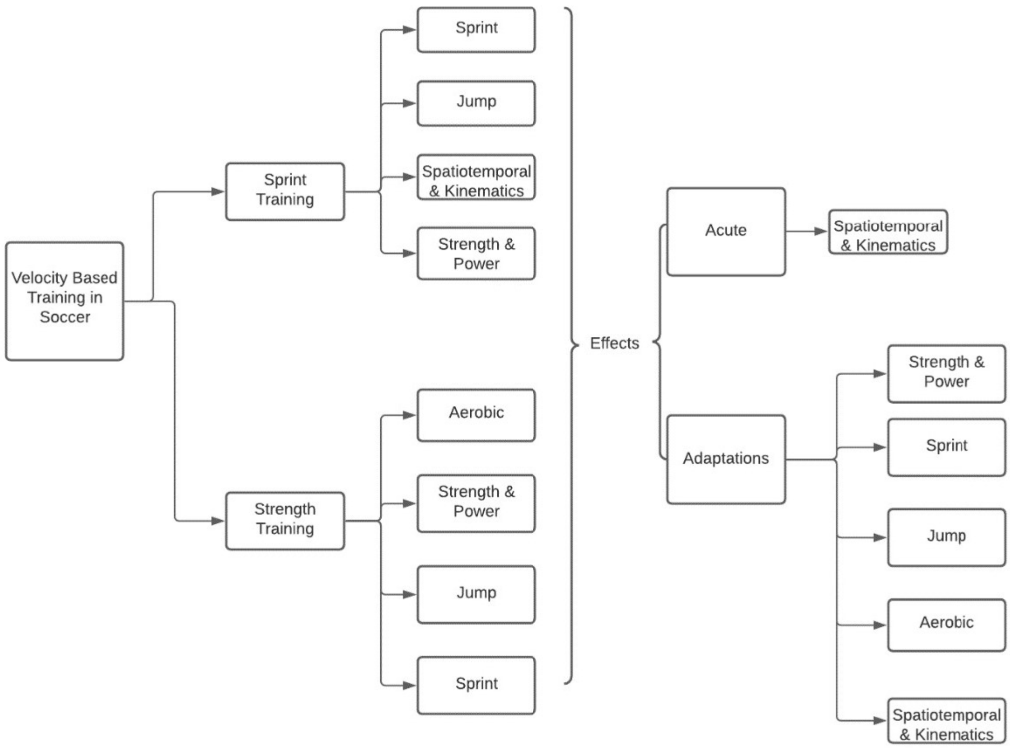

Fig. 2. Concept map.

4. Discussion

This systematic review presents the effects of velocity-based training used in traditional strength training and in resisted sprints, as well as its impact in a soccer context, either in terms of acute responses or chronic adaptations.

4.1. Discussion of evidence: Acute effects

4.1.1.Kinematic and Spatiotemporal

Only the study by Lathi [32] assessed kinematic and spatiotemporal variables such as the ones seen in Table 2. The heavier group (HS60%) had significant increases in all spatiotemporal variables (contact time, step rate, and step length) and some kinematic variables (touchdown CM distance and CM angle at touchdown), whereas the lighter group (HS50%) only influenced kinematic variables (touchdown CM distance and CM angle at touchdown). This difference in spatiotemporal variables, although not a driver for increases in performance, may be a useful tool for coaches to teach their athletes how to push or create force against the ground and project themselves with the right cues since they spent more time on the ground in each step, giving them also more time to improve that skill using a movement pattern very similar to the unresisted acceleration phase.

Kinematic variables also had an immediate response to resisted sprints. CM touchdown distance and CM angle at touchdown, which led to taking steps further behind the CM, but with no carry-over to changes at them of the intervention during unresisted sprints. More research is needed using heavy loads to induce significant velocity decrements according to the individuals' load-velocity profiles.

4.2. Discussion of evidence: Adaptations

4.2.1. Strength and Power

All the studies in this review [7, 31, 32, 36] had a positive outcome in terms of strength, with the exception of [30]. Loturco and Pareja-Blanco [7, 31] used the squat exercise as their training intervention and their exercise test to assess strength improvements. Therefore, it is expected that either due to neuromuscular adaptations or increased squat ability (or a combination of both), their squat 1RM would increase. Another study by the same author [37] compared the effects of the same training intervention but with two different velocity losses (V.Loss) of 20% (VL20) and 40% (VL40%) in various outcomes, one of which was strength. Their results are in line with the results reviewed in this paper, as they found no significant differences between groups in strength adaptations. The other three studies [30, 32, 36] used different exercises in their intervention groups and means to assess strength adaptations. Morin [36] used 80% of athletes' body weight (BW) and Lahti [32] used 94% for HS50% and 120% for HS60% groups, whereas, Grazioli used loads between 45–65%, which are considerably lighter than the other studies. This difference in loads might possibly allow the heavier groups to spend more time on the ground (as happened in Lahti [32] and discussed in Chapter 4.1.1), thus giving athletes more time to achieve their peak force and stimulating strength increases. In fact, the first steps of the acceleration are considered to be dependent on maximal strength [38]. Thus, this relationship could theoretically work in both directions, especially in the early acceleration phase, which is heavily resisted, such as in the studies of Morin and Lahti [32, 36].

It is known that resistance training can improve the power output [39, 40] in the reviewed studies; whether from a squat exercise [31] or resisted sprints [32], interventions had a positive adaptation on power. Loturco based on max strength (%) achieved, and Lahti used max speed (VBT) to improve that physical quality. In Lahti's [32] study, power (Pmax) was significantly greater in the HS50% group than in the control group and was considered the main driver for improving sprint ability. The optimal load that maximizes power output is extremely variable, according to, for example, the exercise, the athlete, and their training status. Therefore, it might be important to access the individual load for each athlete in each exercise [41]. The use of VBT to create an individualized force-velocity profile for squats or sprints should be a good recommendation for strength and conditioning coaches if they want to maximize power output.

Finally, it would be interesting to consider isometric measurements alongside squats 1RM to see how much strength came from neuromuscular adaptations and exercise proficiency. It would also be interesting to standardize the velocity-based training approach. For example, in Loturco [31], increases or decreases in velocity throughout the second part of the intervention were based on %1RM instead of adjusting the load according to the individual load-velocity profile (FVp) or a standardized velocity (ex: between 0.5–0.6 ms).

4.2.2. Sprint

At the other end of the spectrum, sprint increased more when less velocity loss occurred during a set [7] of the squat, velocity stop throughout multiple sets during resisted sprints [30] or relative to their maximum ability [32], HS50% and HS60% groups, were only HS50% had significant differences in changes relative to control group, a better stimulus across the acceleration phase and overall favoritism to improve sprint ability. Indeed, fatigue accumulation seems to be detrimental to velocity outcomes. In Grazioli [30], declines of 10 and 20% conducted to the finding that G20 completed more sprints. Also, although the required percentage of minimum intensity required to stimulate speed is still debatable [42], enhanced acute or chronic fatigue might be detrimental to sprint performance just as they are to jumping ability since they are a metric used to assess fatigue levels [43]. Moreover, the difference between an RAST 6 × 30 m and a true speed training is the interval given between each set, allowing athletes either to recover or not, which also indicates has to avoid fatigue accumulation at least during the same session to allow sprint performance adaptations.

According to a systematic review and meta-analysis by Alcaraz [44], it seems that heavier loads (>20% BM) (hence, greater v.loss) in comparison to max speed tend to have a greater transfer to early acceleration, given that it is more strength-dependent [44, 45] and the GCT allow producing more force, this improvement can be seen in Morin [36], where 5-m distance was improved with 80% BM, which is also in line with Lahti [32], where there was a significant change in GCT for the heavier group (HS60%). Also, in Loturco [31], there were squat 1RM increases and improvements in the 10-m but not 30-m sprint along with [7] the 30-m, reinforcing the same correlation between strength and early acceleration. In this same meta-analysis [44], the authors stated that if the load is too heavy (greater v. loss in comparison to maximum velocity), transfer might be reduced due to a lack of a transfer effect, such as GCT, a lack of the stretch-shortening cycle, and H-reflex. Partially in line with Lahti, where athletes' 10-, 20-, and 30-m sprint times were improved with loads between 94% and 120%, the lighter group (HS50%) had better improvements than their counterparts in the 10-m sprint. It is also worth mentioning that subjects also performed unresisted sprints, and thus, improvements in the longer distances of 20 and 30 m might not be correlated with sled, mainly because of the differences in transferability has mentioned above.

In conclusion, interpreters must understand the difference between velocity loss utilized in Grazioli [30], where G10 and G20 stop when sprint times decrease by 10 or 20%, respectively, and fatigue was accumulated with a bigger magnitude in the latter group. The same was found by Loturco [31] during squats and the velocity loss due to increased load, such as in Lahti and Morin [32, 36] but not necessarily accumulating the same magnitude of fatigue related to the inability to contract faster and stronger.

It seems that for the acceleration phase, greater velocity loss is induced by external load. However, the same probably does not apply to maximum sprint due to the differences in kinetics and kinematics [44]. However, with the studies in this review, certain conclusions should not be made because some studies used a mix of resisted and unresisted sprints.

Finally, since 50% velocity loss during a sprint showed better results than 60%, it would be interesting to know at what point increases in velocity loss stop being resisted sprints and become a general overload exercise.

4.2.3. Jump

Three studies addressed jumping performance. Two of them used the squat exercise or a close variation [7, 31] to increase either velocity or intensity and velocity loss during a set. The other one used resisted sprints [30], also using velocity loss cap throughout sets.

Jumping—more specifically, CMJ—is the result of interaction between muscular proprieties during the concentric and eccentric phases in combination with the elastic elements and neural properties [46]. Jumping performance is ultimately determined by impulse [47], but since the time taken to produce force is limited due to the nature of the task, the rate of force development (RFD) may be of great importance for jumping performance [12]. Moreover, in the same paper by Suchomel and colleagues [12], of 59 studies, 57 (97%) reported a positive correlation of greater than or equal to 0.3 (moderate relationship), of which 44 (75%) had a large (0.5) relationship between strength and RFD. Thus, Loturco [31] found improvements in Squat 1RM in conjunction with gradual exposure to different parts of the strength curve (30–60% 1RM) focused on power development helped improve subjects' jumping performance. The same happened in Pareja-Blanco's study [7], but only in the VL15 group. This could be due to less positive increases in Squat 1RM or to greater v. loss accumulated throughout each set. Pareja-Blanco [7] reported that the VL30 group performed more repetitions more slowly than the VL15 group. This slower velocity of repetitions caused greater velocity losses within a set, which are related to fatigue and could negatively affect neural adaptations that are also related to RFD [37]. In the latter study [37] with a similar protocol to the one in this review [7], this time with 20%

vs. 40%, resulted in similar outcomes in jump performance. Only one study addressed the impact of resisted sprints, with loads varying between 45-65% BW, accumulation 10 or 20% of velocity, with no positive effects. Therefore, further investigations of different velocity loss to either a unresisted sprint or within session v.loss fatigue related should be employed.

In summary, it seems that when the focus is to increase strength, it can also benefit jump performance (at least for the squat exercise), low v.loss (<=20%), during a set seems to be more beneficial than higher thresholds (>=30%). It can also be a strategy during the soccer season, where fatigue management is of great importance due to congested schedules. It would also be interesting to use v.loss during a set of squats also across an entire training session, where athletes would stop performing squats when total velocity loss was, for example, 10% or 20%, as in Grazioli's study [30].

4.2.4. Aerobic

Only Pareja-Blanco [7] addressed the differences in aerobic components when using two different velocity losses within the same set, showing positive outcomes and finding no differences between groups.

There are three key components for endurance performance: VO2max, lactate threshold, and efficiency (also known as running economy) [48]. Strength training is known for its effects on running economy [49,50]. Since both groups had similar strength increases and the soccer-specific training was kept equal to both groups at first, this result should be expected only when accounting for strength gains. On the other hand, due to higher v.loss in one of the groups, jumping performance (as mentioned above) was affected, which could indicate a decrease in the utilization of the stretch-shortening cycle, which is also a contributing factor to running economy [51], but no test has fully addressed this situation. Meanwhile, the study by Pareja-Blanco implemented the 20 and 40% velocity loss during the squat and addressed changes in muscle fiber type changes. The results indicated that the VL40% had a shift in fiber type, from the faster (IIX) to slower IIA but was more resistant to fatigue. This result might also occur in the reviewed study [7], counterbalancing the possible diminishing utilization of the SSC.

Finally, although both groups improved their aerobic performance, the VL15 [7] and the VL20 groups [37] accumulated considerably less fatigue with the same outcome. In the long term or during specific soccer training, the same fatigue could diminish aerobic improvements due to a poor ability to perform endurance training.

4.2.5. Kinematic and Spatiotemporal

There was only one study [32] in this review that addressed the impact of different velocity losses during sprint training in kinetic and spatiotemporal variables.

Although there was an immediate impact in both early acceleration and in upright sprint, those mechanics did not transfer to unresisted sprint in either phase. By contrast, light resisted sprint training has shown a slight increase in trunk lean [44,52]. In the study by Spinks [52], thirty first-level grade male subjects from various sports (soccer, rugby union, and Australian soccer) endured either the sprint plus the resisted sprint (RS) (10% v.loss), sprint training (RS) or the control group (C). The training protocol lasted for eight weeks with a frequency of two times per week, totaling 16 sessions, where kinematic factors such as trunk lean, where both RS and NRS groups significantly improved trunk lean. However, only the RS group was significantly different than the control group. It is also worth mentioning that in this same study [52], athletes only sprinted 15 m, and the load that induced the 10% velocity loss was calculated by Lockie [53], whereas Lathi [32] used the induvial force-velocity profile proposed by Cross [54], using distances between 20 and 45 m. This difference in the load selection test could mean that the "lighter" load in Spinks [52] could actually be different if they had used an induvial load-velocity profile as in Cross [54].

Therefore, it is recommended to use a standardized test—preferably the individual load-velocity profile—to ensure that precise velocity loss is induced and studies can be better compared. Finally, it seems that heavy resisted sprint training does not affect unresisted sprint kinematics in either the acceleration or upright sprint phases. The long-term use of this training method is also recommended.

4.3. *Study limitations*

Due to the limited research using the same loading protocols (%1RM or VBT), training protocols, and different ways to impose velocity loss (fatigue, external load), as well as the lack of research on heavy resisted sprints, more research should be done using standardized methods such individual load-velocity profile or velocity targets (e.g., squat 3 × 3 at 0.4-0.5 ms).

4.4. *Future research and practical applications*

- It seems that increases in strength for low v. loss (<20%) during the squat exercises do not differ in terms of outcomes.
- Although higher loss has an increased potential for hypertrophy [37], it also increases fatigue and has less positive (or even negative) effects on jumping performance [7, 37].
- Therefore, the use of velocity loss imposed by fatigue accumulation should be both monitored and periodized during every training session. Thus, velocity should be monitored to understand increases in a given exercise or to adjust load according to the athlete’s readiness. Periodize v.loss according calendar, for example, imposing higher v.loss during the off-season and lower v.loss during the season, or even body parts, allowing higher velocity thresholds for the upper body in soccer players if hypertrophy is desired, as thresholds that are too high for the lower body might impose too much fatigue when combined with specific soccer training.
- Regarding specific sprint training with overload (sled), it seems that when too much velocity loss is imposed throughout a training session, the overall fatigue accumulated during every set decreases sprint performance, as seen in Grazioli [30], where G10 had better improvements in the 10- and 20-m sprint than the G20, which completed more sprints.
- Performing more traditional strength training, such as squats with a high v.loss during a set (30%+), also lead to an overall accumulated fatigue in every set, as a decrease in resisted sprint training done with low-velocity loss by accumulated fatigue (as in the G10) if performed in the same day or training session?
- If so, should matching traditional strength training speeds and v.loss due to fatigue for a given exercise be paired with speed- and agility-based training or soccer-specific training?
- It seems that higher v.loss due to external low during resisted sprints improves sprint performance.
- External loads should be imposed according to time decreases compared to unresisted sprints instead of using %BM, hence v. loss compared to maximum velocity.
- If possible, practitioners should use an individual load-velocity profile to prescribe loads that induce v.loss compared to maximum velocity. If not possible, a recommendation is to choose a fixed load (%BM) and see if improvements in resisted sprints match improvements in unresisted sprints. The same can be done for other exercises (e.g., squat jump) at a given fixed speed and CMJ height.
- Heavier loads up to a certain point (60% v.loss relative to maximum speed according to Lahti [32]) can also improve sprint performance with effects in kinematic variables.
- A v.loss of 50% compared to maximum speed during sprints has a clearly superior effect to a v.loss of 60%.

5. Conclusions

With increases in VBT technology's availability and reliability, practitioners should consider using these devices to accurately prescribe training according to the athlete's readiness, objectives, and schedule. VBT metrics like v.loss due to fatigue accumulation should be implemented to better manage fatigue manly during the soccer season.

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