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The association between training load and physical development in professional male youth soccer players: a systematic review

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Abstract

Objectives: 1) To evaluate current physical performance tests used within professional male youth soccer; 2) to understand the relationship of these tests performance in relation to specific measures of external and internal training load (TL) to conclude if there is a subsequent change in test performance.

Methods: Relevant literature was searched using five electronic databases (PubMed Medline, SPORTDiscus, Web of Science, CINAHL and Scopus), with additional articles identified by the authors. Articles relating to TL and physical development assessment within professional male youth soccer players were evaluated.

Results: Database searches yielded 5683 articles following removal of duplicates. After screening the titles, abstracts and full texts, 28 articles were identified. Both external TL (total distance, high speed distance, duration) and internal TL (rating of perceived exertion, training impulse) measures were found to be associated with improvements in physical test performance across both pre-season and in-season phases. Field-based testing was found to be sensitive to changes in physical performance for aerobic capacity, lower body power/strength and sprint performance. However, limited sensitivity to change was found when assessing player agility performance.

Conclusion: Future research in this area should look to enhance our understanding of the dose-response of TL with changes in fitness across different age groups in professional male youth soccer.

Keywords

Aerobic capacity, association football, power, rating of perceived exertion, speed, sprint performance, training impulse

Introduction

Within professional male youth soccer, the training process is deemed central for a successful transition of players through playing pathways and development programmes.[1] For players to advance successfully they must be prepared for the next level of competition, whether that be from youth player to scholar, scholar to professional, or professional to first team regular, from a physical, mental, technical and sociological perspective.[2] Soccer coaches and support practitioners are responsible for both the design and delivery of player development programmes with the ultimate aim to produce a player worthy of a regular place within the senior team. This notion has led to significant investment across professional soccer clubs to enhance the resources available for both the recruitment and development of their youth players.[3] Whilst player development can be impacted by internal factors, such as genetics,[4] the structure of training programmes is within the control of the practitioner to appropriately manage in order to maximise the chance of success.

From a physical perspective, it is common for practitioners to monitor the training load (TL) undertaken by their players in order to understand both the external load and internal response of each individual player.[5] External

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load is defined as the physical work prescribed in the training plan, whereas internal load refers to the psychophysiological responses to the external load.[5] The quantification of external load is often monitored using micro-electro-mechanical (MEMS) devices containing a global positioning system (GPS) processor and inertial sensors to collect information of variables such as distances covered at different velocities, acceleration and deceleration efforts and estimated metabolic power.[6] The internal load is typically quantified using heart rate telemetry and subjective scales, such as the rating of perceived exertion (RPE) and wellness ratings.[6] Whilst assessment of the daily external load helps coaches understand whether the planned content matches that of the observed load, the internal load represents the stimulus for training induced adaptation.[7]

In order to understand the long-term effects of accumulated TL, it is imperative that practitioners employ soccer-specific physical performance tests to understand how each player is responding to the development programme. Practitioners will often incorporate multiple testing points during an annual macrocycle to determine changes across different physical qualities.[8] Testing protocols are typically conducted within the field due to the practical limitations of laboratory-based testing across large numbers of players. In addition, it has been suggested that laboratory-based tests are not appropriate protocols for soccer, especially when assessing match stimulation protocols, and therefore their specific relation to soccer match performance may not be accurate.[9,10] Common tests used within youth soccer include the Yo-Yo intermittent test,[11] the 30–15 intermittent fitness test,[12] countermovement jump (CMJ), sprint testing (10m and 30m), repeated sprint ability test (RSA)[13] and agility testing.[14,15] The tests used in practice should be reliable, valid and sensitive to changes in fitness across longitudinal periods.[8]

In order to determine the effectiveness of youth soccer player development programmes, it is important that practitioners understand the associations between measures of TL and physical performance tests. Whilst this association has recently been evaluated in senior professional soccer players,[13] there is limited information available to practitioners around which TL measures and physical tests are most suitable for youth player development. Therefore, the purpose of this systematic review was to: 1) To evaluate current physical performance tests used within professional male youth soccer; 2) to understand the relationship between test performance in relation to measures of external and internal training load (TL).

Table 1. Search strategy used to locate relevant research articles.

Variable	Search Terms
Search String 1 (Soccer)	Soccer OR Football
Search String 2 (Youth)	Youth OR Junior OR Young
Search String 3 (Training Load)	Soccer OR Football AND Youth OR Junior AND Load OR Stress OR Work OR Workload OR Type OR Frequency OR Volume OR Time OR Duration OR Intensit* OR Training
Search String 4 (Physical Development)	Soccer OR Football AND Youth OR Junior AND (Fitness OR Capacit* OR Adaptation OR Development OR Physical development OR Aerobic capacity OR Power OR Strength OR Testing OR Abilit* OR Competition OR Game OR Speed OR Repeated Sprint OR Perform*

Table 2. Key terms and definition used for the systematic review process.

Variable	Definition
Training Load	The product of volume, frequency and intensity of a given training program (Impellizzeri et al., 2014)
Physical Development	Physical development which can also be termed as 'physical training' is the systematic repetition of physical exercises, and it can be described in terms of its outcome (anatomical, physiological, biochemical, and functional adaptations) or its process. (Impellizzeri et al., 2019)
Internal Load	The internal training load represents the physiological stress imposed on the athlete in response to the training stimulus (e.g. perceptual rating of intensity, heart rate, hematological measures.) (Scott et al., 2013).
External Load	External load is defined as the work completed by the athlete, measured independently of his or her internal characteristics (Wallace et al., 2009)
Adaptation	Biomechanical adaptations take place through mechanical stresses to the various musculoskeletal tissues. Muscular adaptations are perhaps best known and the most responsive to mechanical stimuli.
Aerobic Performance	Aerobic performance is determined by both aerobic power and aerobic capacity
Aerobic Capacity	Expresses the ability to sustain exercise for a prolonged period and is synonymous with endurance.

Materials and methods

Literature search strategy

Articles were systematically identified via five electronic databases (PubMed, Medline, SPORTDiscus, Web of Science, CINAHL and Scopus) using the search strategy presented in Table 1. Terms within the search strategy (search strings 1, 2, 3 and 4) were connected with the 'OR' function. Three articles were identified from additional sources known to the authors. The search was conducted on 30th April 2020 (registration no: 10.17605/OSF.IO/DYP38), therefore any article published after this time was not included. The key terms and definitions used for the systematic review process are presented in Table 2.

Selection criteria

This review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines[16] (Figure 1). Articles were excluded from the initial search (title and abstract only) if (1) the participants were not male soccer players; (2) the article was not an original article in a peer-reviewed scientific journal; (3) the article was not related to training load and fitness. Following this, from the remaining articles, the full texts were analysed, and articles were excluded if they fit the following criteria: (1) Participants were over the age of 23; (2) the participants were non-professional; (3) the article investigated other aspects of training (e.g. rehabilitation, nutrition); (4) the article did not report any training load measures; (5) the article did not report any physical development measures; (6) the article was unavailable in English.

Methodological quality assessment

Methodological quality was assessed using the risk of bias for included studies assessment tool and more specifically the NIH quality assessment tool for observational cohort and cross-sectional studies;[17] https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). All the studies that were included were measured against the answers to fourteen questions (Table 3). Each item is scored as 1 = "Yes", and 0 = "No/unable to determine". Every article received a total score out of 14 which was then deemed 'poor', 'fair' or 'good' according to the assessment tool independently by two authors (J.R and J.M). These assessments were then used to provide an overall quality of the available evidence using the beforementioned ratings.

Data extraction and analysis

When searching each database, the lead author (JR) examined the article title, abstract and keywords in the first stage of screening according to the established inclusion and exclusion criteria. The process was cross-checked for accuracy by a second author (J.M.). The texts were examined to identify the terminologies employed in reference to the method used and for physical development by definition. The following data, where possible, were extracted from each article:

- Participants Characteristics - sample size, playing level, sex, age, stature and body mass
- Study Methodology - monitoring period, TL measures and physical test measures
- Study Results - TL and physical test measures compared and the results of statistical analyses (i.e. association statistic, interpretation, and statistical significance)

Results

Search findings and methodological quality

The electronic search yielded 9521 articles, with an additional 3 articles identified from an additional journal (Science and Medicine in Football). Following the removal of duplicates, 5683 articles remained for title and abstract screening. 5536 articles were removed based on initial study criteria (Figure 1). 147 full-text articles were screened and 119 were removed based on the second level of criteria, leaving 28 articles included in the final review. Ratings from the NI quality assessment tool for each article are presented in Table 4, with scores ranging from 6–11. The overall quality of available evidence was rated as 'fair' by two authors (JR and JM) independently (see Table 3 for individual study ratings). Participant characteristics and study details are presented within Table 5.

Physical performance tests and change in physical performance

Aerobic fitness

Eleven studies[18,20,23,24,26,29,34,35,37,39,42,43] used physical performance tests to detect changes in aerobic fitness across various testing points (Table 6). Four studies[26,29,39,42] used Yo-Yo intermittent testing, revealing improvements in test performance from the start of pre-season to the end of pre-season[39,42] and late in-season,[29] with trivial changes in performance across a 5 day tournament.[26]

Seven studies used both laboratory and field tests, including an incremental test derivative performed on a

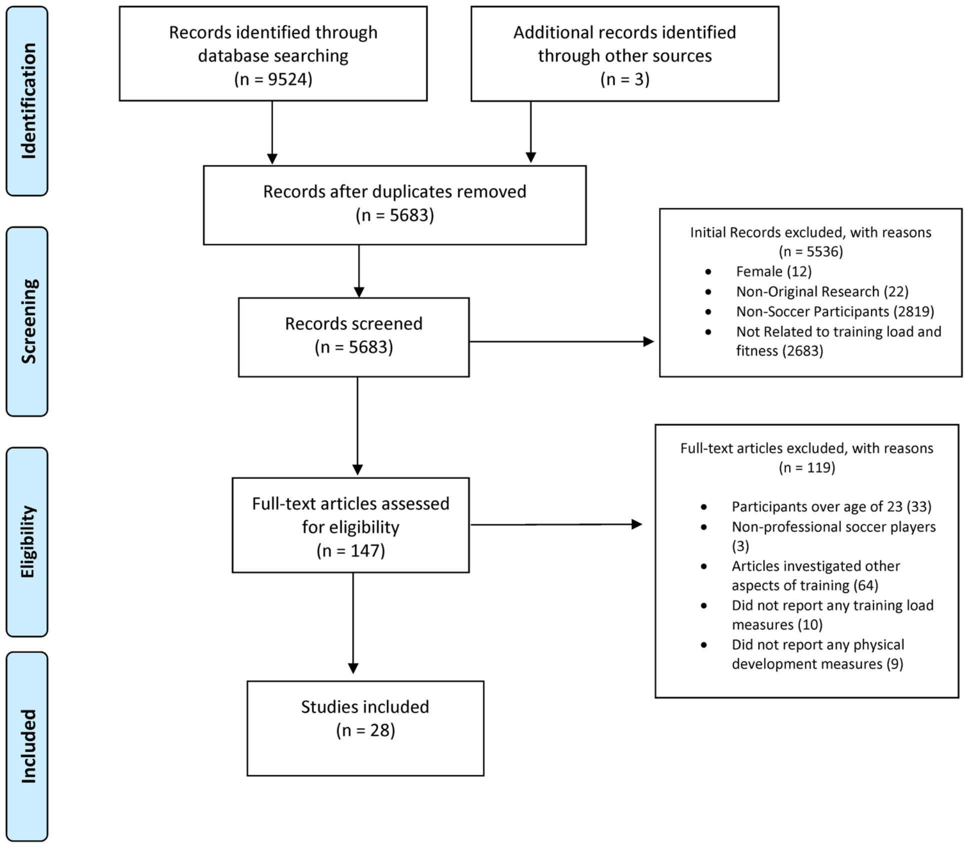

Figure 1. PRISMA flow diagram.

laboratory treadmill;[18,23,35,37] cycle ergometer[34] and field-based protocols.[20,43] Three studies found significant improvements in $\dot{V}O_{2max}$ from the start to the end of the pre-season phase.[23,34,35] Two studies[37,43] found significant improvements in lactate thresholds across a similar time period. Di Giminiani and Visca[20] found a ~5.7% improvement in $\dot{V}O_{2max}$ over a two-season period. Akubat et al.[18] found no changes in aerobic fitness parameters across a 6-week pre-season phase.

Lower body power

Twelve studies assessed lower body power through CMJ performance using different technologies: a contact jump mat,[22,30,31,33,36,41,44,45] photocell system[19,29,42,45] and portable force plate[22,26] (Table 6). Six studies found a significant improvement in CMJ performance from the start of pre-season to the end of the in-season phase.[22,29,31,33,38,42,44] This improvement was also observed from the start to end of the pre-season phase.[29,42] Conversely, no significant change in CMJ performance was observed across a training microcycle,[26,45] mesocycle (4–9 weeks)[19,36] and full season.[30]

In relation to strength-based measures, only two studies analysed seasonal physical changes.[22,44] The studies found small to moderate improvements in isometric mid-thigh pull (IMTP) peak force[22] and a significant increase in hamstring:quadtricep (H:Q) ratio peak torque values[41] from the start to the end of a season.

Sprint, agility and anaerobic capacity

The assessment of changes in sprint and agility capabilities was assessed in eight studies[19,22,33,36–38,42,46] (Table 6). Three studies found significant improvements in 5 m,[36] 15m[46] and 30m[38] sprint performance across the pre-season phase. Two studies[38,46] also found improvements in 10 m and 30 m sprint performance across a competitive season, with no change observed for 5 m performance.[46] No changes in agility performance were observed across both a full season[39] and 4-week training block.[19] However, Morris et al.[22] did observe significant improvements in arrowhead agility performance across a season across different peak height velocity (PHV) group players. Jastrzebski et al.[34] found significant improvements in anaerobic relative peak power at the end of the season compared to the start of pre-season using a 30-s Wingate test

Table 3. Questions within the quality assessment tool for observational cohort and cross-sectional studies as observed within NIH guidelines.

Question	Details
1	Was the research question or objective in this paper clearly stated
2	Was the study population clearly specified and defined
3	Was the participation rate of eligible persons at least 50%
4	Were all the subjects selected or recruited from the same of similar populations (including the same time period). Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants
5	Was a sample size justification, power description, or variance and effect estimates provided
6	For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured
7	Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed
8	For exposures that can vary in amount of level, did the study examine different levels of the exposure related to the outcome (e.g. categories of exposure, or exposure measured as continuous variable)?
9	Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants
10	Was the exposure(s) assessed more than once over time
11	Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants
12	Were the outcome assessors blinded to the exposure status of participants
13	Was loss to follow-up after baseline 20% or less
14	Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)

Associations between training load measures and changes in physical performance

External training load and changes in aerobic performance

Five studies[25,26,28,40,41] examined the association between external TL and changes in aerobic performance (Table 6). Two studies found significant correlations between total distance accumulated in both training and matches compared with improvements in aerobic capacity.[26,40] Buchheit et al.[25] found moderate to large correlations between distance covered > 16.1 km.h^{-1} during matches and improvements in the VAM-Eval test across a 4-month period, particularly within the striker's group. There was no analysis directly related to the influence of match or training involvement. Significant correlations were observed across a 6-week training period between external load variables (total distance, distance covered > 17 km.h^{-1} and > 21 km.h^{-1}) and improvements in maximal aerobic speed (MAS) scores.[41] Gil-Rey et al.[28] found large correlations between total training volume (i.e. duration) accumulated and improvements in the Université de Montreal Track Test

External training load and changes in neuromuscular performance

Two studies examined the association between external TL and changes in neuromuscular performance[28,45] (Table 6). Gil-Rey et al.[28] found trivial to small correlations between total training volume and both changes in CMJ and sprint (5 and 15 m) performance across a 9-week period. Similarly, Malone et al.[45] found no significant correlations between external TL variables (duration, total distance, average speed, distance covered > 19.8 km.h^{-1}) and changes in CMJ performance across an in-season microcycle.

Internal training load and changes in aerobic performance

Four studies[18,27,32,36,47] examined the association between internal TL and changes in aerobic performance (Table 6). Figueiredo et al.[47] found a large negative correlation between weekly mean internal TL variables (RPE and Edward's training impulse (TRIMP)) and improvements in Yo-Yo intermittent recovery test level 1 (IR1) performance across a pre-season phase. One study observed a significant large correlation between mean weekly individual TRIMP (iTRIMP) and improvements in velocity at 2 mmol.l^{-1} of blood lactate and during an incremental treadmill test across a 6-week period.[18] Los Arcos et al.[36] revealed moderate to large correlations between RPE derivatives (RPE respiratory (RPEres) and RPE muscular (RPEmus)) and improvements in submaximal running lactate values (12 km.h^{-1}, 13 km.h^{-1} and velocity at 3 mmol.l^{-1} of blood lactate) across a season. Conversely, Saidi et al.[32] found no significant correlations between RPE-based load and changes in Yo-Yo IR1 performance.

Internal training load measures and changes in neuromuscular performance

One study[36] evaluated the association between internal TL and changes in neuromuscular performance (Table 6). The authors found moderate to large correlations between RPEres and

Table 4. Results of methodological quality assessment for included articles.

	Question Number															
Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Rating
Akubat et al.[18]	1	1	1	1	0	1	1	1	1	0	1	0	1	0	**10**	**Fair**
Buchheit et al.[19]	1	1	1	1	0	0	1	0	0	0	0	0	1	0	**6**	**Poor**
Di Giminiani & Visca.[20]	1	1	1	1	0	0	1	0	0	1	1	0	0	0	**7**	**Poor**
Figueiredo et al.[21]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Fitzpatrick et al.[22]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Francioni et al.[23]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Gibson et al.[24]	1	1	1	1	0	1	0	1	1	1	1	0	1	0	**10**	**Fair**
Gil-Rey et al.[25]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Hammami et al.[26]	1	1	1	1	0	0	1	0	0	1	1	0	1	0	**8**	**Fair**
Hammami et al.[27]	1	1	1	1	0	0	1	0	0	1	1	0	1	0	**8**	**Fair**
Impellizzeri et al.[28]	1	1	1	1	0	1	1	1	1	1	1	0	0	0	**10**	**Fair**
Jastrzebski et al.[29]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Lopez-Segovia et al.[30]	1	1	1	1	0	1	1	1	0	1	1	0	1	0	**10**	**Fair**
Los Arcos et al.[31]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Los Arcos et al.[32]	1	1	1	1	0	1	1	0	1	1	1	0	1	0	**10**	**Fair**
Malone et al.[33]	1	1	1	1	0	1	0	1	1	0	1	0	1	0	**9**	**Fair**
McMillian et al.[34]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Miranda et al.[35]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Morris et al.[36]	1	1	1	1	0	0	1	0	0	1	1	0	0	0	**7**	**Poor**
Noon et al.[37]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Paul et al.[38]	1	1	1	1	0	1	1	1	1	1	1	0	1	0	**11**	**Good**
Perroni et al.[39]	1	1	1	1	0	0	1	0	0	1	1	0	1	0	**8**	**Fair**
Saidi et al.[40]	1	1	1	1	0	1	1	1	1	1	1	0	0	0	**10**	**Fair**
Silva et al.[41]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Silwowski et al.[42]	1	1	1	1	0	0	1	0	0	1	1	0	0	0	**7**	**Poor**
Silwowski et al.[43]	1	1	1	1	0	1	1	0	0	1	1	0	0	0	**8**	**Fair**
Sporis et al.[44]	1	1	1	1	0	1	1	0	0	1	1	0	1	0	**9**	**Fair**
Williams et al.[45]	1	1	1	1	0	0	1	0	0	1	1	0	1	0	**8**	**Fair**

improvements in 15 m sprint and CMJ with arm swing performance across a 9-week period. However, no correlations were found between internal TL (RPE, RPEres and RPEmus) variables and changes in CMJ or 15 m sprint performance. In addition, RPEmus was found to show no correlations with neuromuscular performance variables.

Discussion

The purpose of the present systematic review was to: 1) To evaluate current physical performance tests used within professional male youth soccer; 2) to understand the relationship of these tests performance in relation to specific measures of external and internal training load (TL) to conclude if there is a subsequent change in test performance. In terms of aerobic capacity evaluation, both field-based (e.g. Yo-Yo test derivatives) and laboratory-based (e.g. treadmill incremental test) tests were sensitive to changes across both pre-season and in-season phases. CMJ testing demonstrated limited sensitivity to detect acute changes in lower body power (e.g. across a microcycle), but with some evidence of sensitivity when evaluating across a full season. In addition, 10 m and 30 m sprint performance appeared sensitive to seasonal changes, whereas agility testing demonstrated limited sensitivity. In terms of the relationship between physical tests and TL measures, associations were found across tests with both external TL (total distance, high speed distance, accumulated duration) and internal TL (RPE, TRIMP) measures. Therefore, practitioners should be aware of some of the limitations in sensitivity of commonly used physical tests (e.g. CMJ and agility) when developing professional male youth soccer players.

It is important that practitioners include a series of testing battery points during an annual macrocycle to determine changes within individual players across different physical qualities.[8] The present review revealed that the majority of physical tests were sensitive to change across the pre-season phase. Typically, the pre-season phase is designed to rebuild the fitness of players following the off-season phase.[48] The TL during the pre-season phase is higher than that observed during the in-season.[49] Therefore, it would seem logical that the phase with the highest TL (i.e. pre-season) would also demonstrate the most sensitivity in terms of physical test

Table 5. Demographic characteristics of participants examined in each included article.

Study	N	Age (Years)	Duration	Playing Standard	Location
Akubat et al.[18]	9	17 ± 1	6 weeks	English Football League Youth alliance	UK
Buchheit et al.[19]	46	15 ± 1.5	4 Months	Qatar National League	Qatar
Di Giminiani & Visca[20]	19	13.3 ± 0.1	2 Year Analysis	Italian First Division Youth	Italy
Figueiredo et al.[21]	16	18.7 ± 0.7	3 weeks	Brazil first division team	Brazil
Fitzpatrick et al.[22]	14	17 ± 1	6 weeks	U18s Premier League	UK
Francioni et al.[23]	33	14-15 Year olds	Full season	Italian Premier League	Italy
Gibson et al.[30]	30	14.0 ± 0.4	5 days	Professional Youth academy	UK
Gil-Rey et al.[25]	14 Elite/14 Non-Elite	17.6 ± 0.6	9 Weeks	Spanish first division (U19s)	Spain
Hammami et al.[26]	24	14.4	8 months	Youth Academy Tunisia	Tunisia
Hammami et al.[27]	20	14.4 ± 0.3	2 Year Analysis	national selection of Tunisia	Tunisia
Impellizzeri et al.[28]	29	17.0 ± 0.8	12 weeks	Italian Championship	Italy
Jastrzebski et al.[29]	19	16 ± 0.3	Season Long	Poland	Poland
Los Arcos et al.[31]	19	20 ± 1.9	9 weeks	Spanish 2nd B Division	Spain
Los Arcos et al.[32]	20	20.6 ± 1.8	32 weeks	Spanish 2nd B Division	Spain
Lopez-Segovia et al.[30]	19	18.4 ± 0.6	16 weeks	U19s Spanish first division	Spain
Malone et al.[33]	9	16.4 ± 0.5	1 week	U18s Premier League	UK
McMillian et al.[34]	9	18.3 ± 0.3	Full season	Scottish Youth Premier League	Scotland
Miranda et al.[35]	13	17.0 ± 0.7	10 weeks	French Youth Premier League	France
Morris et al.[36]	112	U12 – U18	Season Long	English Football League Academies	UK
Noon et al.[37]	14	17 ± 1	Season Long	Category 2 Academy	UK
Paul et al.[38]	19	16 ± 0.8	4 weeks	Qatar National League	Qatar
Perroni et al.[39]	35	14 ± 0	8 weeks	Italian Youth League	Italy
Saidi et al.[40]	13	20.4 ± 0.4	6 weeks	Tunisia Youth league	Tunisia
Silva et al.[41]	18	N/A	Season Long	Tier 2 Portugal	Portugal
Silwowski et al.[42]	15	14-15 Year olds	Full season	Polish Youth League	Poland
Silwowski et al.[43]	Not mentioned in article	14-15 Year olds	Full season	Polish Youth League	Poland
Sporis et al.[44]	64	N/A	Season Long	First Croatian Junior League	Croatia
Williams et al.[45]	200	5 age groups	3 Year analysis	English Football League Academy	UK

improvements. Changes in physical testing qualities were also observed from the start of pre-season to the end of the competitive season (e.g. Hammami et al.;[29] Morris et al.[36]) These observed improvements are crucial for the physical development of players to successfully prepare them for the next level of competition within the development pathway.[2] It should be noted that limited data was available using regular in-season assessments of physical performance. This may be due to the reluctance of soccer coaches to incorporate physical fitness testing during this phase due to the competition demands.

Of all the physical tests evaluated, it appeared that assessment of agility via a number of varied testing protocols provided limited results in terms of sensitivity to changes in TL. This may be due to the lower reliability and validity of field agility tests, possibly attributed to the complexity of the tests that incorporate both physical and perceptual aspects of speed.[50] For instance, in a recent review by Altmann et al.,[50] the authors reported change of direction testing reliability ranging from 0.37 to 0.99 (ICC), suggesting large variance in the reliability of agility tests within soccer. Caution should also be made when using physical tests to detect acute changes in fitness, such as a weekly training microcycle, as this showed lower sensitivity compared to when assessing over a longitudinal period.[19,45]

When assessing the long-term development of youth soccer players, with specific reference to enhancing physical qualities, it seems necessary to have a good understanding of the physiological and maturational characteristics that differ across the youth players' physical development pathway.[21] The articles within this review have limited information around the potential influence of maturation with the majority of studies not factoring this into their analysis models. As such, it would be interesting for future studies to analyse the effect of maturation as perhaps this

Table 6. Associations between load measures and changes in fitness.

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
Akubat et al.[18]	s-RPE, Banister's TRIMP, Team TRIMP and iTRIMP	Velocity at 2mmol, Heart rate at 2mmol, Velocity at 4mmol, Heart rate at 4mmol	In-Season Period Specific information unavailable from article	Significant positive correlation found between iTRIMP and velocity at 2mmol ($r = 0.67$, $p = 0.04$)	No change in fitness observed
Buchheit et al.[19]	N/A	HRex, Vam-Eval, HRR	In-Season Period Specific information unavailable from article	N/A	Within-player decrease in HRex submaximal HRex, HRR and Ln rMSSD at the start of the season were moderately-to-largely correlated with changes in most of the performance variables over the entire season, moderate relationships were found between individual changes in HRR and sprint and repeated-sprint performance
Di Giminiani & Visca[20]	N/A	Explosive strength (Squat Jump & CMJ) Pre-match augmentation (CMJ-SJ) 15 and 30m Sprints Aerobic Endurance via test of leger V˙O2max	Beginning of Preparation period (preseason) of the 1^{st} (T1), 2^{nd} (T2) and 3^{rd} (T3) year.	N/A	A significant main effect on the V˙O2max (+5.72%; $F(2.49) = 3.822$; $p = 0.029$; $ES = 1.00$), HR (−1.70%; $F(2.54) = 3.472$; $p = 0.038$; $ES = 0.97$), SJ (+10.26%; $F(2.54) = 15.254$; $p = 0.0001$; $ES = 1.53$), CMJ (+7.36; $F(2.54) = 8.270$; $p = 0.001$; $ES = 1.33$), SP15 (−3.50%; $F(2.44) = 12.760$; $p = 0.0001$; $ES = 1.53$), and SP30 (−4.44%; $F(2.44) = 5.797$; $p = 0.006$; $ES = 1.16$) was observed in the two soccer seasons. Notation on effects of growth and maturation effect were mentioned
Figueiredo et al.[21]	sRPE-TL and HR-based methods (Edward's-TL)	YoYo IR1	Start of Pre-Season (T1) & 3 weeks later (T2)	Negative correlations were observed between weekly mean sRPE-TL ($r = -0.69$), Edward's TL ($r = -0.50$) and change in YoYo IR1.	YoYo scores significantly improved from T1 to T2 (t = 5 22.6; ES 5 0.83; p, 0.05).
	Total distance, accel &		6-week in season period of the	A very large linear relationship	Mean change in MAS over training

(continued)

Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
Fitzpatrick et al.[22]	decel distance >2m/s,[2] distance and time > 17 km/h, distance and time >21 km/h, distance and time >MAS (individualised zones), distance covered and time > ASR, heart rate exertion, s-RPE	MSS MAS	competition phase (August to September)	was found between time>MAS and changes in MAS ($r = 0.77$ [90% CI 0.48 to 0.91], $R2 = 0.59$) Also, large relationships were found between t > ASR ($r = 0.62$ [90% CI 0.22 to 0.84], $R2 = 0.38$), meters >MAS ($r = 0.50$ [90% CI 0.06 to 0.78], $R\ 2 = 0.25$) and changes in MAS. Relationships between all other mean weekly arbitrary and individualised training load measures and changes in fitness parameters were found to be unclear	period was 0.11 ± 0.12 km.h-1 (ES: 0.15, possibly trivial, 31/69/0) and the mean change for MSS was 0.27 ± 0.20 km.h^{-1} (ES: 0.16, possibly trivial, 26/74/0).
Francioni et al.[23]	Total sessions and session duration	CMJ 15m sprint	Regular intervals of two months (6 times in total) across a full season T0: August (before the start of the season); T1: October; T2: December; T3: February; T4: April; T5: June (end of season)	non-linear trend of increases along the season in relation to the amount of training sessions performed.	There were significant variations across the six testing sessions with no linear trend
Gibson et al.[30]	Total Distance Low Speed Running <13kmh High Speed Running >13kmh	YoYo IE2 CMJ 15m Sprint	International tournament of 5 consecutive match days (testing was on day 1 and 5 respectively)	N/A	Differences in YoYo IE2 between low and high match exposure groups were trivial Differences in time to complete a 15m sprint between groups were small and non-significant No significant differences for changes of lower body power
Gil-Rey et al.[25]	RPEres, RPEmus, total duration	CMJ CMJ-AS 5 and 15 m sprints Université de Montreal endurance test - time to	In-season T1 (January) & T2 9 weeks later (March)	Can't determine - performed correlation analysis with both 'elite' and 'non-elite' players as a single data set (i.e. didn't	Small effect size (0.32) improvement in Montreal aerobic test time to exhaustion, no other fitness changes noted (all trivial)

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
		exhaustion (aerobic fitness)		differentiate between the two groups)	
Hammami et al.[26]	N/A	Anthropometric measurements, aerobic (YoYo IR1) and anaerobic (CMJ), (SJ), five-jump-test (5JT), and speed (5m, 10 m, 30 m sprints)	In-season T1 (October) and T2 8 months later (May)	N/A	Significant improvements for following tests from T1 to T2 for soccer players (*significant at $P = 0.05$) CMJ 31.2 ± 4.1 to 34.5 ± 4.4 SJ 29.1 ± 3.6 to 32.3 ± 3.7 10m sprint 2.0 ± 0.1 to 1.9 ± 0.1 30m sprint 4.6 ± 0.2 to 4.5 ± 0.2 V˙O2max 47.9 ± 1.9 to 55.7 ± 2.2
Hammami et al.[27]	N/A	SJ CMJ Running speed test over 30m YoYo IR1 RPE	The soccer players and control subjects were evaluated at five different time points: - First test, (T0) baseline at the start of the preparatory period in October 2008. - Second test, (T1) in February 2009 in the middle of the first season. - Third test, (T2) in May 2009, the end period of the first competitive season. - Fourth test, (T3) in November 2009. - Fifth test, (T4) in the end of May 2010, the end period of the second competitive season.	N/A	The 30m-sprint performances were statistically significant ($p = 0.07$) for soccer players during the period T2-T3 (-0.17s) and the final period compared with control subjects.
Impellizzeri et al.[28]	s-RPE and HR (< 80%, 80–85%, 85–90%, 90–95%, and > 95% HRmax)	V˙O2max, HRmax, V˙O2 at lactate threshold, % of V˙O2max, velocity at lactate threshold, running economy at lactate threshold, Ekblom's test (time)	Both Pre-season and In-season. T1 (July), T2, 4 weeks later (August) and T3, 8 weeks later (October).	N/A	Ekbloms test significantly improved from baseline-post preseason and also pre-season to in-season. 723 ± 47 > 629 ± 36 > 609 ± 33 Significant improvement in V˙O2max 3.96 ± 0.38 to 4.20 ± 0.42 to 4.20 ± 0.44 and velocity

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
					at Tlac 11.3 ± 0.7 to 11.9 ± 0.7 to 12.4 ± 0.5†
Jastrzebski et al.[29]	Exposure Time	V˙O2max Wingate Test Sprint Test Shuttle run of 150m	Both Pre-season and In-season T1 (Start of Preseason), T2 (Middle of season) and T3 (end of season)	N/A	The relative peak power at the end of the season (11.96 ± 0.75 Wkg^{-1}) was significantly higher (p > 0.00) than before the preparation period (11.24 ± 0.78 $W.kg^{-1}$). A significant positive improvement in the 150-m shuttle run time was also observed at the end of the season.
Los Arcos et al.[31]	RPE, RPEres, RPEmus, total duration	CMJ, CMJ-AS, CMJ-dominant leg, CMJ-non dominant leg, 5m sprint, 15m sprint, velocity at 3mmol, lactate concentration at 12 km/h, lactate concentration at 13 km/h	Start of pre-season (T1) and 9 weeks later at start of in-season (T2)	Significant negative correlations found between RPEmus and CMJ-dominant (-0.57), CMJ-non dominant and lactate at 13 km/h (-0.7); Total duration significant negative correlations with CMJ-AS, 5m and 15m sprint tests	Significant improvement in 5m and 15m sprint scores (p = -0.07) no difference in other tests pre-post
Los Arcos et al.[32]	sRPEres-TL & SRPEmus-TL	CMJ CMJ with Arm Swing (CMJ-AS) 5 & 15m Sprint Aerobic fitness test (four sub maximal runs between 11-15 km.h with 3 min recovery)	Start of pre-season (T1) and 32 weeks later at start of in-season (T2)	Practice volume correlated negatively and largely with the change in the V3 Lac12 and Lac13 (values. Furthermore, sRPEres-TL and sRPEmus-TL correlated largely and negatively with the change in Lac13, whereas the changes in 15 m sprint time correlated with sRPEres-derived measures (r = -.53/-.51)	Very likely moderate (ES = .62 ± .28) and possibly small (ES = .21 ± .22) improvements in CMJ and CMJ-AS performance, respectively, were found from T1 to T2, while the changes in the rest of the variables (i.e. acceleration and aerobic fitness) were trivial
Lopez-Segovia et al.[30]	Volume of Training exposure (total number of sessions and duration)	CMJ & CMJ 20 (with and without load) Acceleration capacity (10m, 20m, 30m and	Start of in-season period (T1) and 16 weeks later coinciding with end of first half of regular season (T2).	N/A	CMJ: both groups improved, but not significantly statistically CMJ 20 both teams improved significantly (team A, p = 0.05;

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
		10-20m, 10-30m, 20-30m) MAS			team B $p = 0.01$) For this variable, team A improved significantly at T2 ($p = 0.01$), whereas team B worsened. The differences between the two teams at T2 were significant ($p = 0.01$).
Malone et al.[33]	GPS HR	CMJ	One week in season micro cycle (7 days)	No correlation between absolute changes in TL and jump height	No significant differences were observed
McMillian et al.[34]	Training Diary/Log	Lactate threshold test	Start of Pre-Season (T1), October (T2), December (T3), January (T4), April (T5), and June (T6)	N/A	Mean running velocity at V-Lac (from 11.67 ± 0.29 to 12.96 ± 0.28) and V4mM (from 13.62 ± 0.25 to 14.67 ± 0.24) increased from the start of preseason training to October. No other statistical changes across the season
Miranda et al.[35]	Foster's TRIMP	10, 20 and 50m sprints Lactate minimum test Running anaerobic sprint test	Start of pre-season (T1) and 10 weeks later during an in-season period (T2)	N/A	Possible increases in 30 and 50m time trial performance, running intensity at lactate minimum test and the anaerobic parameters of the running anaerobic sprint test (not statistically different)
Morris et al.[36]	N/A	IMTP CMJ 10 and 30m Sprint times Arrowhead agility test	Start of pre-season (T1) and end of in-season (T2)	N/A	Analysis was matched on maturity status with control groups For elite group alone improvements seen CMJ and peak force for IMTP – not statistically significant
Noon et al.[37]	Total Duration	30m sprint Arrowhead agility test YoYo IR1 CMJ-AS	Start of pre-season, (T1), In-season 1, 6 weeks later (T2), In season 2, 13 weeks later (T3) and in-season 3, 10 weeks later (T4)	Lack of correlations between fitness and training load variables. The training durations are 'estimated' at 2 h if they completed the session,	30m sprint decreased ($P < 0.05$; $\eta_P^2 = 0.48$) post pre-season 4.31 ± 0.18 to 4.24 ± 0.22 to end of in-season. YoYo test scores improved from baseline to in-season (both blocks) ($P < 0.05$; $\eta_P^2 = 0.93$) 2203 ± 334 to

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
				rather than the actual training durations	2537 ± 235 and further improved between in-season block 1 and 2: 3150 ± 269
Paul et al.[38]	sRPE and HR zones	30-15 test CMJ height COD test	Four weeks in season period (T1) October, (T2) November	Lack of correlation analysis to provide this information	Significantly improved 30-15 score in SSG intervention group (from 17.0 to 18.4km/h; p < 0.05; ES = 0.57) No other fitness changes
Perroni et al.[39]	N/A	CMJ YoYo IR1	Eight-week preseason training camp (T1) August, (T2) October	N/A	Significant increase for both squads for pre and post preseason testing for CMJ (25.23 to 29.40; ES 1.62) and YoYo IR1 V˙O2max (42.93 to 44.95; ES 0.62)
Saidi et al.[40]	Session RPE	YoYo IR1 RSSA SJ CMJ	Six weeks in season period consisting of 10 matches (T1) Mid-April, (T2) late May	No significant relationship between performance in YYIR1 and training load parameters however there was a significant relationship between training load and changes in RSSA (r = -0.60; p < 0.003)	General trend was physical fitness decline over the 6-week period although more specifically significant differences were found for the YoYo IR1 (2520m to 1640m; p < 0.001; ES = 0.5), RSSA (8.07s to 8.28s; p < 0.01, ES = 0.6) and SJ (36.5cm to 35.5cm; p < 0.046, ES – 0.7).
Silva et al.[41]	Match minutes (duration)	5m and 30m sprint CMJ Agility Knee Extensor and Flexor YoYo IE2	Full Season (T1) July, (T2) August, (T3) January, (T4) June.	The individual match playing time from T1 to T3 was correlated with the individual changes in 5m sprint time (r = 20.705; $p > 0.01$;). From T2 to T3, playing time was also significantly correlated with KEND (r = 0.786; p, 0.05) and H/QND (r = 20.738; p, 0.05). From T3 to T4, the playing time was correlated with KFD (r = 0.590; p, 0.05), KFND (r = 0.575; p, 0.05)	Significant improvements in CMJ and YYIE2 from T1 to T2 were observed ($p < 0.05$). The 30m sprint time improved from T2 to T3 ($p < 0.01$). The CMJ decreased from T2 to T3 and T4, and YYIE2 from T2 to T4 ($p < 0.05$). There were increments in the H/Q ratio and agility from T1 and T2 to T3 and T4 ($p < 0.05$).

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
				and H/QND ($r = 0.794$; p, 0.05)	
Silwowski et al.[42]	N/A	Incremental treadmill test	Full calendar year in duration (T1) after completion of the basic preparatory period; March, (T2) before the commencement of the shortened preparatory period; July, (T3) before the commencement of the basic preparatory period, January, (T4) after the completion of the basic preparatory period, March.	N/A	The tests showed significant differences in aerobic performance of young footballers in individual periods of the annual training cycle. The most favourable changes in terms of exercise adaptation of the participants were noted after the basic preparatory period
Silwowski et al.[43]	Total Duration	Field based lactate threshold test	Full calendar year in duration (T1) after completion of the basic preparatory period; March, (T2) before the commencement of the shortened preparatory period; July, (T3) before the commencement of the basic preparatory period, January, (T4) after the completion of the basic preparatory period, March.	N/A	Significant improvements from test 2 to 4 in comparison to 2 and 3
Sporis et al.[44]	Hours and days practice and match mins	5, 10, 20 & 30m Sprints CMJ Slalom Test for Agility $\dot{V}O_2max$ – incremental treadmill test	In Season period of length (T1) end of pre-season, (T2) one week after end of competition period.	N/A	Starters showed small but significant differences for 21 out of 24 variables measured. The most significant findings of this study point to the fact that official games help in maintaining and improving agility parameters (6 out of 7 tests) as well as in maintaining and improving overall power performance of soccer players which includes

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Table 6. (continued)

Study	Training Load measures	Fitness Measures	Time points in season at which physical tests were administered	Associations between training load and fitness changes	Fitness Change Outcome
					sprinting, jumping and kicking the ball.
Williams et al.[45]	N/A	30m sprint CMJ	At six-month intervals following the start of preseason in year 1 (for 3 full years)	N/A	Increased 30m Sprint time and CMJ as increases in age were seen

Abbreviations: 5JT = Five Jump Test; ASR = Anaerobic Speed Reserve; CMJ = Countermovement Jump; CMJ20 = Countermovement Jump with 20kg load; CMJ-AS = Countermovement Jump with Arm Swing; COD = Change of Direction; GPS = Global Positioning System; H/Q Ratio = Hamstring:Quadricep Ratio; H/QND = Concentric Hamstrings Quadriceps Strength Ratio Nondominant Leg; HRex = Heart Rate; HRR = Heart Rate Recovery; IMTP = Isometric Mid-Thigh Pull; iTRIMP = Individualised Training Impulse; KEND = Peak Torque in Knee Extension Nondominant Legs; KFD = Peak Torque in Knee Flexion Dominant Legs; KFND = Peak Torque in Knee Flexion Nondominant Legs; MAS = Maximal Aerobic Speed; MSS = Maximal Sprint Speed; rMSSD = Root Mean Square of Successive Differences between Normal Heartbeats; RPEmus = Rating of Muscular Perceived Exertion; RPEres = Rating of Respiratory Perceived Exertion; RSSA = Repeated Shuttle Sprint Ability; SJ = Squat Jump, s-RPE = Session Rating of Perceived Exertion; SSG = Small Sided Games; T = Test Point; TL = Training Load; Tlac = Lactate Threshold; TRIMP = Training Impulse; Vam-Eval = Modified Version of the University of Montreal Track Test; V˙O2max = Maximal Oxygen Uptake; YoYo IE2 = Yo-Yo Intermittent Endurance Test Level 2; YoYo IR1 = Yo-Yo Intermittent Recovery Test Level 1.

may explain some of the physical improvements observed within youth soccer players throughout their long-term development programmes. For instance, previous research has suggested that factors such as maturation, hormones and musculoskeletal changes that incur when going through the development phase have direct impacts on the physical capabilities of youth players and that the training programmes which are implemented should account for these factors in order to optimally cater for development opportunities.[2] Overall, it should be concluded that both the effects of growth and maturation alongside the systematic training programmes are important in terms of physical performance development within junior athletes.

The quantification of TL is now commonplace within professional male youth soccer, with practitioners routinely collecting both external and internal TL information on a daily basis.[6] The present review revealed that common GPS-derived measures of external TL (e.g. total distance, high speed distance) were associated with positive changes in fitness. Despite the plethora of GPS variables available to quantify external TL currently, the evidence around their association to changes in fitness in professional male youth soccer players was found lacking. Indeed, the beforementioned more 'traditional' external TL variables and their association with changes in fitness has also been recently observed in senior professional players.[13] In terms of internal TL variables, both RPE-based and heart rate TRIMP-based measures demonstrated the strongest association to changes in fitness. It would appear that both measures were associated with improvements in fitness across both the pre-season[47] and in-season[36,48] phases. Both RPEres and RPEmus were found to be associated with changes in fitness,[48] which could be a future direction for practitioners rather than using the standard RPE approach. Interestingly, there appeared to be more studies revealing associations with external TL variables compared to internal TL variables. One reason may be due to external TL data being 'easier' for practitioners to collect during training and matches.[6] Internal TL measures face practical issues, such as erroneous heart rate data[51], which may dissuade practitioners from collecting and trusting this type of data, which is a limitation of the present literature available.

Limitations within the literature

Limitations of the present systematic review must be acknowledged. Only English language articles were considered, and only articles using professional male youth soccer players were included. It could be argued that the definition of a 'professional' youth soccer player can vary depending on the country of origin and standard of competition. In addition, limitations were found within consistency of the TL measures and physical fitness procedures used, thus limiting the ability to fully compare across articles. For example, there were differences observed in the threshold used for 'high speed distance' based variables (e.g. 17 and > 19.8 $km.h^{-1}$). The limited available studies evaluating the association between internal TL and physical test performance must also be acknowledged and recommended for future study in this area.

Based on the present available literature, it's clear that further work is required in order to understand the association between training load and physical development in professional male youth soccer players. There were a number of studies that only used a short study duration to examine the response to load (e.g. 1 – 6 weeks). Longitudinal data is required to understand the long-term athletic development in youth players across the different age groups. Of those that used longitudinal designs, often the physical testing points were too infrequent or the training load quantification was limited. With more teams now investing into the training process of youth players, it is hoped that future work in this area will comprehensively quantify the training load and physical response over longitudinal periods.

Conclusion

The present review was the first to provide a systematic evaluation of the association between training load and physical development using the current literature available within professional male youth soccer players. Both external TL (total distance, high speed distance, accumulated duration) and internal TL (RPE, TRIMP) measures were found to be associated with improvements in physical test performance across both pre-season and in-season phases. In addition, field-based testing was found to be sensitive to changes in physical qualities for aerobic capacity, lower body power and strength and sprint performance. However, limited sensitivity to change was found when assessing player agility performance. Future research in this area should look to enhance our understanding of the dose-response of TL (particularly internal TL) with changes in fitness across different age groups in professional male youth soccer. It would also be pertinent to examine whether enhancement of these physical quality improves a player's chance of making it as a senior professional player. It is also clear that there is very limited information which accurately monitors training load in conjunction with physical fitness changes in youth soccer and this should be explored in more detail in future work.

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