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REVIEW ARTICLE

Effects of Flywheel Resistance Training on Sprinting and Change of Direction Performance in Elite Adolescent Football Players

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ABSTRACT

Background: Numerous studies have reported accelerated muscle hypertrophy, strength, and power adaptations following chronic bouts of isoinertial Flywheel Resistance Training (FRT). These factors contribute to Change of Direction (CoD) speed and sprinting performance, which are key determinants of performance in football. Progression through to the senior elite level dictates the necessity to develop these qualities in adolescent populations.

Aim: To determine whether ≥ 4 weeks' FRT enhances CoD and sprinting performance in adolescent football players versus traditional strength training.

Methods: PubMed and SPORT Discus electronic databases were used in February 2021. The search strategy identified randomised controlled trials, randomised crossover trials, and controlled non-randomised, full-text peer-reviewed publications written in English. Study quality was assessed by conducting a modified Downs and Black checklist.

Results: A total of 21 studies were found, and following the removal of duplicates and studies based on title and abstract screening, eight studies remained. Following eligibility screening, three studies were included in the systematic review. A total of 67 subjects participated in the included studies. FRT training provides evidence that sprint performance over distances from 10 to 40-m can be improved (effect sizes: 10m = -1.8 ± 2.4%); 20m (ES = 0.37); 30m (ES = -1.5 ± 1.1%); 40m (ES = -1.1 ± 1.0%); and flying 10m (ES = 0.77) and that FRT induces significant improvements in CoD (different distances and for dominant and non-dominant limbs) compared to a control condition where subjects continued with their football training.

Conclusion: Although the included studies suggest that 10-27 weeks' FRT may improve CoD and sprint performance in adolescent football players, paucity in the available literature makes such a conclusion premature. Further research in the area would ideally account for the device, moment of inertia, and transfer mechanism.

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Introduction

It is widely recognised that sprint speed and Change of Direction (COD) are often determining factors to the outcome of games [1,2], and, as such, both sprint speed and COD remain pillars of high-performance training programmes across numerous sports. The identification of coordinative and physiological components of sprinting [3,4] and COD [5,6] suggests that performance coaches should look to train these qualities specifically during the task itself, and look for ways to support development of these qualities via gym-based exercises. Eccentric Overload Training (EOT) constitutes one such modality. Lower-limb eccentric strength represents an important quality needed for deceleration of the lower-

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limb at terminal swing [7], maintenance of spring-mass mechanics during stance [8], and braking required during the penultimate step of COD [9]. Providing an overload to eccentric muscle contractions, with exercises such as the Nordic hamstring curl, has been suggested to enhance tissue tolerance to high eccentric forces realised during sprinting and COD [10]. The eccentric component of muscle contraction produces more force than the concentric phase of muscle contraction [11-13], a significant consideration for strength and conditioning professionals aiming to enhance athletic performance. Initially believed to be solely due to the complementary nature of actin-myosin cross-bridge formation within muscle sarcomeres upon lengthening [14,15], more recent research proposes the additional role of titin in residual force production under active stretching [16-18]. Not evident in concentric or isometric contractions, neural strategies adopted during eccentric contractions exist during submaximal and maximal conditions, involving greater activation at the cortical level and lower activation at the individual motor unit [19]. Combining these factors can contribute to an amplified load-induced signalling response in type II muscle fibres [20,21]. As a result, increases have been reported in the number of type IIa muscle fibres expressing type IIx myosin heavy chain mRNA, androgen receptor mRNA, satellite cell activation and proliferation, and lactate dehydrogenase isoform mRNA [22,23].

The relationship between increased eccentric load and augmentation of gene expression toward type II muscle phenotypes [22,24,25] has not been observed in type I muscle fibres [23,26]. The aforementioned acute responses to eccentric training most likely account for the unique chronic adaptations evident following extended bouts of eccentric training [24]. The lower relative eccentric load achieved through traditional resistance training, where an identical load is used during both the concentric and eccentric phases [22], has generated interest in eccentric overload techniques for achieving greater structural adaptations, improving physical performance and resistance to injury [24,25,27-29]. A contemporary method of achieving an eccentric overload stimulus uses isoinertial Flywheel Resistance Training (FRT). Flywheel devices operate without gravitational acceleration and use a high-velocity concentric contraction to dictate the magnitude of the resultant eccentric impulse experienced by the user, affording a relatively safe way to implement an eccentric overload strategy into a resistance training program.

Flywheel leg curl exercise elicited substantial recruitment of all hamstring musculature [30] with the largest electromyographic activity evident in biceps femoris and semitendinosus muscles [31]. Comprehensive motor unit recruitment has also been reported following electromyographical analysis of the quadriceps muscles during FRT [32,33]. It has been hypothesised that the higher electromyography readings observed during FRT, versus traditional weight training methods, are due to the unique isoinertial loading mechanism evident in FRT [34]. Higher eccentric electromyographic readings may explain a hypertrophic response observed following FRT versus weight stack resistance training [34]. Numerous research studies have reported accelerated structural adaptations following FRT versus traditional gravity-based resistance training methods [35-39]. Thus, increases in muscle cross-sectional area and neuronal activity are suggested as underpinning subsequent strength and power improvements following FRT [37], in line with previous studies that report concurrent increases in strength and power alongside hypertrophic responses to FRT [32,40,41]. Despite the somewhat equivocal nature of literature regarding the mechanistic basis of a performance-enhancing effect, the outcome itself is well supported [25,39], particularly versus traditional training methods [36,40-44]. Power increases following FRT interventions are susceptible in horizontal force applications [25]. Such expressions of horizontal force include sprinting and Change of Direction (CoD) speed, which are key determinants of football performance [45,46]. Sprinting and change of direction ability are of particular importance to adolescent populations within football, whose successful transition to the elite level through an academy or collegiate system can be heavily influenced by on-field performance associated with the progression of these physical and movement qualities [47-50].

Previous research has elucidated the efficacy of acute FRT interventions on CoD speed and sprinting performance in adolescent football players [51], suggesting alterations in muscle contractile function eliciting a post-activation potentiation effect [52]. Furthermore, improvements in CoD speed following chronic FRT interventions in football players have previously been reported [44,53], including adolescents [54,55]. However, the studies mentioned earlier have included FRT in combination with other training modalities such as....high-intensity interval training or traditional resistance training exercises, while systematic reviews offer little specificity regarding the nature of the eccentric overload stimulus. Difficulty isolating or reinforcing the eccentric from the concentric portion of the muscle action in isoinertial devices [56] calls for eccentric training categorised into isokinetic, isoweight, and isoinertial modalities [57], which would suggest future reviews should be particularly stringent regarding inclusion criteria. Therefore, this paper aims to provide a systematic review of research on FRT as a chronic training intervention to elicit improvements in sprinting and CoD speed in adolescent football players.

Materials and Methods

Ethical approval was granted by the Cardiff School of Sport and Health Sciences Ethics Committee (PGT-3503). The systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [58].

Eligibility and search strategy

Participants were healthy male football players aged ≤ 19 years, who underwent ≥ 4 weeks of FRT utilising an eccentric overload. Outcome measures were derived from reliable tests from existing research (such as linear sprints over various splits, and 505 tests) [59] to determine CoD speed and sprinting performance. Studies involved comparison with a control group or a group undertaking comparable traditional, gravity-based resistance training. Eligibility criteria dictated that studies included randomised controlled trials, randomised crossover trials, and controlled non-randomised trials. Studies were excluded if the effect of FRT was assessed in combination with another stimulus, the moment of inertia was not quantified, or the full text was not in English. One reviewer performed electronic database searches of academic journals using SPORTDiscus via EBSCO (1985-present) and PubMed (1950-present). Terms were searched within the article title, abstract, keywords and Boolean operators using search conjunctions 'OR' and 'AND'. The following terms were used for each database: (eccentric overload OR flywheel resistance training) AND (change of direction OR cod OR agility OR sprinting) AND performance AND (soccer OR football). Reference lists of identified studies were also searched for relevant studies. A single reviewer screened the full text of identified studies.

Data extraction and quality assessment

Data was recorded on EPPI-Reviewer Web (EPPI-Reviewer version 4.11.5.3, EPPI-Centre Software, London, United Kingdom). A standardised data extraction form was used for logging data items from included studies. Data quality was assessed using a modified Downs and Black checklist [60] Item 27 of the Downs and Black checklist was modified to 0 = No/unable to determine; 1 = Yes, where the item reads "did the authors of the study provide sample size calculations or information regarding alpha and beta error?" for power analysis. As such, the maximum score for the quality assessment was 28, with boundaries for grading of studies at: Excellent = 26-28; Good = 20-25; Fair = 15-19; and Poor = ≤14 [61].

Results

Literature search

The literature search (Figure 1) identified 21 potential records in total from PubMed (12), SPORTDiscus (6) and three from checking reference lists. Once duplicates were removed, 16 articles remained to be screened via title and abstract, of which a remaining eight were identified as suitable for full-text screening against selection criteria. Of the remaining eight articles, five were excluded following full-text screening due to outcome: using kinetic data to measure performance [54]; and intervention: not determining moment of inertia [62], not using a flywheel device [63], using an intervention duration of <4 weeks [51], and assessing the effect of FRT with a unique concurrent stimulus [55]. Upon conclusion of the literature search, three studies were identified as suitable for inclusion in the review [64-66].

Characteristics of included studies

Of the studies included in the review (Table 1), two were non-randomised controlled trials [64,65], and one was a randomised controlled trial [66]. Sample sizes ranged from 14-33 subjects (mean = 22). All studies recruited elite junior football players from teams' academies in the highest tiers of either Spanish or Italian leagues. Subject age groups ranged from under-16 to under-19 years. All studies measured linear sprint times ranging from 20-40m. Each study adopted split time recordings at 10m intervals for the given distance, with one study measuring a flying 10m time [64]. One study measured CoD ability, using outcomes derived from the time taken to complete two separate CoD tasks with differing approach speeds, and alternating which foot to undertake a predetermined 90-degree cutting manoeuvre [66]. The flywheel ergometers used included K Box, Versa Pulley, and YoYo devices, with inertias ranging from 0.025-$0.26 \text{kg} \cdot \text{m}^2$ depending on the device and the inertia selection method adopted. For the selected exercises, two studies instructed subjects to conduct the concentric phase as fast as possible, while imposing constraints on the timing at which resistance could be applied during the concentric phase [64,66]. Intervention durations ranged from 10-27 weeks (mean = 16 weeks), with training sessions conducted on 1-2 days per week. The two studies that adopted 2 sessions per week had progressed from one day per week in subsequent training phases [64,65].

Study quality assessment

Quality assessment using the Downs and Black checklist [60] determined scores of 12 (Poor), 13 (Poor), and 22 (Good) for each of the included studies, deeming the mean quality of selected studies to be 16 (Fair). The selected studies scored relatively well on items relating to reporting quality but poorly for items assessing external validity. Scoring was low for two studies on confounding and biased aspects of internal validity and statistical power [64,65]. Scoring for confounding and bias aspects of internal validity appeared to be the discernible difference between the studies, which received 'Poor' scores, and the study that received a 'Good' score [66]. Only one study included information on alpha and beta values and calculation of the required sample size [66].

Discussion

The current review investigated the existing literature on the efficacy of FRT as an intervention to improve CoD and sprint speed in adolescent football players. The literature search returned three studies meeting the inclusion criteria [64-66]. These investigations suggest that 10-27 weeks of

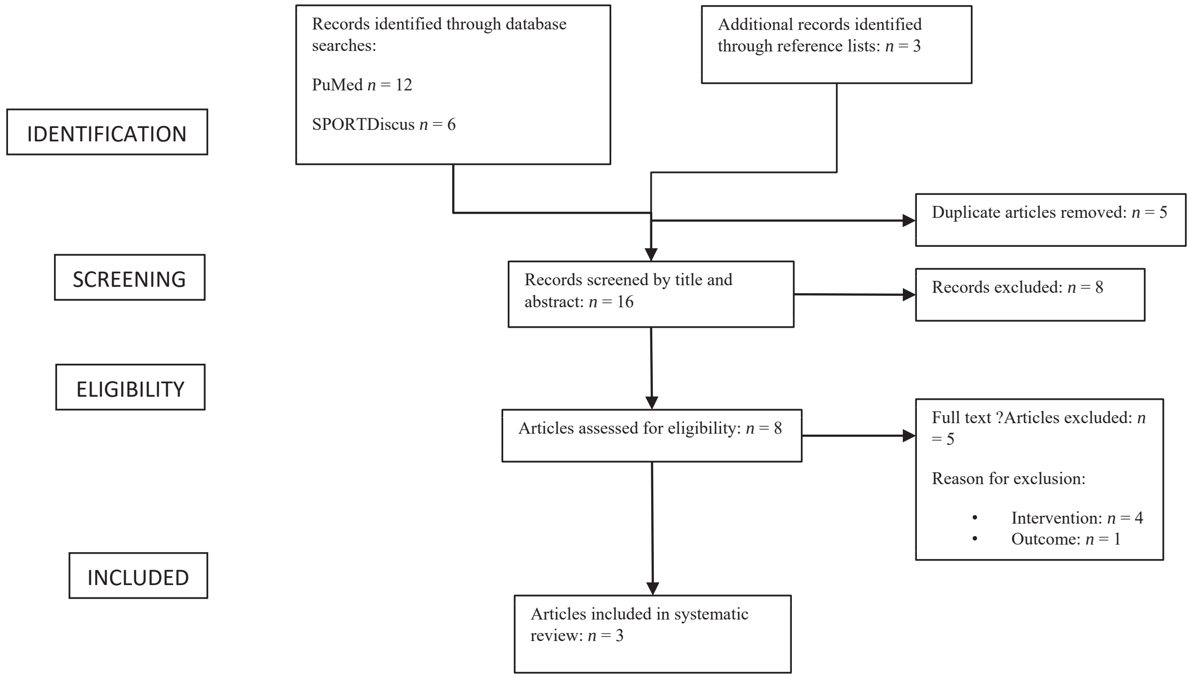

Figure 1 Search strategy.

FRT elicits a performance-enhancing effect for CoD speed and linear sprinting at distances transitioning toward maximum velocity. However, equivocal results were evident for acceleration performance, with only one of the three studies demonstrating an improvement [65].

One study reported findings on CoD performance using 180-degree directional changes at varying entry speeds and transitioning off both dominant and non-dominant limbs [66]. The significant findings reported for all variables relating to CoD speed demonstrate the potential for improvements in performance following FRT in tasks requiring a significant deceleration component. Accelerated increases in strength [25,36,39,40,44,67] may underpin an improved ability to express power in a horizontal force vector [25], as required in the initial acceleration and reacceleration components of CoD effectiveness [68-70]. Prior research has demonstrated an association between eccentric strength and 180-degree CoD performance in elite senior football players, with this impact most evident in the penultimate step, where the most considerable deceleration occurs [71]. The ability to reach a higher approach and exit velocity and withstand high levels of force experienced in decelerating later from a higher velocity may contribute to the performance enhancement. However, equivocal results between the included studies regarding acceleration over 10m may suggest that the performance benefit is more significant via increases in eccentric strength and deceleration rather than horizontal power expression.

Linear sprinting test performance was less conclusive than CoD speed. Two of the included studies reported a non-significant effect on sprint performance over 10m [64,66]. However, one study reported a large effect size from all split times over the first 10m (ES = -1.8) [65]. This study used a longer intervention length, with greater variation in exercises. These factors may have enhanced robustness adaptations for subjects to improve proficiency with the execution of exercises, as mentioned within previous research as contributing to the efficacy of FRT [36].

Interestingly, the study reporting improvements in 10m time did not report instructing participants to delay braking force application until reaching latter stages of the eccentric phase during flywheel exercises (~90° knee flexion), as the other studies did. The influence of joint angle specificity for neural adaptations in knee extensors [72], and lower-limb power output [73] may explain why the greater transfer was not evident during linear sprint acceleration, in which knee angles of ≤ 60° are evident during the stance phase [74]. However, this hypothesis is somewhat confounded when considering the review findings for sprint performance over distances associated with upright running mechanics.

Kinematics associated with upright sprinting performance suggests that joint angles during stance for the hip, knee, and ankle should gradually decrease from initial acceleration to maximum velocity [74]. Therefore, joint angle specific training adaptations do not necessarily account for considerable reductions in sprint times between 10 and 40m reported in two of the three studies included in the current review. Improvements in hamstring force production capability may represent a mechanistic basis for reductions in sprint times. Research has demonstrated

Table 1: Studies investigating the effect of isoinertial flywheel resistance training on change of direction and sprinting performance in adolescent football players.

Study Year	Population	Intervention Components	Intervention Dose	Intervention Duration	Outcomes Measured	Relevant Findings
[65]	14 subjects, mean age: 17.5 years, Playing level: elite (professional).	*EG:* Exercise selection: UB: 10 total exercises including various "functional" unilateral push/pull modalities with Versa Pulley; LB: 10 total exercises including unilateral Yo-Yo leg curl, unilateral hip extension variations, lunge variations, multiplanar half-squat variations, "ankle extension" exercises. Inertia: K Box: 0.10kg·m^2 or 0.05kg·m^2, Versa Pulley: 0.19kg·m^2 or 0.26kg·m^2. *CG:* ~9 hours of football training and 1-2 competitive matches per week.	*EG:* density/volume: 2 days per week, 1-2 sets per exercise, with a large variation in repetitions per exercise, depending on intervention phase/match schedule, 60s rest between exercise series. Phases were volume-matched over primary intervention phases. *CG:* n/a.	27 weeks (full competitive season).	40m linear sprint test with split times at 10m, 30m, and 40m.	Reductions in 10m (ES = -1.8 ± 2.4%), 30m (ES = -1.5 ± 1.1%), and 40m (ES = -1.1 ± 1.0%) sprint times.
[66]	20 subjects (*EG*: *n* = 10; *CG*: *n* = 10, mean age: U16* (not provided), playing level: elite.	*EG*: Lateral squat on K Box, instructed to perform concentric action as fast as possible, and delay braking action to last third of eccentric phase of exercise. Inertia: 0.025kg·m^2. *CG*: normal weekly training routine.	*EG*: 1 day per week, 2-4 sets of 8-10 repetitions, 3 minutes of recovery between sets. *CG*: n/a.	10 weeks.	30m linear sprint test with split times at 10m, 20m, and 30m. COD and COD_{def} over 10m (5 + 5m) and 20m (10 + 10m), with a predetermined 90° COD, for both dominant and non-dominant legs.	*EG* versus *CG*: no significant difference for 10m (F = 0.69, p = 0.42), 20m (F = 4.33, p = 0.06), or 30m (F = 3.94, p = 0.07) sprint time. *EG* versus *CG*: significant improvements in $COD10_{d}$ (F = 4.25, p = 0.05*), $COD10_{nd}$ (F = 19.15, p = 0.001), $COD_{def}10_{d}$ (F = 14.58, p = 0.001), $COD_{def}10_{nd}$ (F = 11.01, p = 0.004), $COD20_{d}$ (F = 5.10, p = 0.03), $COD20_{nd}$ (F = 12.88, p = 0.002), $COD_{def}20_{d}$ (F = 5.79, p = 0.02), and $COD_{def}20_{nd}$ (F = 10.19, p = 0.005).
[51]	33 subjects (*EG*: *n* = 18; *CG*: *n* = 15), mean age: *EG*: 18 years; *CG*: 17 years, playing level: elite.	*EG*: YoYo leg curl and YoYo half squat exercises, both instructed to perform concentric action as fast as possible. YoYo leg curl: concentric up to 130-140° knee flexion, resist eccentric phase once at 90° knee flexion; YoYo half squat: up to 90° knee flexion. Inertia: 0.11kg·m^2. *CG*: normal technical-tactical training, avoided strength training all season.	*EG*: 1-2 days per week, 3-6 sets of 6 repetitions, 3 minutes of recovery between sets. *CG*: n/a.	10 weeks.	20m linear sprint test with split times at 10m and 20m, as well as 10m flying sprint time.	*EG* versus *CG*: Improvements in 20m sprint time (ES = 0.37) and flying 10m time (ES = 0.77). Unclear difference in 10m sprint time.

CG: Control Group, COD: Change of Direction, COD_{def} : Change Of Direction Deficit, ° Degrees, $_{d}$ Dominant Leg, EG: Experimental Group, ES: Effect Size, kg·m^2: Kilograms Per Metre Squared, LB: Lower Body, m Metres, $_{nd}$ Non-Dominant Leg, UB: Upper Body.

a significant relationship between horizontal ground reaction force, biceps femoris electromyographic activity at the terminal swing, and eccentric peak torque during sprint acceleration [69], providing evidence of the role of the hamstrings in the horizontal reorientation of ground reaction forces, a key determinant in sprint acceleration performance in team sport athletes [70,75]. However, the role of individual hamstrings may differ depending on the sprint phase. Biceps femoris long-head activation has been shown as highest relative to other hamstrings during acceleration, where hip extension torque represents the largest joint contribution in early stance [76]. As research has demonstrated elite sprinters' ability to apply increased force during ground contact in sprint acceleration earlier than non-elites [77], it can be inferred that hip extension torque represents a source of this augmented rate of force development. In a study on elite football players, eccentric overload was only observed for peak power during flywheel hip extension, and activation of biceps femoris long-head was greater when compared with flywheel leg curl [30]. Marked reduction in stiffness of biceps femoris post-exercise following flywheel hip extension at high velocity, afforded from work at an inertial load of 0.075kg·m^2, may suggest increased biceps femoris recruitment during high-velocity hip extension [78]. Suarez-Arrones and colleagues used flywheel hip extension as part of the intervention and was the only study to report worthwhile reductions in 10m sprint time (ES = -1.8) [65]. However, it should be noted that the inertial load was set at either 0.19kg·m^2 or 0.26kg·m^2 [65]. In contrast, Piqueras-Sanchiz and colleagues [78] reported higher semitendinosus activation during flywheel hip extension when the moment of inertia was higher (0.1kg·m^2).

Semitendinosus activation has been documented to be higher than the biceps femoris long-head during maximum velocity sprinting, where a greater knee flexion moment is evident [76]. Versus flywheel hip extension and flywheel leg curl recruit all four hamstrings more evenly [30]. Increases in biceps femoris long-head fascicle length have also been documented but in the absence of rate of force development or strength [79]. The two studies reviewed reporting improvements in sprint times transitioning to and at assumed maximum velocity (>10m) [80] and used flywheel leg curl as part of an experimental arm [64,65]. Raya-Gonzalez, et al. [66] provide further evidence favouring a performance-enhancing effect of joint action-specific hamstring activation following FRT. Neither isolated hip extension nor knee flexion exercises were included, nor were no significant improvements in linear sprint time reported [66]. Notwithstanding such evidence, a causal link is discredited by previous research reporting high levels of semitendinosus activation during flywheel hip extension [78]. An alternative transfer mechanism may be provided by a facilitative effect of isoinertial eccentric qualities on reactive strength and subsequent benefit on leg stiffness for improving maximum velocity sprinting performance [81]. Despite this hypothesis being somewhat supported by research documenting the role eccentric preactivation plays in enhancing joint torque via the stretch-shortening cycle [82], further research would be required to demonstrate such an effect following FRT.

Limitations

The nature of the data presented difficulty in reliably quantifying evidence via meta-analysis. Thus, the review was restricted to reporting qualitatively. Despite de Hoyo, et al. [64] not evidencing use of concurrent exercise interventions, it is uncertain if the performance enhancements were due to the inclusion of other exercises in the intervention alongside the FRT stimulus. In addition, the included studies used various devices, each with drastically different moments of inertia, making it problematic to determine which device or inertia had the greatest effect on CoD and sprint performance variables. Inconsistencies were also evident in the type of resistance training undertaken by control groups, where strength training in some cases was considerably less than in the experimental condition. These confounding factors may have been avoided if the inclusion criteria had accounted for them. In practical application, little guidance was provided on how FRT would be best implemented for long-term athlete development models, such as those brought forward by Pichardo, et al. [83]. Based on the Downs and Black checklist [60], the overall quality of the studies included in the current review was relatively low. Items that frequently received low scores were in sections of the checklist dedicated to external validity, internal validity, and statistical power. The omission of statistical power considerations further reduces the reliability of the data when a positive training effect was reported.

Conclusion

The current review suggests that 10-27 weeks of FRT may positively affect 180° CoD speed at sub-maximal entry velocities and sprint performance in elite male adolescent football players during the transition and maximum velocity phases. However, the efficacy of isoinertial FRT training is undetermined due to the paucity of existing literature. Intra-study limitations identified using the Downs & Black checklist [60], in experimental procedure and validity make it challenging to justify the use of FRT interventions by practitioners in the field and provide little guidance on practical implementation within a training programme. Specific guidance is particularly important when acknowledging unique considerations associated with the appropriate physical development of elite adolescent football players. Based on findings from the current review, more research of higher quality is required to investigate the effect FRT has on sprinting and CoD performance in adolescent football players. Such studies would ideally isolate the FRT stimulus as an experimental condition, use traditional strength training means as a control, and assess the training effect across different isoinertial conditions to determine best practice. Concurrent testing of relevant physiological markers should be included to establish the mechanism underpinning any performance improvements. Future research should examine the effect of FRT on the regulation of leg stiffness and if this impacts sprinting performance through initial acceleration to maximum velocity (**Appendix**).

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