Small-Sided-Game-Induced Mechanical Load in Adolescent Soccer: The Need for Care and Consideration for Athlete Preservation

Jamie Salter[†*]

Context: The logistical efficiency and flexibility of small-sided games (SSG) to develop various soccer-specific attributes simultaneously make them a staple component of contemporary training programs in youth soccer. Their high ecological validity and consequential high utilization mean that if not considerately prescribed, players may be exposed to frequent repetitive mechanical stress that may induce maladaptation in skeletally and/or load-naïve or sensitive athletes. The purpose of this clinical review is to summarize mechanical load adaptations associated with the manipulation of area per player in SSG to outline the mechanistic pathway of load-related injuries in skeletally maturing athletes and to offer practical guidelines for coaches for the preservation of athlete health.

Evidence Acquisition: A nonsystematic search of computerized databases of peer-reviewed articles in English between 2010 and the present was used, and a critical appraisal of existing literature was subsequently conducted.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: The temporary relative strength deficit and inefficiency of the musculotendinous system associated with accelerated growth increase the mechanical cost of activity. As a result, the load tolerance (ie, tolerant, naïve, or sensitive) of athletes is transiently reduced as the musculoskeletal system struggles to attenuate force absorption adequately. Repeated exposure to submaximal mechanical loads that stimulate the accumulation of "microdamage" in structural tissue may lead to aggravation and/or tissue failure at connective sites in skeletally fragile athletes.

Conclusion: Coaches and practitioners need to individualize exposure to mechanical load for load-tolerant, naïve, and sensitive athletes during adolescence. Subtle changes to SSG prescription including modifying the area per player, inclusion of goalkeepers, constrained floaters, and management of work; rest ratios can offer practical and efficient methods to mitigate risk without derailing the development process. This, in turn, should contribute to reducing injury burden in this population and enhance developmental opportunities for young players.

Strength of Recommendation: A. Recommendation based on consistent and good-quality evidence published from 2010 onwards.

Keywords: mechanical load; adolescent; small-sided games; maturation; injury

From midadolescence, competitive soccer matches are typically played with 2 teams of 11 players in a playing area between 82 × 50 m and 91 × 65 m.[51] It is common for coaches and practitioners to manipulate the area per player (ApP, expressed in square meters) during training practices as an efficient training modality to enhance technical, tactical, psychological, and physical characteristics simultaneously.[3,9,22,46] Extensive research has explored the techno-tactical and the psycho-physiological impact that manipulating area per player can have on player development.[1,3,8,9,10,13,16,31,37] This literature offers valuable practical guidance for coaches targeting specific characteristics in a soccer-specific manner (ie, enhance aerobic

From [†]InSPIRe Group, School of Science, Technology and Health, York St John University, York, UK

*Address correspondence to Jamie Salter, InSPIRe Research Group, York St John University, Haxby Road Sports Campus, York, YO31 8TA, UK (email: j.salter@yorksj.ac.uk) (Twitter/X: @jay_salter).

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endurance or exposure to high-speed running). Manipulating the ApP through small-sided games (SSG) has also been shown to be effective for coaches in identifying, selecting, and developing talented young players.[17,63] Studies indicate that reducing the number of players per team increases the individual technical actions (ie, touches, dribbles, and passes),[4,11,12] which naturally enhances the opportunities for technical and tactical (ie, decision-making) development for young players.

The logistical simplicity, flexibility, and efficiency of SSG mean they are a valuable and versatile modality for coaches and practitioners working with youth soccer players, and, as a result, they are a staple component of contemporary training prescription. However, evidence suggests that reducing the ApP may increase the frequency of high-intensity actions (ie, accelerations, decelerations, changes of direction and short sprints),[10,23,36,39] which may influence fatigue response and extend recovery time as a result of the propulsive and braking forces associated with these movements.[36,39] These mechanical stress-inducing activities impact the musculoskeletal system (ie, cartilage, bone, ligaments, muscle, and tendon) and are related directly to tissue damage and repair, with only a narrow window of exposure considered "optimal."[60] Although effective in many ways, frequent exposure to mechanically demanding components of SSG without adequate recovery between sessions needs careful consideration in adolescent athletes. There is a substantial increase in growth, overuse, and general noncontact-related injury incidence during adolescence, which may be attributed to frequent exposure to low-to-moderate mechanical loads.[56,61] Therefore, the purpose of this clinical review is to summarize the physiological, but primarily mechanical, responses associated with the manipulation of ApP, and to explore the possible mechanistic pathway of load-related injuries in developing athletes, to offer practical guidelines for coaches for the preservation of athlete health.

Load Characteristics of SSG

The flexibility of SSG to expose players to situations or environments to develop specific attributes of performance is connected to an array of variables that can be manipulated by the coach. These include pitch dimension, number of players, numerical balance, the inclusion of goalkeepers and/or goals, game duration, work:rest intervals, rule selection, and coach encouragement.[22] Coaches may wish to either under- or overload the physiological and/or mechanical demands of SSGs, and consequently manipulate these variables to suit their periodized objectives.[32] From a physiological or metabolic standpoint, evidence implies that larger areas (>100 m^2 ApP) typically stimulate higher overall intensities; verified by greater blood lactate response, higher heartrates, elevated perceived intensities, greater overall and high-speed distances, and higher peak velocities.[8,9,22,43,46] Therefore, larger ApP formats may be more useful when developing posterior chain activity due to the increased high-speed running and sprint distances observed in these formats. Unsurprisingly, ApP that more closely replicates competitive dimensions (250-350 m^2) is more representative of match demands and therefore can be used to develop and maintain match fitness in various age groups.[8,46] These findings remain consistent even when additional variables are manipulated and, although responses may be moderated,[9,16,22,45,47,50,53] they follow the same physiological pattern.

From a mechanical perspective, the opposite would appear to be true. Accelerometery-based variables (ie, accelerations, decelerations, and changes in direction) often achieve similar values to peak periods of official matches in high-density SSG.[14] Ispirlidis[23] compared various physical parameters between small (2.4 m^2) and large (150 m^2) ApP, identifying significantly more medium-high-intensity accelerations and medium-intensity decelerations in the smaller ApP condition. This is supported by Guadino et al,[19] who reported more frequent changes in velocity, and increased moderate accelerations and decelerations with smaller ApP conditions (75 m^2 vs 98 m^2 or 135 m^2). In addition, Lacombe et al[32] outlined the relatively higher mechanical work in smaller ApP conditions, particularly when applied for short work durations (~2 minutes). The constitution of rapid changes in velocity and direction elicits high mechanical loads due to the propulsive and braking forces involved.[60] Eccentric work combined with lateral and/or anterior foot placement is required to decelerate the body, with large concentric work and utilization of the stretch-shortening cycle (SSC) required thereafter to accelerate in a new direction.[26,36,54] This chain of events may explain the more intense and prolonged exercise-induced muscle damage response observed after high-density ApP (62.5 m^2) SSG compared with low-density (284 m^2) SSG observed in soccer players.[39] Players reported significantly higher levels of self-reported delayed onset muscle soreness in knee extensors and flexors and concomitant elevated creatine kinase levels between 24 and 72 hours post-SSG intervention.

The findings presented above illustrate that the design, prescription, and delivery of SSG significantly influence the acute response and, possibly, the subsequent chronic adaptations experienced by players, and that care and consideration are required to preserve athlete health. As reported in adult soccer, there is a need to include a diverse selection of training modalities (ie, intensive SSG, extensive SSG, high-speed running, eccentric training) for optimal holistic development of young players, that is periodized within- and between microcycles.[15,21,38] Although likely variable between talent development environments, the logistical and situational constraints facing practitioners and coaches may constrain the format and density of SSG (eg, pitch hire costs, space and goal availability, squad size, club/academy philosophy, and playing style). Therefore, practitioners must be aware of the various ways in which they can manipulate the outlined variables to mitigate risk and prevent excessive fatigue while exposing athletes to adequate, varied, and appropriate physiological and mechanical loads.

Influence of Growth and Maturation

The adolescent growth spurt (often referred to as the period surrounding peak height velocity [PHV]) produces a unique scenario whereby developing athletes experience myriad naturally occurring physical adaptations that may temporarily predispose them to elevated injury risk.[56] Although the physical changes that occur are uniform (eg, increased limb length, increased muscle mass, enhanced SSC function, tendon stiffness, and motor unit recruitment) the timing, tempo, and magnitude of these are highly variable between players.[41,42,57] Biological age can vary between 4 and 6 years (9.6-14.1 years) in chronological age groups, with differences in height (~17%), mass (~50%), and fat-free mass (~21%) being substantial.[18,49] The physical growth of the skeletal structures stimulates a mechanotransductive response from connective and soft tissues, resulting in a transient period of relative strength deficit that impedes coordination, movement, and general athleticism (often referred to as adolescent awkwardness).[33,41] This period exposes athletes to an elevated risk of traction apophyseal injuries due to a transient deficit in bone mineralization, increased bone porosity,[34] and increased stress on connective tissue, even in relaxed states (referred to as tissue preload) due to the musculoskeletal imbalances created.[44] Calculations have predicted that, during this period, lower-limb muscles must develop ~30% more force to produce the same relative acceleration,[59] and that less mature players perceive training sessions to be significantly more intense than more mature counterparts.[49]

The rapidly evolving musculoskeletal composition and the relative disproportionate changes in limb and trunk length create a notion of “skeletal fragility.” This fragility is considered a significant contributor to the increase in injury burden during (57.9 days) and post-PHV (89.4 days) compared with pre-PHV (44.6 days).[6,58] Studies report that 12% to 45% of all injuries were growth-related and that many (46% to 72%) were noncontact and moderate in severity (30% to 43%).[35,48,55,62] Based on this, the mechanical load-adaptation pathway of training and competition is adversely affecting many adolescent athletes, with each severe injury being reported to reduce overall development time by approximately 10%, therefore affecting long-term outcomes.[27] This may well be a byproduct of the naturally occurring process of maturation, but is likely exacerbated by development pathway guidelines prescribing age-related intensification in training time and/or frequency that directly align with key developmental stages.[40,52]

The Elite Player Performance Plan (EPPP) governs UK soccer academies and prescribes staff, facility infrastructure, and coaching exposure criteria that academies must meet to maintain their audited categorization.[40] This criteria-driven process influences the development environment of each academy and includes systemic age-related increments in provision (ie, coaching hours) according to development stage (ie, Foundation, Youth Development or Professional Development Phase), rather than biological age. Although logical as the advanced training age allows players, in theory, to tolerate training demands better, it will likely increase their exposure to SSG, and subsequently mechanical loads. For some athletes, this may present minimal issues and facilitate continual development; however, for many, this progressive and age-informed increment in load coincides with the period of skeletal fragility and may lead to structural failures in the form of chronic, growth and/or overuse-related complaints that escalate into injury.[60] Unfortunately, in most cases, the onset of such issues is difficult to detect and relies primarily on retrospective diagnosis only once lagging indicators (ie, pain and/or discomfort or inflammation) present themselves.

Mechanical Load-Adaptation Pathways in Adolescent Players

Biological tissue (eg, bone, muscle, tendon) failure occurs when the strength of the material is surpassed by excessive stress (ie, force per unit of area) and strain (ie, amount of deformation) induced by the application of force, either singular high-magnitude or repeated lower-magnitude loads.[28,29] Theory indicates that repeated submaximal loading causes the accumulation of ‘micro-damage’ in structural tissue, and when the rate of accumulation exceeds the rate of biological repair, injury, or failure occurs.[64] Thresholds of tissue failure vary between adult and adolescent athletes as repetitive forces applied to an immature skeleton cause aggravation and overuse-related complaints at vulnerable sites (ie, apophyses).[30,34] Jayanthi et al[24] argue that systematic increments in training load exposure are possible and should be encouraged in youth athletes, but recognize variations in load tolerance and thus categorize youth athletes as either (1) load tolerant, (2) load naïve, or (3) load sensitive. Load-tolerant athletes have typically passed PHV (>96% percentage of predicted adult height [PPAH]), have manageable weekly workloads in relation to their age (hours < age) and chronic exposure, limited previous injuries, and have low levels of sport specialisation.[25] Load-naïve athletes may have relatively high acute loads compared with chronic exposure (ACWR > 1.5), be approaching PHV (~85% PPAH), have suboptimal training and competition ratios (<1:1), and a degree of sport specialization. Load-sensitive athletes are typically the most at risk and are characterized by those experiencing PHV (85% to 96% PPAH), high relative workloads (hours > age; ACWR > 2.0), and highly sport-specialized and with suspected overuse injury symptoms.[25] As a result of biological diversity, it is likely that, in a squad of players, coaches will have a mixture of load-tolerant, naïve, and sensitive athletes, and will need to consider each player’s suitability for prescribed practices; thus, an individualized approach is required.

Frequent exposure to the low-to-moderate intensity mechanical loads typically produced by small ApP practices may be a contributing factor to the high prevalence of growth/overuse injuries in adolescent populations, at least for load-naïve or sensitive athletes. A theoretical mechanistic-causal pathway to explain this notion has been presented recently by Kalkhoven,[28] who suggested that the repetitive mechanical loads elicited by frequent exposure to low-to-moderate mechanical loads (eg, reduced ApP SSG) will gradually fatigue a tissue until a critical damage threshold is exceeded. The mechanical strength of a tissue is considered time-varying as it deteriorates progressively over time owing to the cycling loading, which can be accelerated in athletes who are "skeletally fragile," have minimal recovery time, and are exposed to age, rather than biological-related, intensification of loading (eg, due to EPPP requirements). The transient changes outlined above related to maturation (i.e., deficit in bone mineralization, increased bone porosity, and tissue preload) result in a reduced critical damage threshold, and thus may partially explain the increased injury incidence at this time.[35,48,61] The frequent changes in direction and velocity require rapid activation of the SSC and co-contraction of major muscle groups to maintain the structural integrity of joints, both of which are influenced substantially by maturation.[42] There is a gradual increase in SSC function with biological age, attributed to various factors, including increased motor-unit (particularly Type II motor-unit) recruitment, contraction speeds, preactivation, pennation angle, rate of force development and cross-sectional area.[41,42] Combined with suboptimal SSC function, the relative strength deficit imposed by immature muscular development on a heavy skeletal frame elevates the relative mechanical cost of even submaximal activities, reducing the athletes 'ceiling' (ie, critical damage threshold).[24] As a result, the load tolerance of athletes is reduced as the musculoskeletal system struggles to attenuate force absorption adequately. Estimates examining the nonlinear relationship between load, magnitude, and muscle damage suggest that reducing imposed stressors by 10% generally yields a corresponding 100% increase, or more, in the number of cycles to failure.[29] Thus, we are recommending that only small modifications in SSG prescription for load-naïve and sensitive athletes are required, which may mean they can continue to train and compete as prescribed by policy without experiencing adverse mechanical load adaptations/injury.

PRACTICAL APPLICATIONS

It is important to clarify that the author is not suggesting that utilizing SSG or high-density ApP activities is detrimental to adolescent players. In contrast, the author believes SSG to be a highly effective, efficient, and pragmatic way of identifying, developing, and monitoring adolescent players throughout biological maturation.[17,63] However, the focus of this clinical review is to highlight the potential consequences of a poorly considered, or "one size fits all" prescription of a fundamental modality of player development, and to promote proactive and cognisant prescription of this to help reduce growth-/overuse-related injury burden. Therefore, the final section outlines some constraints and variable manipulations that might offer coaches practical, efficient, and effective ways to preserve load-naïve or sensitive athletes (Figure 1).

There is a consensus in the literature that lower-density ApP activities (ie, extensive) increase the physiological load via increased distances covered in various speed thresholds, maximum velocities achieved and overall metabolic load.[9] Therefore, these larger area sizes may elicit larger peak deceleration forces, higher peak eccentric forces (particularly on the posterior chain) and higher body impacts, but at lower frequencies compared with high-density ApP.[7,19,20] Therefore, utilizing SSG formats with an extensive focus would reduce the overall mechanical load (due to less frequent actions), while also exposing athletes to other critical performance attributes required for their development (ie, metabolic stress, maximal velocity running). In addition, Lacome et al[32] concluded that decreasing the number of players per team increased the high-intensity actions and changes in velocity (ie, accelerations and decelerations) and, therefore, teams with more players reduce the frequency of high-intensity involvements, which may, in turn, lessen the overall load of the SSG. They also suggested that high mechanical load from high-density SSG was sustainable only for short SSG bouts (<5 minutes) with longer rest periods (ie, 90-120 seconds). Therefore, although paradoxical in theory, another strategy to minimize the mechanical load is to prescribe longer, or continuous, bouts with shorter recovery periods—a notion that Branquinho et al[5] support. Therefore, coaches looking to prescribe sessions with reduced mechanical load should strive for larger ApP (>250 m^2), include goalkeepers, have a focus on possession, and increase the number of players per team (ie, >6 vs 6). Contrastingly, if practitioners wish to prescribe sessions with high-mechanical loads (ie, intensive) they would utilize smaller ApP (<75 m^2), have no goalkeepers, and use small teams (ie, <4 vs 4). Ideally, at least 1 exposure to both formats across the microcycle would provide adequate load prescription for most players; however, if logistical constraints prevent this, coaches should incorporate as many of the desired variables as possible when implementing SSG sessions.

As previously outlined, there is a likelihood that teams will be comprised of players with varying load tolerance levels and biological diversity. Therefore, practitioners may need to utilize some of the confined area and/or mismatched team constraints to adequately load those players differently within the same session. For example, Guard et al[20] compared the load profiles of players in unbalanced teams and observed elevated metabolic and mechanical loads in players on teams with an inferior number of players (ie, 4 vs 6). Therefore, this offers practitioners a useful option to subtly reduce the stress imposed on naïve or sensitive athletes, by placing them on an overloaded team for longer durations, while challenging load-tolerant athletes on underloaded teams more so. Also, Asian-Clemente et al[2] suggest that including players as floaters may be a useful strategy to minimize mechanical stress, and that modifying their involvement to either internal, external, or zonal floaters can all incrementally reduce loads. Therefore, load-naïve or sensitive players may be utilized as floaters or confined to zones for a greater proportion of the session than load-tolerant athletes, as a method of individually managing their exposure. The simple manipulation of overloads and floater formats is a logistically

Mechanical Load Adaptation Variables for SSG Prescription	
Reduced Mechanical Load (Extensive)	**Increased Mechanical Load (Intensive)**
Inclusion of Goalkeepers in both small and large ApP formats	Larger ApP (i.e., 250 m2 ApP) SSG formats elicit larger peak body impacts, deceleration forces and eccentric loads (but less frequently)
Utilise possession focus (i.e., focus on ball retention) rather than number of goals	Smaller ApP (i.e., <75 m2 ApP) stimulate highly frequent small to moderate mechanical stress through increased high intensity actions (e.g., change of direction and velocity)
Position athlete in an overloaded team (i.e., 6 v 4) 23 x 23 m (53 m2 ApP) 8 x 2 mins with 90 s recovery	Position athlete in an underloaded team (i.e., 4 v 6) 23 x 23 m2 (53 m2 ApP) 8 x 2 mins with 90 s recovery
Utilise confined (square or zonal) floater (i.e., 4 v 4 + 2) 40 x 30 m (120 m2 ApP) 4 x 4 mins with 120 s recovery	Utilise freely movable (internal or external) floater (4 v 4 + 2) 40 x 30 m (120 m ApP) 4 x 4 mins with 120 s recovery
Increase the number of players on each team 6 v 6, 8 v 8, 10 v 10 (>80 m2 ApP) >5 mins with 30-60 s recovery	Reduce the number of players on each team 1 v 1, 2 v 2, 3 v 3, 4 v 4 (<75 m2 ApP) 2-5 min bouts with 90-120 s recovery

Contextual factors that may influence load tolerance categorisation of athletes
- Maturity timing
- Previous training exposure (i.e., training age)
- Acute/residual fatigue from previous activity/match
- Recovery time between training sessions and/or matches
- Previous injury history

NB. Prescribed ApP, formats and durations are examples adopted from studies referenced in this article and may not be directly applicable to all environments

Figure 1. Guidance on variables to manipulate mechanical load-adaptation pathways in SSG activities. ApP, area per player; SSG, small-sided game.

simple tool that can be utilized by practitioners "on-the-fly" as they monitor the session but requires previous appreciation and awareness of those in the various load tolerance groups for effective application.

SUMMARY

The logistical efficiency and flexibility of SSG to develop various attributes simultaneously mean they are a staple component of contemporary training programs for youth soccer coaches. The host of manipulative variables available makes the SSG format pliable to accentuate the development of various technical, tactical, or physical properties. The frequency of their prescription in adolescent football (ie, 1-3 times per week) means that, if not considerately prescribed, players will be exposed to overly frequent repetitive mechanical stress that may induce maladaptive load-adaptations in skeletally and load-naïve or sensitive athletes. Therefore, coaches need to embrace subtle variations in rules, format, team configuration, and duration to optimize the load response and preserve athlete health. These modifications may be discrete and athlete-specific or applied to whole groups as required (eg, biobanded). They should then be reviewed regularly in conjunction with specialist support staff through longitudinal monitoring of biological maturation and injury symptoms.

ORCID ID

Jamie Salter https://orcid.org/0000-0002-7375-1476

REFERENCES

1. Ade JD, Harley JA, Bradley PS. Physiological response, time-motion characteristics, and reproducibility of various speed-endurance drills in elite youth soccer players: small-sided games versus generic running. *Int J Sports Physiol Perf*. 2014;9(3):471-479.
2. Asian-Clemente JA, Rabano-Muñoz A, Requena B, Santalla A, Suarez-Arrones L. The influence of the floater position on the load of soccer players during a 4 vs 4 + 2 game. *Kinesiology*. 2022;54(1):82-91.
3. Bezerra L, Teoldo da Costa I, Silva D, Vasconcellos F. How modifications in goals in small-sided and conditioned games in soccer influence the tactical actions of young soccer players. *Hum Move*. 2021;22:92-100.
4. Bintang Abrori R, Rini Sukamti E, Fauzi, Nurfadhila R. The effect of small sided game training on passing accuracy and dribbling ability in 10 years-old junior soccer players. *IJMRA*. 2023;6(7):3422-3427.
5. Branquinho L, Ferraz R, Travassos B, Marinho DA, Marques MC. Effects of different recovery times on internal and external load during small-sided games in soccer. *Sports Health*. 2021;13(4):324-331.
6. Bult HJ, Barendrecht M, Tak IJR. Injury risk and injury burden are related to age group and peak height velocity among talented male youth soccer players. *Orthop J Sports Med*. 2018;6(12):232596711881104.
7. Castillo D, Raya-González J, Javier Y, Clemente F. Influence of pitch size on short-term high intensity actions and body impacts in soccer sided games. *J Hum Kinet*. 2021;78:187-196.
8. Castillo-Rodríguez A, Durán-Salas Á, Giménez JV, Onetti-Onetti W, Suárez-Arrones L. The influence of pitch dimensions during small-sided games to reach match physical and physiological demands on the youth soccer players. *Sensors (Basel)*. 2023;23(3):1299.
9. Clemente F, Praça GM, Aquino R, et al. Effects of pitch size on soccer players' physiological, physical, technical, and tactical responses during small-sided games: a meta-analytical comparison. *Biol Sport*. 2023;40(1):111-147.
10. Clemente F, Praça GM, Bredt SDGT, van der Linden CMI, Serra-Olivares J. External load variations between medium- and large-sided soccer games: ball possession games vs regular games with small goals. *J Hum Kinet*. 2019;70(1):191-198.
11. Clemente F, Sarmento H. The effects of small-sided soccer games on technical actions and skills: a systematic review. *Hum Move*. 2020;21(3):100-119.
12. Clemente FM, Sarmento H, Costa IT, Enes AR, Lima R. Variability of technical actions during small-sided games in young soccer players. *J Hum Kinet*. 2019;69:201-212.
13. da Costa JC, Borges PH, Ramos-Silva LF, Weber VMR, Moreira A, Ronque ERV. Body size, maturation and motor performance in young soccer players: relationship to technical actions in small-sided games. *Biol Sport*. 2022;40(1):51-61.
14. Dalen T, Sandmæl S, Stevens TGA, Hjelde GH, Kjøsnes TN, Wisløff U. Differences in acceleration and high-intensity activities between small-sided games and peak periods of official matches in elite soccer players. *J Strength Condit Res*. 2021;35(7):2018-2024.
15. Dalen-Lorentsen T. Training load quantification in a Norwegian professional football team: within and between microcycle comparisons. *Sport Perf Sci Rep*. 2022;165(1):1-4.
16. Fanchini M, Azzalin A, Castagna C, Schena F, McCall A, Impellizzeri FM. Effect of bout duration on exercise intensity and technical performance of small-sided games in soccer. *J Strength Condit Res*. 2011;25(2):453-458.
17. Fenner JSJ. The evaluation of small-sided games as a talent identification tool in highly trained prepubertal soccer players. *J Sports Sci*. 2016;34(20):1983-1990.
18. Figueiredo AJ, Coelho E Silva MJ, Cumming SP, Malina RM. Size and maturity mismatch in youth soccer players 11- to 14-years-old. *Pediat Exerc Sci*. 2010;22(4):596-612.
19. Gaudino P, Alberti G, Iaia FM. Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. *Hum Move Sci*. 2014;36:123-133.
20. Guard AN, McMillan K, MacFarlane NG. The influence of relative playing area and player numerical imbalance on physical and perceptual demands in soccer small-sided game formats. *Sci Med Football*. 2021;6(2):221-227.
21. Handford MJ, Bright TE, Mundy P, Lake J, Theis N, Hughes JD. A conceptual framework of different eccentric training methods. *Strength Condit J*. 2024;46(2):148-158.
22. Hill-Haas SV, Dawson B, Impellizzeri FM, Coutts AJ. Physiology of small-sided games training in football: a systematic review. *Sports Med*. 2011;41(3):199-220.
23. Ispirlidis I. Effects of two different small-sided games protocols on physiological parameters of professional soccer players. *J Hum Sport Exerc*. 2021;S164-S171.
24. Jayanthi N, Saffel H, Gabbett T. Training the specialised youth athlete: a supportive classification model to keep them playing. *Br J Sports Med*. 2021;55(22):1248-1249.
25. Jayanthi N, Schley S, Cumming SP, et al. Developmental training model for the sport specialized youth athlete: a dynamic strategy for individualizing load-response during maturation. *Sports Health*. 2022;14(1):142-153.
26. Jones PA, Herrington L, Graham-Smith P. Braking characteristics during cutting and pivoting in female soccer players. *J Electromyog Kinesiol*. 2016;30:46-54.
27. Jones S, Almousa S, Gibb A, et al. Injury incidence, prevalence and severity in high-level male youth football: a systematic review. *Sports Med*. 2019;49(12):1879-1899.
28. Kalkhoven JT. Athletic injury research: frameworks, models and the need for causal knowledge. *Sports Med*. 2024;54(5):1121-1137.
29. Kalkhoven JT, Watsford ML, Coutts AJ, Edwards WB, Impellizzeri FM. Training load and injury: causal pathways and future directions. *Sports Med*. 2021;51(6):1137-1150.
30. Killian ML. Growth and mechanobiology of the tendon-bone enthesis. *Semin Cell Dev Biol*. 2022;123:64-73.
31. Köklü Y, Asçi A, Koçak FÜ, Alemdaroglu U, Dündar U. Comparison of the physiological responses to different small-sided games in elite young soccer players. *J Strength Condit Res*. 2011;25(6):1522-1528.
32. Lacome M, Simpson B, Cholley Y, Lambert P, Buchheit M. Small-sided games in elite soccer: does one size fits all? *Int J Sports Physiol Perf*. 2018;13(5):568-576.
33. Lloyd RS, Oliver JL, Radnor JM, Rhodes BC, Faigenbaum A, Myer G. Relationships between functional movement screen scores, maturation and physical performance in young soccer players. *J Sports Sci*. 2015;33(1):11-19.
34. Longo UG, Ciuffreda M, Locher J, Maffulli N, Denaro V. Apophyseal injuries in children's and youth sports. *Br Med Bull*. 2016;120(1):139-159.
35. Materne O, Chamari K, Farooq A, et al. Injury incidence and burden in a youth elite football academy: a four-season prospective study of 551 players aged from under 9 to under 19 years. *Br J Sports Med*. 2021;55(9):493-500.
36. Merks BMT, Frencken WGP, Den Otter AR, Brink MS. Quantifying change of direction load using positional data from small-sided games in soccer. *Sci Med Football*. 2022;6(2):234-240.
37. Nunes NA, Gonçalves B, Roca A, Travassos B. Effects of numerical unbalance constraints on workload and tactical individual actions during ball possession small-sided soccer games across different age groups. *Int J Perf Anal Sport*. 2021;21(3):396-408.
38. Nyberg M, Fiorenza M, Lund A, et al. Adaptations to speed endurance training in highly trained soccer players. *Med Sci Sports Exerc*. 2016;48(7):1355-1364.
39. Papanikolaou K, Tsimeas P, Anagnostou A, et al. Recovery kinetics following small-sided games in competitive soccer players: does player density size matter? *Int J Sports Physiol Perf*. 2021;16(9):1270-1280.
40. Premier League. The Elite Player Performance Plan. Accessed October 23, 2023. https://www.premierleague.com/youth/eppp.

41. Radnor JM, Oliver JL, Waugh CM, Myer G, Lloyd RS. The influence of maturity status on muscle architecture in school-aged boys. *Pediatr Exerc Sci*. 2020;32(2):89-96.
42. Radnor JM, Oliver JL, Waugh CM, Myer G, Moore IS, Lloyd RS. The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports Med*. 2018;48(1):57-71.
43. Rampinini E, Impellizzeri FM, Castagna C, et al. Factors influencing physiological responses to small-sided soccer games. *J Sports Sci*. 2007;25(6):659-666.
44. Read P, Oliver JL, De Ste Croix MBA, Myer G, Lloyd RS. Neuromuscular risk factors for knee and ankle ligament injuries in male youth soccer players. *Sports Med*. 2016;46(8):1059-1066.
45. Riboli A, Castagna C. Soccer-drill specificity in top-class male players with reference to peak match locomotor demands. *J Sports Sci*. 2023;41(6):573-583.
46. Riboli A, Coratella G, Rampichini S, Cé E, Esposito F. Area per player in small-sided games to replicate the external load and estimated physiological match demands in elite soccer players. *PLoS One*. 2020;15(9):e0229194.
47. Riboli A, Olthof SBH, Esposito F, Coratella G. Training elite youth soccer players: area per player in small-sided games to replicate the match demands. *Biol Sport*. 2021;39(3):579-598.
48. Rommers N, Rössler R, Goossens L, et al. Risk of acute and overuse injuries in youth elite soccer players: body size and growth matter. *J Sci Med Sport*. 2020;23(3):246-251.
49. Salter J, Julian R, Mentzel SV, Hamilton A, Hughes JD, De St Croix M. Maturity status influences perceived training load and neuromuscular performance during an academy soccer season. *Res Sports Med*. 2024;32(2):235-247.
50. Sarmento H, Clemente FM, Harper LD, Costa ITD, Owen A, Figueiredo AJ. Small sided games in soccer - a systematic review. *Int J Perf Anal Sport*. 2018;18(5):693-749.
51. The Football Association. The FA guide to pitch and goalpost dimensions. Accessed October 16, 2023. https://www.thefa.com/-/media/cfa/essexfa/files/miscellaneous/2022/handbook-2022/section-34–goalpost-and-pitch-sizes-and-line-marking.ashx.
52. The Football Association. The FA Handbook 2023-24. Accessed October 16, 2023. https://www.thefa.com/-/media/files/thefaportal/governance-docs/rules-of-the-association/2023-24/the-fa-handbook-2023-24-update-311023.ashx.
53. Soylu Y, Arslan E, Kilit B, Lane AM. Effects of coach encouragement on psychophysiological responses and technical actions in different small-sided soccer games. *Int J Sport Exerc Psychol*. Published online October 26, 2023. doi:10.1080/1612197X.2023.2273274.
54. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci*. 2013;13(6):646-652.
55. Tears C, Chesterton P, Wijnbergen M. The elite player performance plan: the impact of a new national youth development strategy on injury characteristics in a premier league football academy. *J Sports Sci*. 2018;36(19):2181-2188.
56. Towlson C, Salter J, Ade J, et al. Maturity-associated considerations for training load, injury risk, and physical performance within youth soccer: one size does not fit all. *J Sport Health Sci*. 2021;10(4):403-412.
57. Tumkur Anil Kumar N, Oliver JL, Lloyd RS, Pedley JS, Radnor JM. The influence of growth, maturation and resistance training on muscle-tendon and neuromuscular adaptations: a narrative review. *Sports*. 2021;9(5):59.
58. van der Sluis A, Elferink-Gemser M, Brink M, Visscher C. Importance of peak height velocity timing in terms of injuries in talented soccer players. *Int J Sports Med*. 2015;36(4):327-332.
59. van der Sluis A, Elferink-Gemser M, Coelho-e-Silva M, Nijboer J, Brink M, Visscher C. Sport injuries aligned to peak height velocity in talented pubertal soccer players. *Int J Sports Med*. 2013;35(4):351-355.
60. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training load monitoring in team sports: a novel framework separating physiological and biomechanical load-adaptation pathways. *Sports Med*. 2017;47(11):2135-2142.
61. Wik EH, Chamari K, Tabben M, Di Salvo V, Gregson W, Bahr R. Exploring growth, maturity and age as injury risk factors in high-level youth football. *Sports Med Int Open*. 2023:a21804594.
62. Wik EH, Lolli L, Chamari K, et al. Injury patterns differ with age in male youth football: a four-season prospective study of 1111 time-loss injuries in an elite national academy. *Br J Sports Med*. 2021;55(14):794-800.
63. Wilson RS, Hunter AH, Camata TV, et al. Simple and reliable protocol for identifying talented junior players in team sports using small-sided games. *Scand J Med Sci Sports*. 2021;31(8):1647-1656.
64. Zitnay JL, Jung GS, Lin AH, et al. Accumulation of collagen molecular unfolding is the mechanism of cyclic fatigue damage and failure in collagenous tissues. *Sci Adv*. 2020;6(35):eaba2795.