Differential responses to seasonal soccer training in U-15 and U-17 players: Body composition, strength, agility, and effect size analysis

Rick Stoop[1*,A-F], Georgios Georgiadis[2,D,F], Iván González-García[3,D-F]

[1] Football Club Utrecht, Herculesplein 241, 3584 AA Utrecht, The Netherlands
[2] Department of Nutrition and Movement Sciences, NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht University, Netherlands
[3] Faculty of Health Sciences, Universidad Isabel I, Burgos, Spain

***Corresponding author:** Rick Stoop; Football Club Utrecht, Herculesplein 241, 3584 AA Utrecht, The Netherlands; email: rick.stoop@live.nl

Received: 2026-02-25
Accepted: 2026-05-30
Published: 2026-06-09

A – Research concept and design
B – Collection and/or assembly of data
C – Data analysis and interpretation
D – Writing the article
E – Critical revision of the article
F – Final approval of article

Check for updates

ABSTRACT

Background: Training programs during adolescence play a crucial role in optimizing body composition and physical performance in youth soccer players. However, differences in training adaptations between age groups, particularly in agility performance, remain insufficiently explored.

Objectives: This study aimed to examine the effects of a seasonal soccer training program on body composition, strength, and agility in U-15 and U-17 soccer players.

Methods: A pre–post experimental design was applied to 28 male youth soccer players (U-15: n = 15; U-17: n = 13) competing in a football league in the Netherlands. Participants completed a 16-week training program consisting of technical, conditioning, tactical, and mental components. Body composition (height, body mass, lean mass, fat mass), jump performance (SJ, CMJ, CMJmax), isokinetic strength (knee flexion and extension peak torque), and agility (Illinois Agility Test) were assessed before and after the intervention. Data were analyzed using repeated-measures analysis of variance (ANOVA) and effect sizes were calculated using Cohen's d.

Results: In the U-15 group, significant improvements were observed only in knee flexion (70.2 ± 15.8 vs. 95.4 ± 23.5 Nm, $p = 0.006$, $d = 1.25$) and extension peak torque (75.1 ± 20.4 vs. 96.8 ± 18.9 Nm, $p = 0.012$, $d = 1.10$). In contrast, U-17 players demonstrated significant increases in lean mass (50.2 ± 3.1% vs. 53.4 ± 2.3%, $p = 0.021$), reductions in fat mass (11.0 ± 2.9% vs. 8.7 ± 2.5%, $p = 0.037$), improvements in agility performance (16.2 ± 0.7 vs. 15.4 ± 0.65 s, $p = 0.008$, $d = 1.18$), and knee flexion peak torque (78.4 ± 26.5 vs. 118.3 ± 28.7 Nm, $p = 0.003$, $d = 1.45$), together with significant gains in jump performance ($p < 0.05$). Most significant changes in the U-17 group were accompanied by large effect sizes ($d = 0.85$–1.45).

Conclusions: The training program elicited greater physiological and performance adaptations in U-17 compared to U-15 players. The greater adaptations observed in the U-17 group may be partially influenced by differences in biological maturation; however, maturity status was not directly assessed in the present study.

Keywords: agility, body composition, effect size, strength, training adaptation, youth soccer.

How to cite this article: Stoop, R., Georgiadis, G., & González-García, I. (2026). Differential responses to seasonal soccer training in U-15 and U-17 players: Body composition, strength, agility, and effect size analysis. *Sport, Exercise, and Injury*, *2*(1), 48-63. https://doi.org/10.56003/sei.v2i1.735

INTRODUCTION

Training programs for young soccer players are designed to optimize physical development, including body composition and sport-specific performance. Modern soccer requires players not only to demonstrate advanced technical and tactical abilities but also to possess high levels of physical fitness to cope with the increasing demands of the game (Sarmento et al., 2018; Slimani & Nikolaidis, 2018). Therefore, the development of structured and evidence-based training programs during adolescence is essential to ensure optimal athletic progression. Scientific monitoring and continuous evaluation during the growth and maturation period are particularly important, as these phases represent critical windows for physical and physiological development (Lloyd et al., 2016; Moran et al., 2017).

Soccer is characterized by complex, dynamic movement patterns that involve both cyclic and acyclic activities, such as sprinting, jumping, turning, and tackling. These movements require integrating multiple physical components, including strength, endurance, and coordination (Stolen et al., 2005). During adolescence, players experience rapid growth and maturation, which significantly influence body composition and performance capabilities. Previous research has shown that changes in body composition, particularly increases in lean mass and reductions in fat mass, are closely associated with improved physical performance in youth athletes (Deprez et al., 2015; Malina et al., 2015). Moreover, longitudinal monitoring of these variables is essential for understanding the interaction between growth, training, and performance development in young soccer players.

According to the Youth Physical Development Model, training responsiveness during adolescence is strongly influenced by biological maturation and the interaction between growth-related physiological changes and training stimuli (Lloyd & Oliver, 2012). As athletes progress through puberty, hormonal adaptations, neuromuscular development, and increases in muscle mass may enhance their capacity to respond to strength, power, and agility training. Consequently, players of different age groups may exhibit distinct patterns of adaptation despite being exposed to similar training programs.

Physical performance variables such as muscular strength and explosive power are considered key determinants of success in soccer. Strength development, particularly in the lower limbs, is crucial for executing fundamental actions such as sprinting, jumping, and kicking (Suchomel et al., 2016). Vertical jump performance, including squat jump (SJ) and countermovement jump (CMJ), is commonly used as an indicator of explosive power and neuromuscular function (Claudino et al., 2017). In addition, isokinetic strength assessments provide valuable insights into muscle function and imbalances, which are important for both performance enhancement and injury prevention (Croisier et al., 2008). Therefore, evaluating these variables is essential to understanding the effectiveness of training programs in youth soccer players.

Previous research has demonstrated that growth, maturation, and systematic soccer training play important roles in the development of physical performance in youth players. Philippaerts et al. (2006) reported that the greatest improvements in speed, explosive strength, agility, and endurance occur around peak height velocity, highlighting the strong influence of biological maturation on athletic development in youth soccer players. Furthermore, Hammami et al. (2013) found that a competitive soccer season resulted in significant improvements in anthropometric characteristics and physical fitness parameters, including jumping ability, sprint performance, and aerobic capacity, compared with age-matched controls. More recently, Stastny et al. (2018) emphasized the importance of isokinetic assessment for evaluating knee flexor and extensor strength adaptations in athletic populations and highlighted its value for monitoring training-related neuromuscular changes. Similarly, Sermaxhaj et al. (2024) demonstrated that a seasonal soccer training program improved body composition, jumping performance, and isokinetic strength, particularly in U-17 players, suggesting age-related differences in training responsiveness.

Despite these contributions, several important gaps remain. First, previous studies have generally examined body composition, jumping performance, sprint ability, or strength separately. In contrast, limited research has simultaneously evaluated body composition, isokinetic strength, and agility within the same seasonal training framework. Second, although agility is recognized as a key determinant of soccer performance due to the frequent changes of direction required during match play, longitudinal evidence regarding agility adaptations across different adolescent age categories remains limited. Third, while age- and maturation-related differences have been acknowledged in youth soccer development, few studies have directly compared seasonal training adaptations between U-15 and U-17 players using a comprehensive set of body composition and neuromuscular performance indicators. Therefore, it remains unclear whether players at different stages of adolescence exhibit distinct responses to the same seasonal training program, particularly regarding agility development.

Therefore, the present study aimed to examine the effects of a seasonal soccer training program on body composition, strength, and agility in U-15 and U-17 soccer players. By simultaneously evaluating these performance domains and quantifying the magnitude of change through effect size analysis, this study seeks to provide a more comprehensive understanding of age-related training adaptations during adolescence. By comparing U-15 and U-17 players, this study also aims to provide deeper insights into age-related differences in responsiveness not only in strength and power, but also in agility performance, which remains underexplored in the existing literature.

Based on these considerations, an effective training program requires appropriate periodization to ensure optimal adaptation throughout the preparation and competition phases. Coaches must design training interventions that align with players' biological and developmental characteristics to maximize performance outcomes (Issurin, 2016). However, despite growing interest in youth training, there is limited evidence on how structured soccer training programs differentially affect players at different stages of adolescence, particularly between the U-15 and U-17 age groups.

METHODS

Study Design and Participants

This study employed a pre–post experimental design to evaluate the effects of a seasonal soccer training program on body composition, strength, and agility. Initial measurements (pre-test) were conducted before the start of the training macrocycle (pre-season). In contrast, final measurements (post-test) were conducted after 16 weeks, at the end of the competitive period.

A total of 28 youth soccer players competing in a regional football league in the Netherlands participated in this study. The sample consisted of two age groups: U-15 players (n = 15) and U-17 players (n = 13). All participants were actively involved in regular training and competition during the study period. Convenience sampling was used because all eligible players from the club were invited to participate.

The mean age of participants at baseline was approximately 14–15 years for the U-15 group and 16–17 years for the U-17 group. Prior to data collection, all players underwent routine medical screening and were declared physically fit to participate in the study.

Ethical approval statement

All participants and their guardians were informed about the purpose and procedures of the research and provided written informed consent. The study protocol was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of Maastricht University (approval number: 2-1014-17).

Research Instruments

Data collection was conducted in collaboration with local coaches and staff. Anthropometric and body composition variables were assessed at the beginning of the testing session. Body composition was assessed using the InBody 720 bioelectrical impedance analyzer (InBody, Seoul, Korea), a device that has demonstrated acceptable validity and reliability for estimating body composition parameters when compared with reference methods such as dual-energy X-ray absorptiometry (DXA) (Utczás et al., 2020). Previous studies have reported excellent test–retest reliability for Biodex System 4 knee flexion and extension assessments, with intraclass correlation coefficients generally ranging from 0.86 to 0.99 (Tuominen et al., 2023).

Following these measurements, participants completed a standardized warm-up consisting of approximately 12 minutes of self-paced running. Subsequently, physical performance tests were conducted, including squat jumps (SJ), countermovement jumps (CMJ), maximal countermovement jumps (CMJmax), and isokinetic strength assessments of knee flexion and extension (Lehnert et al., 2014; Philippaerts et al., 2006).

Jumping Performance

The squat jump (SJ) was performed from a static semi-squat position with approximately 90° knee flexion, without any preparatory countermovement. Participants kept their hands on their hips and were instructed to jump vertically as high as possible.

The countermovement jump (CMJ) involved an initial downward movement followed by an explosive upward jump. Participants started from an upright position, descended to approximately 90° knee flexion, and immediately performed a maximal vertical jump while keeping their hands on their hips (Padulo et al., 2013). Previous studies have demonstrated excellent reliability and validity of squat jump (SJ) and countermovement jump (CMJ) tests, with reliability coefficients exceeding 0.95 (Markovic et al., 2004).

The maximal countermovement jump (CMJmax) was executed similarly to the CMJ; however, participants were allowed to use arm swing to enhance jump performance. All jump tests were conducted using a contact mat or equivalent measurement system connected to a digital recording device. Jump height was calculated based on flight time using standard equations derived from kinematic principles.

Knee Flexion and Extension Strength

Isokinetic strength of the knee flexor and extensor muscles of the dominant leg was assessed using an isokinetic dynamometer (Biodex System 4, Biodex Medical Systems, New York, USA). Measurements were performed in a seated position with the hip angle controlled.

Participants were instructed to perform maximal concentric contractions for both flexion and extension movements at a constant angular velocity (e.g., 120°/s). Each participant completed three maximal trials, and the highest peak torque value was selected for analysis.

To minimize fatigue, a 1-minute rest interval was provided between repetitions of the same movement, and a 2-minute rest interval was provided between different movement types (Stastny et al., 2018). Visual feedback was provided during testing to ensure maximal effort.

Agility Performance

Agility was assessed using the Illinois Agility Test. The Illinois Agility Test has demonstrated excellent test–retest reliability and criterion-related validity in team-sport athletes (ICC = 0.96), supporting its use for assessing change-of-direction performance (Hachana et al., 2013). Participants were instructed to complete the course as quickly as possible while maintaining accuracy in movement patterns. Each participant performed multiple trials, and the best recorded time was used for analysis.

Training Program

The training intervention was conducted over a 16-week macrocycle, including both pre-season and competitive phases. Participants trained three times per week, totaling approximately 48 sessions, in addition to playing regular friendly and official matches (Bisanz & Gerisch, 2008). The training program was structured around four main components:

1. technical (TE),
2. conditioning (CO),
3. tactical (TA),
4. and mental (ME).

Qualified coaches supervised all training sessions.

Weekly training cycles were organized to emphasize different components. Technical skills were primarily developed at the beginning of the week, conditioning elements were emphasized midweek, and tactical training was prioritized toward the end of the week. Competitive matches were typically scheduled on weekends. Each training session consisted of three phases: a warm-up (20–25 minutes), a main training segment (40–50 minutes), and a cool-down period (approximately 10 minutes). The training program structure was adapted from previous studies on youth soccer training periodization, with modifications to suit the characteristics of the present sample (Sermaxhaj et al., 2024) (Table 1).

Table 1. Training Program Structure During the First Macrocycle

U-15 Players	U-17 Players
Training Duration: 4-week pre-season followed by a 12-week competitive phase	Training Duration: 4-week pre-season followed by a 12-week competitive phase
Primary Objective: Development of fundamental game skills	Primary Objective: Optimization of competitive performance
Technical (TE): Emphasis on improving basic technical skills and ball control	Technical (TE): Application of technical skills in game-related situations
Conditioning (CO): Focus on coordination, general endurance, speed, and basic strength development	Conditioning (CO): Emphasis on explosive strength, speed, coordination, and sport-specific endurance
Tactical (TA): Introduction to individual and small-group tactical concepts	Tactical (TA): Development of team-based tactical strategies and game systems
Mental (ME): Enhancement of communication, confidence, and social interaction	Mental (ME): Focus on motivation, competitiveness, and team cohesion

Training frequency was three sessions per week throughout the 16-week intervention. Session duration ranged from 70 to 85 minutes. During the pre-season phase (weeks 1–4), training focused on general conditioning, technical development, and progressive strength preparation. During the competitive phase (weeks 5–16), emphasis shifted toward tactical drills, match-specific conditioning, and maintenance of strength and power capacities. Training load was progressively increased during the pre-season period by increasing drill complexity, running volume, and strength-training demands before being maintained during the competitive phase. Running volume was gradually increased across the pre-season phase, while strength-oriented drills progressed from general body-weight exercises to more demanding soccer-specific resistance activities. The coaching staff monitored training intensity to ensure progressive overload while maintaining player safety.

Data Analysis

All statistical analyses were conducted using SPSS software (IBM Corp., Armonk, NY, USA). Prior to hypothesis testing, the normality of data distribution was evaluated using the Shapiro–Wilk test. Descriptive statistics were calculated and expressed as mean ± standard deviation (Mean ± SD) for all variables, including body composition (body height, body mass, lean mass, and fat mass) and physical performance measures (squat jump, countermovement jump, maximal countermovement jump, agility performance, and isokinetic peak torque of knee flexion and extension).

RESULTS

Table 2 presents the pre- and post-training values of body composition variables in both U-15 and U-17 players. In the U-15 group, slight improvements were observed in body height, body mass, and lean mass, along with a small reduction in fat mass; however, none of these changes were statistically significant ($p > 0.05$).

In contrast, the U-17 group demonstrated significant improvements in body composition, with increased lean mass and decreased fat mass ($p < 0.05$). No statistically significant changes were found in body height or body mass ($p > 0.05$).

Table 2. Pre- and Post-Training Body Composition Variables in U-15 and U-17 Soccer Players

Variable	Pre (Mean±SD)	Post (Mean±SD)	F	p
U-15				
Body height (cm)	167.8 ± 7.2	170.1 ± 7.4	0.312	0.581
Body mass (kg)	56.4 ± 6.8	58.2 ± 7.1	0.428	0.519
Lean mass (%)	51.10 ± 2.40	51.85 ± 2.10	0.691	0.415
Fat mass (%)	10.20 ± 3.10	9.85 ± 2.80	0.355	0.557
U-17				
Body height (cm)	174.6 ± 6.1	176.0 ± 6.3	1.145	0.295
Body mass (kg)	63.8 ± 7.9	65.1 ± 7.5	0.502	0.485
Lean mass (%)	50.20 ± 3.10	53.40 ± 2.30	6.212	0.021*
Fat mass (%)	11.00 ± 2.90	8.70 ± 2.50	4.885	0.037*

*Mean = arithmetic mean; SD = standard deviation; F = F-value; p = significance level. *Significant at p < 0.05*

Table 3. Pre- and Post-Training Physical Performance Variables in U-15 and U-17 Soccer Players

Variable	Pre (Mean±SD)	Post (Mean±SD)	F	p	Cohen's d
U-15					
Squat jump (cm)	29.1 ± 5.4	30.3 ± 4.9	0.612	0.442	0.23 (small)
Countermovement jump (cm)	33.2 ± 5.0	34.1 ± 5.1	0.208	0.653	0.18 (small)
Max. countermovement jump (cm)	38.7 ± 4.6	39.2 ± 4.8	0.095	0.760	0.10 (small)
Agility (s)	16.90 ± 0.80	16.50 ± 0.75	1.885	0.181	0.51 (moderate)
Flexion peak torque (Nm)	70.20 ± 15.8	95.40 ± 23.5	9.102	0.006**	1.25 (large)
Extension peak torque (Nm)	75.10 ± 20.4	96.80 ± 18.9	7.556	0.012*	1.10 (large)
U-17					
Squat jump (cm)	32.5 ± 4.7	36.8 ± 3.6	6.112	0.020*	1.02 (large)
Countermovement jump (cm)	35.8 ± 3.9	38.9 ± 3.4	4.285	0.041*	0.85 (large)
Max. countermovement jump (cm)	39.5 ± 3.8	44.6 ± 4.9	7.904	0.009**	1.15 (large)
Agility (s)	16.20 ± 0.70	15.40 ± 0.65	8.115	0.008**	1.18 (large)
Flexion peak torque (Nm)	78.40 ± 26.5	118.30 ± 28.7	10.885	0.003**	1.45 (very large)
Extension peak torque (Nm)	110.20 ± 29.4	121.50 ± 30.1	0.912	0.349	0.38 (small)

*Mean = arithmetic mean; SD = standard deviation; F = F-value; p = significance level; d = Cohen's d Effect size interpretation: trivial (<0.2), small (0.2–0.49), moderate (0.5–0.79), large (≥0.8) p < 0.05; ** p < 0.01*

Table 3 presents the pre- and post-training values of physical performance variables in both U-15 and U-17 players. In the U-15 group, improvements were observed across all performance variables; however, statistically significant changes were found only in the isokinetic strength of knee flexors ($p < 0.01$) and extensors ($p < 0.05$). No significant improvements were observed in jumping performance or agility ($p > 0.05$).

In contrast, the U-17 group demonstrated significant improvements in most physical performance variables, including squat jump, countermovement jump, maximal countermovement jump, agility, and knee flexion peak torque ($p < 0.05$). However, no statistically significant change was observed in knee extension peak torque ($p > 0.05$).

Furthermore, effect size analysis indicated that changes in the U-15 group were predominantly small; however, a moderate effect was observed in agility, while large effects were found in isokinetic strength variables. In contrast, the U-17 group exhibited large effect sizes across most performance variables, indicating substantial practical improvements following the training program.

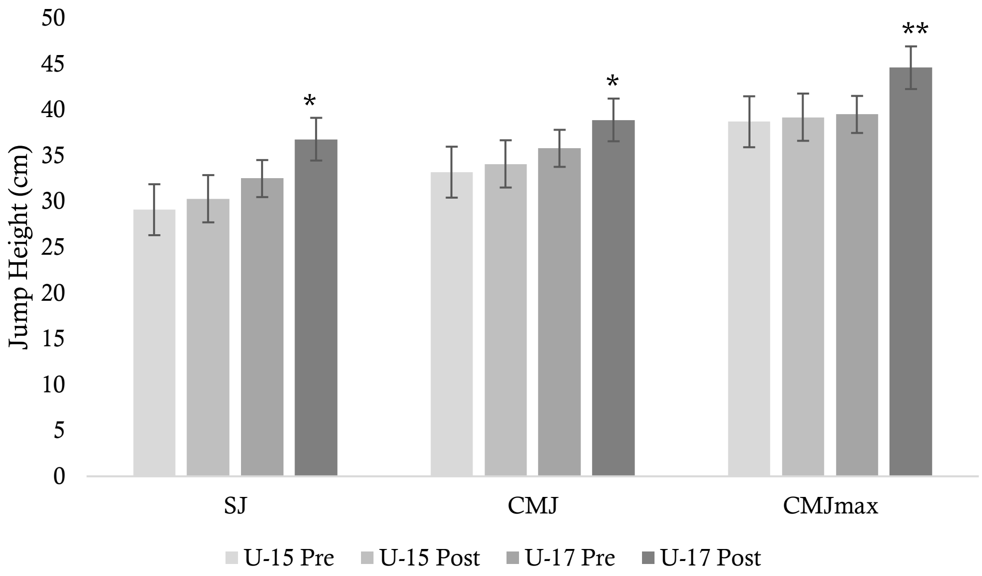

Figure 1. Changes in jump performance (SJ, CMJ, and CMJmax) before and after the training program in U-15 and U-17 soccer players. Values are presented as mean ± SD. *p < 0.05; **p < 0.01.

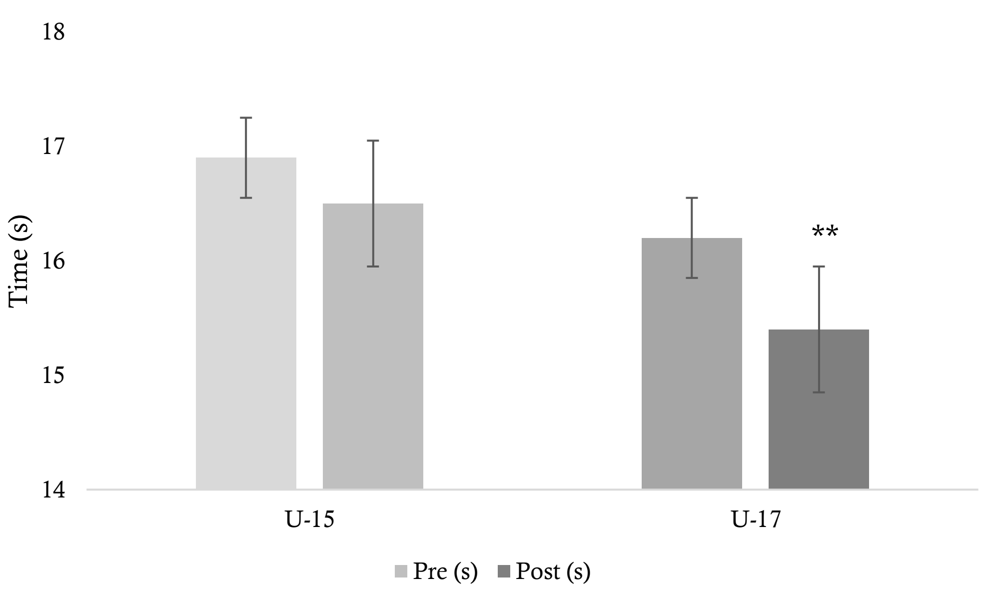

Figure 2. Changes in agility performance before and after the training program in U-15 and U-17 soccer players. Values are presented as mean ± SD. Lower values indicate better performance. *p < 0.05; **p < 0.01.

[Figure 1](#) illustrates the changes in jump performance (SJ, CMJ, and CMJmax) before and after the training program in U-15 and U-17 players. In the U-15 group, slight increases were observed across all jump variables; however, these changes were not statistically significant ($p > 0.05$). In contrast, the U-17 group demonstrated significant improvements in SJ and CMJ ($p < 0.05$) and a highly significant improvement in CMJmax ($p < 0.01$). These findings suggest that the training program was more effective in enhancing explosive lower-limb performance in older players.

Figure 2 presents the changes in agility performance following the training intervention. The U-15 group showed a small reduction in agility time, indicating a slight improvement; however, this change was not statistically significant ($p > 0.05$). Conversely, the U-17 group exhibited a significant decrease in agility time ($p < 0.01$), reflecting a meaningful improvement in change-of-direction speed. These results indicate that the training program had a greater impact on agility performance in the U-17 group compared to the U-15 group.

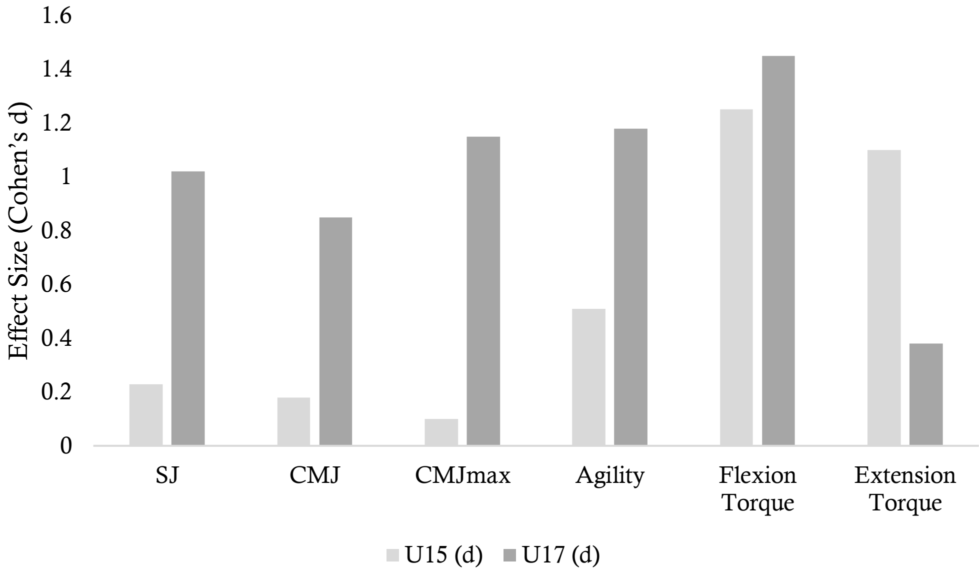

Figure 3. Effect sizes (Cohen's d) of changes in physical performance variables following the training program in U-15 and U-17 soccer players.

Figure 3 shows the effect sizes (Cohen's d) of changes in physical performance variables in both groups. In the U-15 group, effect sizes were generally small to moderate, with larger effects observed in agility and strength-related variables. In contrast, the U-17 group demonstrated predominantly large effect sizes across most variables, particularly in CMJmax, agility, and flexion peak torque. These findings indicate that, beyond statistical significance, the magnitude of training-induced adaptations was substantially greater in U-17 players, highlighting the practical effectiveness of the training program in more physically mature athletes.

DISCUSSION

This study examined the effects of a seasonal soccer training program on body composition, strength, jump performance, and agility in U-15 and U-17 players, representing two critical stages of biological development. During adolescence, players experience rapid physiological changes, including increases in muscle mass, neuromuscular coordination, and overall physical performance (Malina et al., 2004; Philippaerts et al., 2006). Structured training during this period is therefore essential to optimize body composition and enhance sport-specific performance capacities (Helgerud et al., 2001; Lloyd & Oliver, 2012).

In the U-15 group, results indicated improvements across several physical performance variables; however, statistically significant changes were observed only in isokinetic strength variables, particularly peak torque at knee flexion and extension. No significant changes were found in body composition, jumping performance, or agility. These findings are consistent with previous studies suggesting that younger athletes often demonstrate limited adaptations in explosive performance despite regular training (Philippaerts et al., 2006; Sperlich et al., 2011). The relatively small effect sizes observed in this group further support the notion that the magnitude of training-induced adaptations in U-15 players remains modest, particularly for neuromuscular performance variables.

The lack of significant improvement in jumping and agility performance among U-15 players may be explained by the concept of "windows of trainability," in which certain physical capacities are more responsive to training at specific stages of maturation (Ford et al., 2011; Lloyd & Oliver, 2012). At this stage, the neuromuscular system is still developing, which may limit the effectiveness of training programs aimed at improving explosive power and change-of-direction speed. Therefore, although strength gains were observed, these did not translate into significant improvements in functional performance such as jumping and agility. This finding suggests that training interventions for U-15 players may need to emphasize coordination, technique, and movement efficiency rather than maximal power output.

In contrast, the U-17 group demonstrated significant improvements in body composition, including increases in lean mass and reductions in fat mass. These findings align with previous research indicating that late adolescence is characterized by more pronounced adaptations in body composition due to hormonal changes and increased training responsiveness (Milanese et al., 2013; Vänttinen et al., 2011). The observed improvements in body composition are likely the result of both systematic training and the natural progression of biological maturation, which enhances anabolic processes and muscle development. Importantly, the significant improvement in agility observed in U-17 players highlights the importance of including change-of-direction ability as a key outcome in youth soccer training studies, which has been underreported in previous research. From an applied perspective, the large effect size observed for agility ($d = 1.18$) indicates a substantial performance enhancement that is likely meaningful for match performance, even beyond statistical significance. Coaches should interpret effect sizes alongside p-values, as meaningful performance changes may occur even when statistical significance is not achieved. The observed improvements are likely the result of both systematic training and the natural progression of biological maturation, which enhances anabolic processes and muscle development. Because all players participated in the same seasonal program without a non-training control group, some observed improvements may reflect normal developmental changes occurring during adolescence rather than training effects alone.

From a physiological perspective, the greater responsiveness observed in U-17 players can be attributed to more advanced neuromuscular development and hormonal status, particularly increased testosterone levels, which facilitate muscle hypertrophy and strength gains (Lloyd & Oliver, 2012; Malina et al., 2004). This supports the idea that training programs are more effective during and after puberty, when athletes are better able to adapt to higher training loads and intensities. Consequently, the training program used in this study appears more suitable for athletes at this stage of development.

Regarding physical performance, the U-17 group showed significant improvements in jump performance (SJ, CMJ, and CMJmax), agility, and knee flexion peak torque, whereas knee extension peak torque did not change significantly. The absence of significant changes in knee extension torque may indicate that the training stimulus was insufficiently specific to target quadriceps strength development. Another possible explanation is the higher baseline values observed in the U-17 group, resulting in a ceiling effect. These results are consistent with previous studies demonstrating that improvements in explosive performance are closely related to increases in muscle mass and neuromuscular efficiency (Lehnert et al., 2014; Markovic & Mikulic, 2010). Importantly, agility performance also improved significantly among U-17 players, indicating enhanced change-of-direction ability, a key determinant of soccer performance (Sheppard & Young, 2006). This highlights the added value of including agility as a variable in the present study.

The effect size analysis provided additional insight into the practical significance of the findings. While the U-15 group demonstrated predominantly small to moderate effect sizes, the U-17 group exhibited large effect sizes across most variables, particularly in CMJmax, agility, and flexion peak torque. This indicates that, beyond statistical significance, the magnitude of training adaptations was substantially greater in older players. The inclusion of effect size analysis strengthens the interpretation of results, enabling a more comprehensive understanding of the training program's effectiveness (Batterham & Hopkins, 2006; Cohen, 2013).

Coaches working with U-15 players should prioritize movement competency, coordination, and progressive strength development rather than expecting substantial gains in agility and explosive performance over a single season. For U-17 players, incorporating structured strength and change-of-direction training may yield meaningful improvements in agility, jump performance, and lower-limb strength. Age-specific training prescription should therefore be considered when designing long-term player development programs.

Limitations of the study

Despite the positive findings, several limitations should be acknowledged. First, biological maturity status was not assessed, although maturation is known to influence physiological adaptations and training responsiveness during adolescence (Malina et al., 2004). Consequently, interpretations regarding maturity-related differences between U-15 and U-17 players should be made with caution. Second, the relatively small sample size may limit the generalizability of the findings to broader youth soccer populations. Third, the study employed a one-group pretest–posttest design without a non-training control group, making it difficult to distinguish training-induced adaptations from normal growth and maturation processes. Therefore, the observed improvements should be interpreted as changes occurring during a seasonal training period rather than definitive causal effects of the training intervention. Future studies should include biological maturity assessments, larger samples, and appropriate control groups better to isolate the effects of training from developmental influences.

Future research should consider larger sample sizes, include control groups, and assess biological maturity to provide a more comprehensive understanding of training adaptations in youth soccer players. Furthermore, it would be beneficial to examine the specific contributions of different training components, such as technical, tactical, and conditioning elements, to performance development. Such approaches would enable more targeted training strategies for different age groups and developmental stages.

CONCLUSIONS

The present study demonstrated that a seasonal soccer training program elicited different adaptations in U-15 and U-17 players. In the U-15 group, training improved strength variables; however, changes in body composition, jumping performance, and agility were not statistically significant, suggesting limited responsiveness at this stage of development. In contrast, U-17 players showed significant improvements in body composition, jump performance, agility, and knee flexion strength, reflecting a greater capacity to adapt to training stimuli during later stages of maturation. Furthermore, effect-size analysis revealed that the magnitude of change was generally small in U-15 players but large in U-17 players, underscoring the practical relevance of training adaptations in older athletes. These findings suggest that age-related developmental factors contribute to differences in training responsiveness between U-15 and U-17 players. However, the role of biological maturity should be confirmed through direct maturity assessment in future studies.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to all players who voluntarily participated in this study, as well as to their coaches and supporting staff from the Netherlands football league for their cooperation and assistance throughout the research process. The authors also acknowledge Maastricht University for providing ethical approval and institutional support. This research did not receive any external funding. The authors declare no conflicts of interest, financial or otherwise.

AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors used NotebookLM (Google) to assist with grammar checking, language refinement, and improving the clarity and readability of the academic English used in the manuscript. All AI-assisted outputs were carefully reviewed, verified, and substantially edited by the authors to ensure accuracy, appropriateness, and compliance with scholarly standards. The authors take full responsibility for the content, interpretation, and integrity of this manuscript.

DATA AVAILABILITY

The data supporting this study's findings are available on request from the corresponding author. The data are not publicly available because they contain information that could compromise the privacy of research participants

FUNDING

This research does not receive external funding.

CONFLICT OF INTEREST

The author hereby declares that this research is free from conflicts of interest with any party.

PUBLISHER'S NOTE

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or a claim its manufacturer may make, is not guaranteed or endorsed by the publisher.

REFERENCES

Batterham, A. M., & Hopkins, W. G. (2006). Making Meaningful Inferences About Magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50–57. https://doi.org/10.1123/ijspp.1.1.50

Bisanz, G., & Gerisch, G. (2008). *Fussball: Kondition-Technik-Taktik und Coaching*. Meyer & Meyer Verlag.

Claudino, J. G., Cronin, J., Mezêncio, B., McMaster, D. T., McGuigan, M., Tricoli, V., Amadio, A. C., & Serrão, J. C. (2017). The countermovement jump to monitor neuromuscular status: A meta-analysis. *Journal of Science and Medicine in Sport*, *20*(4), 397–402. https://doi.org/10.1016/j.jsams.2016.08.011

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. routledge. https://doi.org/10.4324/9780203771587

Croisier, J.-L., Ganteaume, S., Binet, J., Genty, M., & Ferret, J.-M. (2008). Strength Imbalances and Prevention of Hamstring Injury in Professional Soccer Players. *The American Journal of Sports Medicine*, *36*(8), 1469–1475. https://doi.org/10.1177/0363546508316764

Deprez, D., Valente-Dos-Santos, J., Coelho-e-Silva, M., Lenoir, M., Philippaerts, R., & Vaeyens, R. (2015). Longitudinal Development of Explosive Leg Power from Childhood to Adulthood in Soccer Players. *International Journal of Sports Medicine*, *36*(08), 672–679. https://doi.org/10.1055/s-0034-1398577

Ford, P., De Ste Croix, M., Lloyd, R., Meyers, R., Moosavi, M., Oliver, J., Till, K., & Williams, C. (2011). The Long-Term Athlete Development model: Physiological evidence and application. *Journal of Sports Sciences*, *29*(4), 389–402. https://doi.org/10.1080/02640414.2010.536849

Hachana, Y., Chaabène, H., Nabli, M. A., Attia, A., Moualhi, J., Farhat, N., & Elloumi, M. (2013). Test-retest reliability, criterion-related validity, and minimal detectable change of the Illinois agility test in male team sport athletes. *The Journal of Strength & Conditioning Research, 27*(10), 2752-2759. https://doi.org/10.1519/JSC.0b013e3182890ac3

Hammami, M. A., Ben Abderrahmane, A., Nebigh, A., Le Moal, E., Ben Ounis, O., Tabka, Z., & Zouhal, H. (2013). Effects of a soccer season on anthropometric characteristics and physical fitness in elite young soccer players. *Journal of*

Sports Sciences, *31*(6), 589–596. https://doi.org/10.1080/02640414.2012.746721

Helgerud, J., Engen, L. C., Wisløff, U., & Hoff, J. A. N. (2001). Aerobic endurance training improves soccer performance. *Medicine & Science in Sports & Exercise*, *33*(11), 1925–1931. https://doi.org/10.1097/00005768-200111000-00019

Issurin, V. B. (2016). Benefits and Limitations of Block Periodized Training Approaches to Athletes' Preparation: A Review. *Sports Medicine*, *46*(3), 329–338. https://doi.org/10.1007/s40279-015-0425-5

Lehnert, M., Xaverová, Z., & Croix, M. D. S. (2014). Changes in Muscle Strength in U19 Soccer Players During an Annual Training Cycle. *Journal of Human Kinetics*, *42*(1), 175–185. https://doi.org/10.2478/hukin-2014-0072

Lloyd, R. S., Cronin, J. B., Faigenbaum, A. D., Haff, G. G., Howard, R., Kraemer, W. J., Micheli, L. J., Myer, G. D., & Oliver, J. L. (2016). National Strength and Conditioning Association Position Statement on Long-Term Athletic Development. *Journal of Strength and Conditioning Research*, *30*(6), 1491–1509. https://doi.org/10.1519/JSC.0000000000001387

Lloyd, R. S., & Oliver, J. L. (2012). The Youth Physical Development Model. *Strength & Conditioning Journal*, *34*(3), 61–72. https://doi.org/10.1519/SSC.0b013e31825760ea

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity*. Human kinetics. https://doi.org/10.5040/9781492596837

Malina, R. M., Rogol, A. D., Cumming, S. P., Coelho e Silva, M. J., & Figueiredo, A. J. (2015). Biological maturation of youth athletes: assessment and implications. *British Journal of Sports Medicine*, *49*(13), 852–859. https://doi.org/10.1136/bjsports-2015-094623

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *The Journal of Strength & Conditioning Research, 18*(3), 551-555. https://doi.org/10.1519/00124278-200408000-00028

Markovic, G., & Mikulic, P. (2010). Neuro-Musculoskeletal and Performance Adaptations to Lower-Extremity Plyometric Training. *Sports Medicine*, *40*(10), 859–895. https://doi.org/10.2165/11318370-000000000-00000

Milanese, C., Piscitelli, F., Cavedon, V., & Zancanaro, C. (2013). Body composition changes in elite soccer players along the competitive season. *Italian Journal of Anatomy and Embryology*, *118*(2), 139. https://hdl.handle.net/11562/746564

Moran, J. J., Sandercock, G. R. H., Ramírez-Campillo, R., Meylan, C. M. P., Collison, J. A., & Parry, D. A. (2017). Age-Related Variation in Male Youth Athletes' Countermovement Jump After Plyometric Training: A Meta-Analysis of Controlled Trials. *Journal of Strength and Conditioning Research*, *31*(2), 552–565. https://doi.org/10.1519/JSC.0000000000001444

Negra, Y., Chaabene, H., Sammoud, S., Bouguezzi, R., Abbes, M., Hachana, Y., & Granacher, U. (2017). Effects of Plyometric Training on Physical Fitness in

Prepuberal Soccer Athletes. *International Journal of Sports Medicine*, *38*(05), 370–377. https://doi.org/10.1055/s-0042-122337

Padulo, J., Tiloca, A., Powell, D., Granatelli, G., Bianco, A., & Paoli, A. (2013). EMG amplitude of the biceps femoris during jumping compared to landing movements. *SpringerPlus*, *2*(1), 520. https://doi.org/10.1186/2193-1801-2-520

Philippaerts, R. M., Vaeyens, R., Janssens, M., Van Renterghem, B., Matthys, D., Craen, R., Bourgois, J., Vrijens, J., Beunen, G., & Malina, R. M. (2006). The relationship between peak height velocity and physical performance in youth soccer players. *Journal of Sports Sciences*, *24*(3), 221–230. https://doi.org/10.1080/02640410500189371

Sarmento, H., Anguera, M. T., Pereira, A., & Araújo, D. (2018). Talent Identification and Development in Male Football: A Systematic Review. *Sports Medicine*, *48*(4), 907–931. https://doi.org/10.1007/s40279-017-0851-7

Sermaxhaj, S., Arifi, F., Alaj, I., Kelmendi, D., Gjonbalaj, M., & Sermaxhaj, S. (2024). The Impact of the Soccer Training Season on the Body Composition and Physical Performances of Young Soccer Players. *Sport Mont*, *22*(1), 31–36. https://doi.org/10.26773/smj.240205

Sheppard, J. M., & Young, W. B. (2006). Agility literature review: Classifications, training and testing. *Journal of Sports Sciences*, *24*(9), 919–932. https://doi.org/10.1080/02640410500457109

Slimani, M., & Nikolaidis, P. T. (2018). Anthropometric and physiological characteristics of male soccer players according to their competitive level, playing position and age group: a systematic review. *The Journal of Sports Medicine and Physical Fitness*, *59*(1). https://doi.org/10.23736/S0022-4707.17.07950-6

Sperlich, B., De Marées, M., Koehler, K., Linville, J., Holmberg, H.-C., & Mester, J. (2011). Effects of 5 Weeks of High-Intensity Interval Training vs. Volume Training in 14-Year-Old Soccer Players. *Journal of Strength and Conditioning Research*, *25*(5), 1271–1278. https://doi.org/10.1519/JSC.0b013e3181d67c38

Stastny, P., Lehnert, M., & Tufano, J. J. (2018). Muscle imbalances: Testing and training functional eccentric hamstring strength in athletic populations. *Journal of visualized experiments: JoVE,* (135), 57508. https://doi.org/10.3791/57508

Stolen, T., Chamari, K., Castagna, C., & Wisl??ff, U. (2005). Physiology of Soccer. *Sports Medicine*, *35*(6), 501–536. https://doi.org/10.2165/00007256-200535060-00004

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The Importance of Muscular Strength in Athletic Performance. *Sports Medicine*, *46*(10), 1419–1449. https://doi.org/10.1007/s40279-016-0486-0

Tuominen, J., Leppänen, M., Jarske, H., Pasanen, K., Vasankari, T., & Parkkari, J. (2023). Test-retest reliability of isokinetic ankle, knee and hip strength in physically active adults using Biodex system 4 pro. *Methods and protocols, 6*(2), 26. https://doi.org/10.3390/mps6020026

Utczás, K., Tróznai, Z., Pálinkás, G., Kalabiska, I., & Petridis, L. (2020). How length sizes affect body composition estimation in adolescent athletes using bioelectrical impedance. *Journal of Sports Science & Medicine, 19*(3), 577. https://pmc.ncbi.nlm.nih.gov/articles/PMC7429426/pdf/jssm-19-577.pdf

Vänttinen, T., Blomqvist, M., Nyman, K., & Häkkinen, K. (2011). Changes in Body Composition, Hormonal Status, and Physical Fitness in 11-, 13-, and 15-Year-Old Finnish Regional Youth Soccer Players During a Two-Year Follow-Up. *Journal of Strength and Conditioning Research*, *25*(12), 3342–3351. https://doi.org/10.1519/JSC.0b013e318236d0c2

Young, W., & Farrow, D. (2006). A review of agility: Practical applications for strength and conditioning. *Strength & Conditioning Journal, 28*(5), 24-29. https://doi.org/10.1519/00126548-200610000-00004