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REVIEW

Effects of Maturation Stage on Sprinting Speed Adaptations to Plyometric Jump Training in Youth Male Team Sports Players: A Systematic Review and Meta-Analysis

Ana Filipa Silva[1–3], Rodrigo Ramirez-Campillo[4], Halil İbrahim Ceylan[5], Hugo Sarmento[6], Filipe Manuel Clemente[1,2,7]

[1]Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, Viana do Castelo, 4900-347, Portugal; [2]Research Center in Sports Performance, Recreation, Innovation and Technology (SPRINT), Melgaço, 4960-320, Portugal; [3]The Research Centre in Sports Sciences, Health Sciences and Human Development (CIDESD), Vila Real, 5001-801, Portugal; [4]Exercise and Rehabilitation Sciences Laboratory, School of Physical Therapy, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile; [5]Physical Education and Sports Teaching Department, Kazim Karabekir Faculty of Education, Ataturk University, Erzurum, 25240, Turkey; [6]University of Coimbra, Research Unit for Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, Coimbra, 3040-256, Portugal; [7]Instituto de Telecomunicações, Delegação da Covilhã, Lisboa, 1049-001, Portugal

Correspondence: Ana Filipa Silva, Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, Viana do Castelo, 4900-347, Portugal, Tel +351 258 809 678, Email anafilsilva@gmail.com

Purpose: To determine the effects of maturation stage (eg, classified in the same intervention protocol as early-, and late-mature) on linear sprinting speed adaptations to plyometric jump training (PJT) in youth (aged <18 years) male team sports players.

Patients and Methods: Eligibility criteria was determined based on PICOS: (P) healthy youth male team sport players classified in the same intervention protocol in ≥2 maturation-related categories, based on a recognized maturation stage-determination method, including (but not limited to) Tanner stage; peak height velocity (eg, Mirwald method); radiography-based method (eg, Fels method); (I) athletes exposed to PJT with a minimum of 4 weeks duration; (C) athletes non-exposed to PJT (non-dedicated intervention, ie, only field-based regular training) or performing a parallel intervention not-related with PJT organized by maturation levels; (O) sprinting speed (eg, time, maximal sprint speed) measured in any linear sprint test trajectories before and after the intervention; (S) only randomized controlled and/or parallel trials. Searches were conducted on December 2021 in EMBASE, PubMed, Scopus, SPORTDiscus and Web of Science, restricted to Portuguese, Spanish and English languages, with no restrictions regarding publication date, and no filters applied. The PEDro scale was used to assess the risk of bias in the included studies. Meta-analysis was computed using the inverse variance random-effects model. The significance level was set at $p < 0.05$.

Results: The search identified 1219 titles. From those, four studies were selected for qualitative and quantitative synthesis. Four studies provided data for sprinting performance, involving 10 experimental and 8 control groups showing a small effect of trained participants on sprinting performance (ES = 0.31; p = 0.064; I2 = 41.3%) when compared to controls. No significant moderator effect was noted for somatic maturity (p = 0.473 between groups).

Conclusion: PJT had no significant effect on sprinting performance, although the inclusion criteria partially may explain that.

Keywords: plyometric exercise, team sports, athletic performance, youth sports, puberty

Introduction

Team sports (eg, soccer, rugby, handball, basketball, futsal, volleyball) are typically characterized by an intermittent effort in which low-to-moderate intensities are interspaced by high-intensity demands.[1] Although natural differences exist among team sports, most of them require a multilateral well-developed physical fitness.[2–4] Thus, players must be prepared to sustain efforts (eg, good locomotor profile), while being able to quickly produce force to be able to jump,

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accelerate, sprint, change of direction or perform explosive actions such as shooting or kicking.[5–7] These requirements are key to differentiate older vs younger[8,9] and elite vs non-elite.[10,11] Additionally, holding a better physical fitness can be determinant to contribute for a high success in talent identification and selection, mainly after the peak height velocity.[12]

Among the particularities of team sports, performing high-demanding locomotor activities such as sprinting can be critical considering the relationship with important events such as scoring,[13] or quick transitions.[14,15] Thus, for competing faster, holding a better sprinting capacity is required as an example of studies showing significant correlations between locomotor demands occurring in match with the players physical fitness.[16,17] For instance, in young basketball players a lower physical fitness was found to be significantly associated with external variables during simulated matches in different categories (U14, U16 and U18).[16] Also, in rugby, it was found large and positive relationships between the player's maximal speed and both peak running speeds and metabolic power during competition, and large and negative associations between maximal speed and the rate of decline in running speed and metabolic power during competition.[17]

Since sprinting can be determinant, different training methods are employed to increase this ability in male soccer.[18,19] Closer to this ability emerges the capacity to accelerate and decelerate, which is also important in team sports such as basketball and volleyball [eg[20,21]]. Besides the more specific sprinting training (maximum or near-to-maximum running) and sprinting drills (technical focus),[22] other training methods can be used as assisted or resisted sprints,[23] or non-specific training methods as strength and power training.[24,25] Among power training, plyometric jump training (PJT) can be a way to employ a reactive strength training[26] which may positively affect the sprinting performance. One of the facts can be related with the optimization of stretching-shortening cycle (SSC)[27] and reactive strength[26] during PJT, which is prevalent in maximal speed attained in sprinting.[28] Moreover, considering that PJT has been suggested as a method that improves strength performance,[29] could also play a positive transfer for sprinting mechanics.[30]

Soccer is an intermittent-type sport and includes various explosive ballistic actions such as jumping, sudden changes of direction, accelerations, decelerations, and sprinting. Although these explosive actions make up a small percentage of the total match time, they are considered very important for success.[31,32] Sprinting, which is the most common action when scoring goals for young soccer players,[13] is one of the important determinants of high-level youth soccer performance.[33,34] Within a soccer match, such actions repeatedly generate explosive oscillations and impacts, using the SSC, requiring fast force generation and high-power output. In short, almost every explosive movement during a soccer match involves SSC,[35] during which the previously stimulated muscle is first stretched (eccentric action), and then shortened (concentric action). Plyometric exercise appears to be a crucial tool for the implementation of the SSC mechanism.[36,37] Studies have shown that SSC stimulation ensured by plyometric training (PT) programs improves physical performance characteristics such as sprinting,[38,39] changing of direction,[39] strength and peak power output,[40] jumping,[34] and can even reduce the risk of sustaining injuries.[41]

Considering the above-mentioned assumptions, some systematic reviews have been revealing the beneficial effect of PJT on sprinting in team sport players. As an example, a systematic review conducted in soccer players revealed that PJT was significantly effective for improving sprinting performance.[34] Moreover, a meta-analysis performed in different ages and sports (such as American football, gymnastics, basketball, rugby and soccer) also confirmed the effectiveness of PJT which incorporates horizontal acceleration for imprinting sprinting performance.[42] More examples of training effectiveness of PJT can be observed in adult soccer players,[43] handball players[44] or basketball players.[45]

Although solid evidence regarding the effectiveness of PJT for improving sprinting, it seems important to consider some particularities regarding the effectiveness in specific populations. In the case of youth, maturation status can be an important factor that can influence the response to the training stimulus.[46] In fact, growth and maturation play an important influence on the muscle-tendon and neuromuscular adaptations changing the responses to muscle cross-sectional area, fascicle length, pennation angle, or tendon architecture and stiffness.[46] However, the literature is scarce regarding the effects of maturation status on the adaptations to PJT. One of the few examples considering comparisons of PJT effectiveness between different maturation status was conducted in the change-of-ability gains.[47] In this meta-analysis was found that youth players in mid or post stage of maturation were significantly benefitted by PJT in comparison to early mature players.[47]

In the case of sprinting performance, it is expectable to also assist to some differences between maturation status. In fact, maturation seems to play a critical impact on the ability to absorb and produce power while sprinting.[28] Thus, it is also expected to attend to different adaptations to PJT, since neural and morphological conditions are different regarding the maturation status. Despite these expectations, there is no systematic review with meta-analysis that may help to provide general evidence regarding the impact of maturation status on the PJT effectiveness for improving sprinting performance. This can provide an opportunity to define the most appropriate period for introducing PJT in youth, and to identify the conditions to do that. Thus, the aim of this systematic review with meta-analysis was to determine the effects of maturation stage (eg, classified in the same intervention protocol as early-, and late-mature based on Tanner stage or peak height velocity using Mirwald formula or Fels method using radiography-based method) on linear sprinting speed adaptations to PJT in youth (aged <18 years) male team sports players.

Methods

The current systematic review and meta-analysis was written based on the recommendations of PRISMA 2020 guidelines.[48] The protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols with the number 202240006 and the DOI number INPLASY202240006.

Eligibility Criteria

The eligibility criteria were defined based on PICOS (Table 1). Articles were restricted to those written in Portuguese, Spanish, and English languages, and published as original articles in peer-review journals, with no restrictions regarding publication date, and no filters applied.

Table 1 Eligibility Criteria Based on PICOS

	Inclusion Criteria	**Exclusion Criteria**
Population	Healthy youth (aged <18 years for the case of mean value for the group) male team sport athletes classified in the same intervention protocol as early-, and late-mature based on Tanner stage or peak height velocity (Mirwald formula) or Fels method (radiography-based method). The athletes must be part of a competitive team sport and not part of a physical education programme.	Athletes aged ≥18 years. Female participants. Non-team sport athletes (eg, physical education students; individual sports). Players with injury, illness, or imbedded in return-to-play programmes.
Intervention	Plyometric jump training (eg, bilateral and/or unilateral, loaded and/or unloaded) with a minimum of 4 weeks duration.	Upper-body plyometric training (eg, medicine ball throws only). Plyometric jump training combined with other training method (eg, resistance training).
Comparator	At least two maturation stages. Athletes non-exposed to plyometric jump training either passive (non-dedicated intervention, only field-based regular training) or active (alternative training method)	Studies not including in the same research two (early and late) or more maturation stages. Other plyometric jump training group (ie, plyometric jump training vs plyometric jump training without a control group performing alternative approach). Cases of two plyometric jump training groups and a control, were included.
Outcome	Pre-post intervention values of sprinting speed (eg, time measured by photocells and/or optical systems; maximal sprint speed measured by radar gun and/or optical systems) in linear speed test trajectories.	Non sprinting speed outcomes (eg, acceleration; ground contact time). No change-of-direction testes and/or repeated sprint tests. No numerical data reported as mean and standard deviation (or similar values) at pre- or post-intervention moments.
Study design	Randomized controlled and/or parallel trials.	No-randomized and non-controlled studies

Information Sources

The search for the current systematic review was conducted in the following databases: EMBASE, PubMed, Scopus, SPORTDiscus and Web of Science. Searches were conducted on December 02, 2021. After the conclusion of the automatic search, a manual search was performed using the reference list of the included articles and searching in systematic reviews conducted in similar topics. Systematic reviews were searched in the same databases with the terms "systematic review" OR "reviews" after the regular search strategy. Additionally, we also asked two external experts in plyometric training (with Ph.D. and with publications in indexed journals) for checking the inclusion list of articles and to identify possible articles missing in the list. The experts were found and included based on Expertscape rank for "Plyometric+training" that can be found in the link: https://www.expertscape.com/ex/plyometric+exercise

Search Strategy

Tree text terms and Boolean operators (ie, AND/OR) were applied in the sections of title or abstract, using no filters or limits to conduct the search. The following general search strategy was conducted:

("team sport*" OR "soccer" OR "football*" OR "rugby" OR "futsal" OR "basketball" OR "volleyball" OR "handball" OR "korfball" OR "baseball" OR "softball" OR "polo" OR "hockey" OR "cricket" OR "lacross" OR "dodgeball" OR "netball" OR "ultimate frisbee") AND ("plyometric*" OR "ballistic" OR "stretch-shortening cycle" OR "reactive strength" OR "jump") AND ("sprint*" OR "speed" OR "velocity") AND (male OR men).

Selection Process

Two co-authors (HS and FMC) independently conducted the selection process, using a specially designed Excel file. Each record was screened (title/abstract), reporting any case of doubt. A third co-author (AFS) participated in a final meeting to discuss possible disagreements between co-authors. The automatic filter of EndNote™ 20.1 for Mac (Clarivate™) was used to remove duplicates in the list of references after conducting the searches. The reason for exclusions were registered and organized in the final document.

Data Collection Process

Two co-authors (AFS and FMC) independently collected data. A third co-author (HS) participated in case of disagreements between co-authors. No automatic tools were used for data collection.

Data Items

Primary Outcomes

Sprinting speed (measured in seconds for the case of time or measured in m/s or km/h for the case of maximal sprint speed) was considered as the main outcome. The sprinting time must be obtained in linear trajectories from a minimum of 5-meters to a maximum of 100-meters sprint test. Sprinting time must be obtained using photocells, optical systems, or similar instruments with a high-level of reliability. Specific cases, if any, as stop watches can be included in case of intra and inter-observers' reliability levels presented in the article.

Secondary Outcomes

Cases of injuries or related adverse event due to PJT were recorded.

Additional Variables

Experiment-related variables were considered for characterization of the participants and training interventions/control groups. For the characterization of participants, the following information was obtained: (i) chronological age (years); (ii) years of training and competition experience; (iii) competitive level (eg, regional, national); (iv) country; (v) maturation status (early and/or late) criteria based on Tanner scale, peak height velocity and/or Fels method. For the case of training intervention: (i) duration (weeks); (ii) weekly frequency; (iii) adherence to the program; (iv) type of exercise (eg, unilateral, bilateral, loaded, unloaded, combined); (iii) intensity level; (iv) jump box height; (v) number of total jumps completed per session and/or during intervention; (vi) rest type (active/passive) between sets (min); (vii) rest time between repetitions (s); (viii) rest between sessions; (ix) type of jump surface (eg, unstable, stable, grass); (x) training period of the year (eg, pre-season, in-season). Information about control group included: (i) passive and/or active; and (ii) specification of alternative training method.

Study Risk of Bias Assessment

The risk of assessment was assessed using the Physiotherapy Evidence Database scale (PEDro) which was developed for randomized-controlled trials.[49] The PEDro scale consists in an eleven-items assessment tool, in which the score of 1 means "yes" and 0 means "no". The final score consists in the sum of scores from item 2 to item 11. The item one "eligibility criteria were specified" is not considered for the final score calculation. The PEDro scale was independently used by two of the co-authors (AFS and FMC) to assess and classify the included articles. After the independent assessment, the two lists were compared and discussed with a third author (HS) aiming to solve possible disagreements by discussion.

Effect Measures and Synthesis Methods

A previous established method was followed,[19,34] which the analyze and interpretation of results were only accompanied in the case of at least three studies provided baseline and follow-up data for the same measure. To estimate the effect size (ES; Hedge's g) for each outcome measure in the maturation groups, pre-training and post-training mean and standard deviations (SD) for dependent variables were used. Data were standardized using post-intervention SD values. The random-effects model was used to account for differences between studies that might impact the PJT-based effect.[50,51] The ES values untaken 95% confidence intervals (CI). Estimated ES were interpreted as followed: <0.2, trivial; 0.2–0.6, small; >0.6–1.2, moderate; >1.2–2.0, large; >2.0–4.0, very large; >4.0, extremely large.[52] Heterogeneity was measured using the I^2 statistic, being considered as i) low, with values of <25%, ii) when the values were between 25–75% was moderate, and iii) high levels of heterogeneity are considered with >75%.[53] The risk of bias was investigated using the extended Egger's test.[54] When it was present, the trim and fill method was used,[55] in which case L0 characterizes the default estimator for missing studies.[56] All analyses were conducted using the Comprehensive Meta-Analysis software (version 2; Biostat, Englewood, NJ, USA). Statistical significance was fixed at $p \leq 0.05$. Moderators related with training frequency, training type, or team sport can be considered in case of two or more studies.

Results

Study Selection

The databases identified an initial 1219 titles. Those studies were transferred to reference manager software (EndNoteTM X9, Clarivate Analytics, Philadelphia, PA, USA). Afterwards, the duplicates (372 references) were excluded either automatically or manually. The remaining 847 articles were screened for their relevance based on titles and abstracts, resulting in the exclusion of 736 studies. After the screening procedure, 17 articles were selected for in depth reading and analysis further excluding 94 for not matching the titles and abstracts with the eligibility criteria. Following reading full texts, an additional 13 studies were removed. Nine articles were excluded based on the fact of not having at least two maturation groups in the analysis.[35,36,57–63] Three articles were excluded by the absence of including PJT.[64–66] One study was excluded for not having a linear sprint test.[67] Therefore, 4 articles[40,68–70] were eligible for the systematic review and meta-analysis (Figure 1). The four studies included provided mean and SD of reliability data.

Risk of Bias of Individual Studies

With the PEDro checklist it was possible to determine that 2 studies were classified with 6 points, and 2 studies with 7 points (Table 2). Randomization was not present in two of the studies.[68,69]

Characteristics and Results of the Included Studies

The features of the 4 studies included in the meta-analysis can be observed in Table 3. In addition, the details of the PJT-based programs can be checked in Table 4.

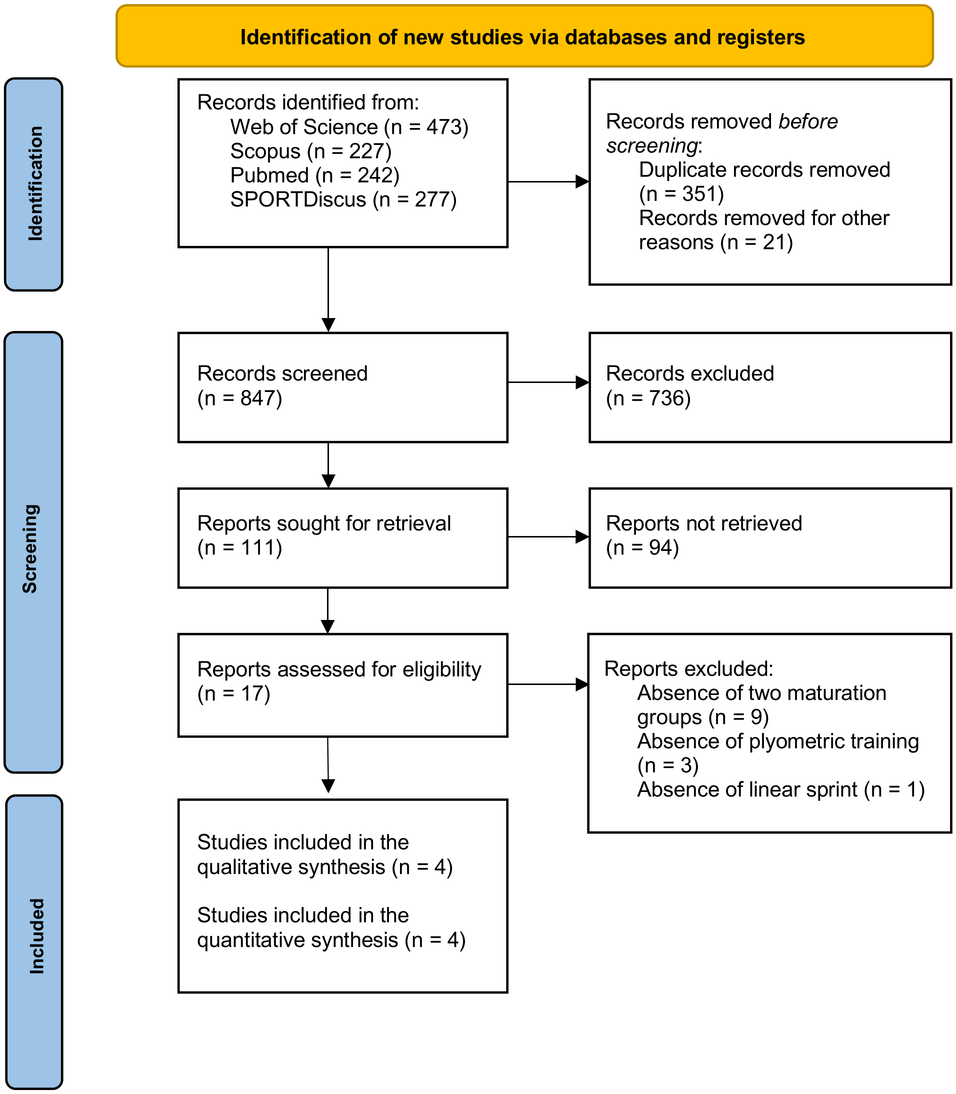

Figure 1 PRISMA flowchart.

Notes: PRISMA figure adapted from Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev 10, 89 (2021). Creative Commons.[48]

Four studies postulated data for sprinting performance, involving 10 experimental and 8 control groups (pooled n = 307). Results showed a small effect of trained participants on sprinting performance (ES = 0.31; 95% CI = −0.02 to 0.65; p = 0.064; I^2 = 41.3%; Egger's test p = 0.761; Figure 2) when compared to controls.

Figure 3 reveals that no significant moderator effect was noted for somatic maturity (p=0.473 between groups). Mid, post, and pre groups included 3, 3 and 4 studies in the analysis, respectively, with I^2 values of 0.0%, 76.0% and 0.0%, respectively.

Discussion

The purpose of the present systematic review with meta-analysis was to determine the effects of maturation stage (eg, classified in the same intervention protocol as early-, and late-mature based on Tanner stage or peak height velocity using Mirwald formula or Fels method using radiography-based method) on linear sprinting speed adaptations to PJT in youth (aged <18 years) male team sports players. The present study found no significant advantages in using PJT programmes overactive control groups in terms of enhancing the sprint performance of soccer players, although minor changes were

Table 2 Methodological Assessment with Physiotherapy Evidence Database (PEDro) Scale

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Asadi et al[40]	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7
Moran et al[68]	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6
Peña-González et al[69]	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	6
Vera-Assaoka et al[70]	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7

Notes: PEDRro scale items number: the total number of points from a possible maximal of 10; N.°1: eligibility criteria were specified; N.°2: subjects were randomly allocated to groups; N.°3: allocation was concealed; N.°4: the groups were similar at baseline regarding the most important prognostic indicators; N.°5: there was blinding of all subjects; N.°6: there was blinding of all therapists who administered the therapy; N.°7: there was blinding of all assessors who measured at least one key outcome; N.°8: measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups; N.°9: all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention to treat"; N.° 10: the results of between-group statistical comparisons are reported for at least one key outcome; and N.°11: the study provides both point measures and measures of variability for at least one key outcome.

Table 3 Characteristics of the Included Studies and Outcomes Extracted

Study	N	Mean Age (yo)	Sex	Type of Control Group	Outcomes	Tests Used in the Original Studies	Measure Extracted from the Tests in the Original Studies
Asadi et al[40]	Pre-PHV =20, Exp:10, ActCon: 10 Mid-PHV = 20, Exp:10, ActCon:10 Post PHV = 20, Exp:10, ActCon: 10	Pre-PHV = Exp: 11.5 ± 0.8, ActCon:11.7 ± 0.4 Mid-PHV = Exp: 14.0 ± 0.7, ActCon:14.2 ± 0.6 Post PHV = Exp: 16.6 ± 0.6, ActCon:16.2 ± 0.3	M	ActCon: Soccer specific training (3 days per week soccer training)	20-m sprint with and without dribbling the ball	20-meter sprint test (Times were recorded to the nearest 0.01 s (JBL Systems, Oslo, Norway).	20-m sprint time (s): The fastest sprint time obtained from the three trials were recorded.
Moran et al[68]	Pre-PHV =21, Exp:9, ActCon: 12 Mid-PHV = 17, Exp:8, ActCon:9	Pre-PHV = Exp: 12.6 ± 0.7, ActCon: 12.8 ± 0.8 Mid-PHV = Exp: 14.3 ± 0.6, ActCon: 14.3 ± 0.6	M	ActCon: low intensity hockey skills training (2 days per week, one competitive game against other school opposition)	10-m and 30-m sprint running times	Acceleration (10 m) and maximal speed (30 m). Running times were measured by TC System timing gates (Brower Timing Systems, Draper, Utah, United States). T	10-m sprint (s) 30-m sprint (s) The best of three trials (one minute of rest between trials) were recorded.
Peña-González et al[69]	Con: 20 Pre-PHV = 43 Mid-PHV = 36 Post PHV = 31	ActCon: 13.2±1.1 Pre-PHV = 12.8±0.4 Mid-PHV = 13.8±0.6 Post PHV = 13.8±0.6	M	ActCon: participated soccer specific trainings (three days a week, 90 min.)	30-m sprint	30-m sprint were used by photoelectric cells (Datalogic S6 Series, Bologna, Italy)	30-m sprint (s): The best of two trials (two minute of rest between trials) were recorded.
Vera-Assaoka et al[70]	Con-Early: 16 PJT-Early: 16 Con-Late: 22 PJT-Late: 22	Con-Early: 11.5±0.9 PJT-Early: 11.2±0.8 Con-Late: 14.5±1.1 PJT-Late: 14.4±1.0	M	Con-Early (Tanner stage 1–3) and Con-Late (Tanner stage 4–5): actively participated soccer specific trainings twice a week for 90 min.	20-m sprint	20-m sprint time were measured by single beam infrared reds photoelectric cells (Globus Italia, Codogne, Italy).	20-m sprint (s): The best of three trials were recorded.

found in favor of the PJT. Furthermore, somatic maturity stage (pre, mid and post) had no significant effect on sprint performance to PJT in youth male team sport athletes.

Considering the four studies included in the current systematic and meta-analysis, 3 were conducted on soccer players,[40,69,70] and one in hockey.[68] The results showed that there were no significant improvements in sprinting performance

Table 4 Characteristics of the Interventions made in the Included Studies

Study	BM	H	SPT	Fitness Level*	Laterality	Freq	Wk	BH	TJ	Comb	PO	TP
Asadi et al[40]	Pre-PHV = Exp: 31.0 ± 3.9, ActCon: 33.1 ± 3.2 Mid-PHV = Exp: 43.5 ± 6.3, ActCon: 41.2 ± 7.6 Post PHV = Exp: 60.6 ± 6.7, ActCon: 62.4 ± 7.2	Pre-PHV = Exp: 138.3 ± 6.0, ActCon: 137.4 ± 5.0 Mid-PHV = Exp: 154.5 ± 6.5, ActCon: 150.1 ± 7.2 Post PHV = Exp: 171.5 ± 6.0, ActCon: 176.4 ± 5.0	One week	Semi-professional soccer players (had at least 2 years of soccer training, performed soccer trainings three days/ week for 60–70 min)	N.D.	2 days/week for 30–40 min.	6	20, 40, 60 cm	60 foot contacts per session	No	2 sets, 10 repetitions. The rest period between repetitions and sets was of 7 and 120 s, the training volume during the 6-week period did not increase	Pre-season
Moran et al[68]	Pre-PHV = Exp: 50.9±8.7, ActCon: 52.9 ± 9.0 Mid-PHV = Exp: 58.8 ± 3.4, ActCon: 64.0 ± 8.1	Pre-PHV = Exp: 155.4 ± 5.1, ActCon: 160.4 ± 5.5 Mid-PHV = Exp: 173.1 ± 5.4, ActCon: 171.2 ± 6.0	N.D.	The participants carried out two hockey training sessions per week in addition to one competitive game against other school opposition.	Vertical, horizontal, bilateral and unilateral, totally 11 movements	2 days/week	6	N.D.	60-foot contacts per session	No	1 set, repetitions ranging from 10–30.	N.D.

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Peña-González et al[69]	Control: 50.5 ± 10.3 Pre-PHV = 45.4 ± 5.7 Mid-PHV = 55.8 ± 5.0 Post PHV = 62.3 ± 6.6	Control: 158.2 ± 11.1 Pre-PHV = 154.9 ± 6.2; Mid-PHV = 165.9 ± 4.8 Post PHV = 171.9 ± 10.4	N.D.	First and second level of the Spanish soccer players (3 days a week soccer training for 90 min)	Lateral	2 days/ week for 20 min.)	8	N.D.	N.D.		Plyometric and resistance exercises	9 exercises (performed exercises at maximal speed in 30 seconds. The work/rest ratio was set as 1:1. Between 5–8 weeks, initial load for some exercises increased
Vera-Assaoka et al[70]	Con-Early: 35.8± 3.8 PJT-Early: 36.8 ± 5.1 Con-Late: 55.8±7.9 PJT-Late: 54.7 ± 6.6	Con-Early: 141±4.0 PJT-Early: 143 ±5.2 Con-Late: 162±8.3 PJT-Late: 163 ±7.2	N.D.	>2 years of soccer training (twice a week for 90 min.) and competition experience (one official game per week)	N.D.	PJT-Early and PJT late: 2 days/ week for about 21 min.	7	20, 40, and 60 cm	N.D.	No	2 sets of 10 repetitions, the rest period between repetitions and sets was 15 and 90 seconds, respectively. The volume of training was the same during the 7 weeks	Competitive season

Abbreviations: BH, box height for plyometric drop jumps (cm); BM, body mass (kg); Comb, combined; F, female; Freq, frequency of training (days/week); H, height of participants (cm); M, male; PO, progressive overload, in the form of either volume (ie, V), intensity (ie, I), type of drill (ie, T), or a combination of these; TJ, total plyometric jumps; TP, training period of the season; Wk, weeks of training, ND, not described.

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Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Peña-Gonzalez et al. 2019, Pre-PHV	-0.359	0.412	0.169	-1.165	0.448	-0.872	0.383
Peña-Gonzalez et al. 2019, Mid-PHV	0.000	0.416	0.173	-0.815	0.815	0.000	1.000
Peña-Gonzalez et al. 2019, Post-PHV	0.000	0.420	0.176	-0.823	0.823	0.000	1.000
Asadi et al. 2018, Pre-PHV	0.198	0.429	0.184	-0.644	1.039	0.460	0.645
Asadi et al. 2018, Mid-PHV	0.583	0.438	0.192	-0.276	1.441	1.330	0.184
Asadi et al. 2018, Post-PHV	1.919	0.525	0.276	0.890	2.948	3.656	0.000
Moran et al. 2017, Pre-PHV	0.214	0.425	0.180	-0.618	1.046	0.505	0.614
Moran et al. 2017, Mid-PHV	-0.135	0.462	0.213	-1.040	0.770	-0.292	0.770
Vera-Asaoka et al. 2020, early	0.422	0.349	0.122	-0.261	1.106	1.212	0.226
Vera-Asaoka et al. 2020, late	0.556	0.302	0.091	-0.036	1.147	1.840	0.066
	0.314	0.169	0.029	-0.018	0.645	1.852	0.064

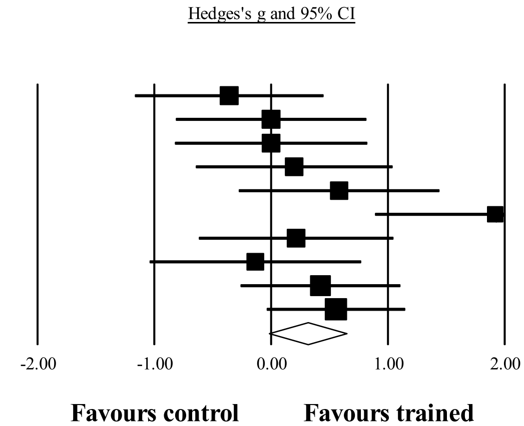

Figure 2 Forest plot of changes in sprinting performance in youth male team sport athletes participating in plyometric jump training compared to controls. Values shown are effect sizes (Hedges's g) with 95% confidence intervals (CI). The size of the plotted squares reflects the statistical weight of the study. The white rhomboid reflects the overall results.

Group by Maturity	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
mid	0.153	0.252	0.064	-0.342	0.648	0.607	0.544
post	0.767	0.482	0.232	-0.177	1.712	1.592	0.111
pre	0.144	0.200	0.040	-0.247	0.535	0.722	0.470

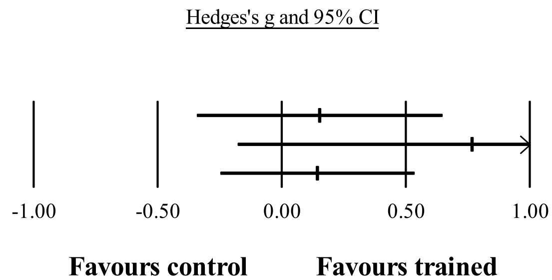

Figure 3 Sprint performance moderated by participant's somatic maturity.

in youth male team sport athletes participating in PJT compared to active controls. The effect of PJT on the sprint performance was observed to have a small effect size (ES = 0.31). Our results are consistent with some studies, such as Padrón-Cabo et al,[71] whom observed that 6 weeks of PT combined with soccer training provided no additional benefits in sprint performance (effect sizes of 0.13, 0.28 and 0.75 for 5m, 10m and 20m, respectively) compared to a normal training routine in youth soccer players. Likewise, Thomas et al[37] showed that 6-week plyometric exercises depend on depth jump or countermovement jump exercises did not improve the sprint performance of young soccer players. Additionally, Peña-González et al[69] found that eight weeks (twice per week) of plyometric training was insufficient for the speed development of young football players. Conversely, regarding the included studies, the results obtained by Asadi et al[40] demonstrated that 6 weeks of low-to-high intensity PT performed twice a week, including 60 foot contacts per session, improved 20 m sprint time with (ES = −0.44, −0.8 and −0.55, for pre, mid and post-PHV, respectively) and without the ball (ES = −0.12, −0.58 and −0.66, for pre, mid and post-PHV, respectively) in youth soccer players. Similarly, it was observed that PT enhanced the 20 m sprinting performance of young male soccer players regardless of maturation status,[70] while 10 m sprinting performance of Mid-PHV hockey players.[68] According to recent systematic review with meta-analysis conducted on youth soccer players demonstrated that PJT induced significant enhancements in linear sprint performance (small to moderate magnitude, ES = 0.60–0.98) compared to active controls, and also PJT applications > 7 weeks and > 14 were reported to possibly cause greater effects on 10 m sprint performance compared to PJT applications with ≤ 7 weeks and ≤ 14 total sessions.[34] As in our study, it was previously asserted that the lack of significant improvements in sprint performance after PT might be associated with the fact that the ground-contact times (especially during acceleration) were not short enough to augment the ability to produce explosive ground-reaction forces during sprinting.[35,37] Moreover, in the present study, the reason why there is no significant or very small differences in the sprint performance between PJT and active control groups may be due to the sample composition, since in the four included studies, the sample encompassed athletes who were active and regularly participated in soccer exercise programmes. Peña-González et al[69] reported similar changes in sprint performance after PT, which overlap the results of our study. The same researchers attributed the absence of a significant (or small) difference in sprint performance between the PT and active control groups to the fact that the active soccer groups also had high training stimulus for speed-related tasks in their normal soccer training. Lastly, the conflicting results in four studies included in this study and in the previous studies mentioned above may be caused by the differences in the duration, severity, frequency, total number of the plyometric training program, the progression of the load, or the season period.[34]

Maturation plays a critical role in training-related performance adaptations, ie, it mediates training responses.[40,72] In a study that supports this claim, it was showed that peak improvements in physical performance characteristics were concurrent with the onset of PHV.[73] Therefore, PT is frequently preferred to develop the explosive movements of young football players from pre-pubertal to late pubertal period.[36] Several previous studies found that PT was more effective especially in sprint performance with increasing maturity.[34,72,74] The reason for this situation can be explained as follows: during growth and maturation, the natural development of the SSC is the relevant key for sprint performance and this occurs due to larger muscle size, augmented leg length, changes in muscle-tendon tissue, improved neural and motor development, and better quality of movement and coordination.[75,76] Furthermore, the present study revealed that somatic maturity stage had no significant effect on sprinting performance to PJT. Individualized analysis of selected studies propounded some substantial results. In a previous study supporting the findings of our study noted that biological maturation had no effect on 20 m sprint performance and the PJT-late group and PJT-early group showed similar changes in sprint performance to the plyometric drop jump training.[70] Additionally, consistent with the present study, Peña-González et al[69] reported that Pre-, Mid- and Post-PHV groups exhibited similar adaptation after a combination of plyometric and resistance exercises program for 30 m sprint performance. Although hormonal and physiologically driven maturation thresholds exist that regulate training adaptations training,[70] our current results do not support this assertion. Conversely, our results are not consistent with the previous study. For instance, Asadi et al[40] stated that the magnitude of improvement in 20 m sprint performance after PT was greater in the post-PHV group (ES; −0.66, moderate) as compared with the mid-PHV (ES; −0.58) and pre-PHV (ES; −0.12, trivial) groups, so Post-PHV group had higher adaptations to PT. Finally, another study notified that PT programme resulted in a greater enhancement in 10 m sprint performance rather than 30 m sprint performance in the Mid-PHV group than in the Pre-PHV group.[68] Also, in a previous study, it was observed that sprint performance could be further improved by PT in Mid-PHV than Pre-PHV youths.[72]

Asadi et al[40] asserted that one of the possible explanations for the decrement in sprint time in the post-PHV group (more mature players) could be related to anthropometric changes affecting stride speed and stride length, which were important components to attain superior sprint performance. In the present study, the biased effect of maturation on sprinting performance seemed to be not only dependent on strength and power but could be dependent on technique. This suggestion was also supported by Peña-González et al,[69] since they found that strength (through the maximal repetition) and power (through the peak power output) performance in the same maturation groups had no effect on improvement in linear sprint performance, although the relationship between the strength and speed improvements have been widely reported.[77,78]

The present systematic review with meta-analysis includes several limitations. The major limitation may be the small number of studies (only four study studies) showing changes in sprint performance after PJT in young players at different maturation stages. Secondly, the small number of studies participating in this study also limited the conduct of moderator and subgroup analyzes. In the present study, the changes in sprint performance to PJT according to the maturation factor were examined. In order to estimate the effect of PJT on sprint performance in future studies and to generalize the results, it is recommended to carry out comprehensive studies by taking into account different moderator variables (ie, gender, frequency, duration, and total number of sessions of PJT) in different populations or sports branches.

Conclusion

The present systematic review with meta-analysis asserts that PJT ensures no significant benefits on sprinting performance as compared with active control programmes (specific soccer training) in youth soccer players. Furthermore, our study revealed that the changes in sprint performance after plyometric training were similar in different maturity groups.

This result may be due to the small number of studies including in the meta-analysis related to the topic and the conflicting results. Considering the importance of sprint performance in a soccer game, especially in young soccer players, increasing the number of studies may contribute to the understanding of possible physiological mechanisms that play a role in the effect of maturation and/or PT on the performance status of players (increase, decrease or lack of change). Nevertheless, although there was no significant difference in our study, it can be said that plyometric training has a positive effect on the development of explosive movements, especially sprinting performance, and that trainers should consider the biological maturation stage of the players when planning and prescribing these training programmes.

Disclosure

The authors report no conflicts of interest in this work.

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