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Effects of a Small-Sided Games Training Programme with Cognitive Demands on Aerobic Fitness in Young Elite Footballers: A Controlled Longitudinal Study

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ABSTRACT

Small-sided positional games now play a central role in integrated physical preparation for football, but relatively little is actually known about the long-term effects of a programme that combines them with proprioceptive training and technical skills, alongside physical training organised around a monthly (or weekly) focus and functional core strengthening, particularly among young footballers. This is what this study sought to demonstrate: the effect of a 16-week programme focusing on positional games with cognitive demands (45 mins), combined with set routines (15 mins of proprioception with technical skills, 15 mins of associated physical training and 10 mins of functional core training), on performance in the Yo-Yo Intermittent Recovery Test Level 1 (YYIR1). Fifty-eight youth academy players, divided into four age groups (U13 to U16, experimental group, n = 49) and a control group (n = 9) following a conventional training programme, were tested before and after the intervention. The analyses combined paired and independent t-tests, ANOVA with Tukey's post-hoc test, and corrections for multiple comparisons (Bonferroni, Benjamini-Hochberg), calculated using Python (SciPy, statsmodels). All age groups showed improvement in raw test scores ($p < 0.05$), with gains ranging from +38.3% to +77.8% depending on age in the experimental group, compared with +14.2% for the control group; once the corrections have been applied, the gains for the U13, U14, U15 and U16 age groups remain robust under the Bonferroni test, whilst that of the control group is only significant under the less conservative FDR correction. The integrated programme ultimately produces an average gain (+61.2 per cent) significantly higher than that of conventional training, which is particularly marked among the U13, U14 and U16 age groups.

Keywords: positional play; proprioception; physical conditioning; functional core training; aerobic fitness; Yo-Yo Intermittent Recovery Test; young footballers.

1. Introduction

In recent years, the use of small-sided games has established itself as one of the most widespread approaches in integrated physical training for football. It allows for the simultaneous development of technical, tactical, physiological, cognitive and socio-emotional aspects, rather than separating these dimensions as was the case with more analytical methods (Clemente et al., 2021; Sarmento et al., 2020). Position-based small-sided games with cognitive demands constitute a specific variant of this, popularised in particular by Pep Guardiola's style of play. The addition of marked zones or channels imposes an organisational structure which, on top of the decision-making speed already required in a classic small-sided game, adds a dimension of spatial awareness and anticipation. Players' perceptual and decision-making abilities are thus heavily taxed, whilst they experience intermittent physiological demands similar to those encountered in a match (Owen et al., 2021; Riboli et al., 2020; Low et al., 2020).

On the pitch, this cognitive demand and the physical exertion it generates are inseparable: the player must read the game situation, anticipate developments, and constantly reposition themselves in relation to zones and teammates; and it is this very demand that produces a high locomotor load, consisting of frequent repositioning, changes of direction and repeated accelerations and decelerations. Several GPS studies confirm this: compared with free-form small-sided games or official matches, positional games generate a frequency of high-intensity accelerations and decelerations that is at least equivalent, due to the changes of direction and repositioning imposed by the spatial structure, particularly when a tactical rule requires players to return to their initial position after each movement (Asian-Clemente, Beltran-Garrido, & Requena, 2025). This characteristic aligns with the principle of integrated training mentioned above, which aims to develop, within a single representative task, both the player's physical qualities and their technical and tactical skills.

It is also known, thanks to several studies, that small-sided games can improve the aerobic performance of footballers (Buchheit & Laursen, 2013; Hill-Haas et al., 2011; Halouani et al., 2017). More recent studies confirm and refine this finding in young players: an intermittent format of small-sided games produces better effects on certain indicators of athletic performance than a continuous format (Pancar et al., 2025), whilst a programme incorporating interval training, interval training and small-sided games according to a periodised 3:1 micro-cycle significantly improves VO_2max as estimated by the Yo-Yo test in U16 and U19 players (Gorouhi et al., 2026). This approach to periodisation is also consistent with practices already observed in youth academies: a survey of fitness coaches at French clubs shows that a significant proportion of weekly sessions alternate, depending on the day of the cycle, between a focus on aerobic capacity, strength or speed, although this alternation is not systematically combined with technical skills within the same exercise (Douchet, Paizis, Carling, Cometti, & Babault, 2023). The programme tested here follows this approach, but takes it a step further: in each session, 'Rituals' (at the start of sessions, consisting of 15-minute blocks of proprioception, 15 minutes of associated physical work, followed by 10 minutes of functional core training at the end of sessions on one side) and 45 minutes of positional drills on the other side form the main focus of this study. Its focus changes each month (aerobic training in the first month, explosive strength in the second, speed in the third and recovery/maintenance in the fourth month…), but remains, week after week, coupled with a specific football technique. It is precisely this systematic coupling that is most often missing from the literature: existing studies focus on short timeframes (four to six weeks), on a single isolated physical component, or on older age groups, but rarely on a combination of positional drills, periodised physical training, proprioception and core stability in young footballers in the U13 to U16 age groups (Clemente et al., 2022; Nobari et al., 2023).

This issue must also be viewed within a broader context: modern physical preparation tends to favour ecological approaches, which seek a direct transfer to match performance, rather than the isolated analytical exercises of the past (Araújo & Davids, 2016; Coutinho et al., 2022). In line with this, assessing aerobic adaptations using the Level 1 Yo-Yo Intermittent Recovery Test is particularly relevant for young footballers, as this test itself replicates intermittent efforts similar to those encountered in a match (Krustrup et al., 2003; Bangsbo et al., 2008).

1.1. Position-specific drills involving cognitive demands, proprioception, associated physical work, and functional core training: four combined levers for energy economy

Whilst positional drills involving cognitive demands constitute the main aerobic stimulus in the programme studied here, combining this stimulus with proprioceptive training, associated physical work and functional core training is by no means arbitrary: it is a response to the specific physiological needs of the U13–U16 age group, a period in which biological maturation varies enormously from one player to another, sometimes by two to three years even when chronological age is the same. The programme actually comprises four components. In addition to the positional drills—which form the cognitive foundation of the programme—there is proprioception combined with technical skills (15 mins), followed by a second 15-minute block of physical training, also combined with technical skills, the focus of which (aerobic training, explosive strength, speed, then recovery/maintenance) changes each month throughout the 16-week cycle: aerobic training in weeks 1 to 4, explosive strength in weeks 5 to 8, speed in weeks 9 to 12, recovery/maintenance in weeks 13 to 16 (see periodisation, Table 2a), followed by 10 minutes of functional core training to round off the session.

This integrated physical training block is based on the principles of specificity and non-dissociation, in line with what was outlined in the introduction. Rather than treating explosive strength, speed and aerobic fitness as qualities to be developed separately through analytical exercises, each month of the 16-week cycle focuses on one of these key areas (aerobic fitness, explosive strength, speed, followed by recovery/maintenance at the end of the cycle), with each session of the week placing a different emphasis on the same monthly focus area, and always through a technical skill (control, passing, shooting, dribbling, ball control…), or a tactical situation (positional play) (ball possession, loss of possession or transition): the player therefore never works on a physical quality 'in isolation'. This approach of monthly blocks partly mirrors practices already documented in youth academies, where the alternation of physical focus areas tends to take place on a weekly basis (Douchet et al., 2023). The programme tested here differs in that it operates on a monthly scale and is systematically coupled with a technical skill – a feature less frequently documented, which brings it closer to the logic of periodised interval training recently tested by (Gorouhi et al., 2026). In terms of aerobic fitness, this block acts as a direct complement to physically demanding positional drills: months with an aerobic focus strengthen the same energy system as that called upon in physically demanding small-sided games, whilst months focusing on explosive strength or speed target footwork quality and the ability to repeat brief, intense efforts – two parameters which, as mentioned above, determine the energy cost of each repeated action in small-sided games.

1.2. Cognitive demands of small-sided games

In small-sided games, the cognitive demands do not correspond to an isolated cognitive exercise. They arise from the constant interaction between the player, the ball, teammates, opponents and the playing area. Players must direct their attention, seek out useful information, quickly recognise game situations, anticipate events and make decisions under time pressure. In particular, a reduction in space can increase the density of information and the need to make rapid decisions. Recent data show that a smaller playing area can increase mental load, whilst a larger playing area can further increase perceived physical exertion (González-Fernández et al., 2026). This relative dissociation between mental load and physical load is particularly important when designing positional drills capable of targeting different components of the training load.

1.3. From cognitive demand to aerobic fitness: an explanatory model

Small-sided positional games involving cognitive demands create an environment in which perceptual-cognitive constraints and physiological demands are simultaneously present. Repeating these situations over the course of a 16-week programme could promote a specific adaptation to the demands of football. However, it should not be claimed that cognitive stimulation, on its own, directly increases aerobic capacity. The most plausible model is that of integrated training in which the cognitive load accompanies and structures intermittent exertion sufficient to elicit aerobic adaptations. Thus: small-sided positional games → perceptual-cognitive demands + high-intensity intermittent activity → repetition of stimuli → physiological and functional adaptations → improvement in aerobic/intermittent performance.

Intervention data support the use of small-sided games to develop cardiorespiratory fitness in young people. A meta-analysis published in 2024, covering 16 studies and 2,872 children and adolescents, demonstrated a significant improvement in cardiorespiratory fitness following interventions based on small-sided football games (Gómez-Álvarez et al., 2024). A systematic review published in 2023 also reported improvements in VO_2max and endurance performance across several small-sided games interventions in young people (Makhloufi et al**.,** 2023). Among young footballers, a 2020 study observed a comparable improvement in VO_2max following eight weeks of small-sided games training and specific high-intensity training (Selmi et al., 2020; Arslan et al., 2020)**.** More recently, a study published in 2026 examined the integration of interval training and small-sided games into a structured periodisation programme and confirmed the benefits of this combination for the development of aerobic capacity in young footballers (Gorouhi et al., 2026).

1.4. In terms of proprioception

Several recent studies show that specific training directly improves technical skills and balance in young footballers. A 12-week programme combined with football training improved ball control, shooting accuracy and body composition in young professional players (Eraslan et al., 2025), whilst an 8-week proprioceptive training programme improved balance and power in young players (Lee & Joo, 2024). Among adolescents (the population of interest here), a positive effect has also been reported on balance, strength, agility and dribbling (Gidu et al., 2022).

This proprioceptive need is not constant over time: it varies significantly depending on the stage of maturation. The period of peak height velocity (PHV), which occurs on average around the ages of 13–14 but with considerable individual variability, is accompanied by a temporary disruption in coordination and balance, a phenomenon well documented under the name 'adolescent awkwardness' (Borato et al., 2025). During this period, the lower limbs grow faster than the trunk can adapt, resulting in a temporary decline in kinesthetic sensitivity and motor coordination. This phenomenon is also associated with an increased risk of injury during this window, as well as a measurable deterioration in balance during the season among rapidly growing adolescent footballers. It is this window, often centred on the U15–U16 age groups, that justifies targeted proprioceptive training, not as a compensatory measure in response to a period of transient postural instability.

1.5. Functional core training

Functional core training follows a complementary approach, focusing on the core rather than the points of contact. The core acts as a transmission chain between the upper and lower limbs: reduced core endurance and control are associated with an increased risk of injury in young athletes (De Blaiser et al., 2021), whilst a specific core training programme improves sprinting (10m) and changes of direction in young footballers by optimising force transfer between the core and the limbs (Sanchez et al., 2021). From a metabolic perspective, core training has also been linked to improved running economy in young athletes, via better force transmission between body segments and more effective body stabilisation (Hung et al., 2019). However, this link must be qualified: the relationship between stability and movement economy is not strictly linear. Some studies even show that, in trained runners, lower dynamic stability may coincide with better running economy, suggesting a trade-off between stability and efficiency rather than a one-to-one relationship (Arellano et al., 2014; Hafer et al., 2015/2019).

It is this last point that directly links these two components to positional games involving cognitive demands and aerobic fitness as measured by the YYIR1. Cognitively demanding positional drills involve intermittent efforts characterised by high variability (accelerations, decelerations, one-on-one duels, changes of foot) in which every poorly controlled postural readjustment results in additional energy expenditure, without any technical or tactical benefit in return. The integration of positional drills in football is a key strategy for simultaneously developing tactical structure and aerobic capacity, offering an integrated and specific alternative to analytical methods (Clemente et al., 2021; Impellizzeri et al., 2006). From a cardiorespiratory perspective, continuous exposure to these situations places demands on the aerobic system by maintaining the heart rate at high intensities (> 85–95% of maximum heart rate), which are essential for the development of VO_2Max and maximum aerobic speed (Bujalance-Moreno et al., 2020; Hill-Haas et al., 2011). The physiological impact is modulated by adjusting structural constraints, notably the individual space per player: a large-scale format (> 100–150 m² per player), such as a 6-a-side positional game with 2 substitutes on a 40 x 30 m pitch, promotes sustained movement and overall aerobic power, whilst a restricted format (< 40 m² per player), such as a 4-a-side game with 3 wildcards on a 25 x 25 m pitch with two touches per player, increases the density of one-on-one duels, accelerations and decelerations, and the metabolic cost to the muscles (Praça et al., 2021; Riboli et al., 2020). The presence of wildcards and the limit on touches impose a continuous tempo that stimulates intermittent recovery capacity and muscular reoxygenation, directly improving performance in specific field tests such as the Yo-Yo Intermittent Recovery Test Level 1 (Moran et al., 2019; Setiawan et al., 2024). Thus, positional games induce cardiovascular adaptations equivalent to those of conventional interval training whilst optimising motor efficiency and decision-making under conditions of metabolic fatigue (Clemente et al., 2022; Impellizzeri et al., 2006). Improved proprioception allows for more precise and rapid foot placement and correction in these situations, whilst a better-stabilised core limits energy loss during load transfers between the lower and upper body. In other words, proprioception and functional core stability do not directly train the aerobic systems (this role falls to the positional drills with cognitive demands themselves), but they improve performance by reducing the energy cost of each repeated action in small-sided games. This hypothesis of energy conservation takes on particular significance in our study, where the age groups going through the PHV period (notably the U15s) show precisely the most inconsistent response to the programme, a point to which we shall return in the Discussion.

2. Objective

The aim of this study is to examine the effects, over a 16-week period, of an integrated programme comprising four components, centred on small-sided games with cognitive demands (45 mins) and specific routines: 15 mins of proprioception combined with technical skills, 15 minutes of physical training with a monthly focus (aerobic fitness, explosive strength, speed and recovery/maintenance), also combined with a technical skill, and 10 minutes of functional core training, on the aerobic fitness of young high-level footballers, as measured by the YYIR1.

3. Hypotheses

H1: the programme significantly improves the distance covered in the YYIR1 test, compared with a group following a conventional physical training programme.

H2: The gains achieved are at least comparable to those reported for more conventional continuous or interval training methods (Hill-Haas et al., 2011; Halouani et al., 2017).

H3: The extent of these adaptations varies according to age; the oldest age group (U16) is expected to respond differently from the younger age groups (U13–U15), particularly due to their already more advanced biological maturation.

4. Materials and methods

4.1. Study design

This is a controlled longitudinal study: the players were divided into an experimental group (EG), which followed the integrated programme, and a control group (CG), which continued with the club's standard training programme. Measurements were taken in week 0 and then in week 16.

4.2. Participants

The sample comprised 58 youth academy players, divided into five groups according to age category (Table 1). To be included, participants had to be registered for competitive matches, must not have sustained an injury in the preceding three months, and must have attended at least 90 per cent of the scheduled sessions. Informed parental consent for minors, as well as the agreement of the coaching staff, was of course obtained before the study began.

Table 1. Breakdown of participants by group.

Group	No.	Training sessions per week
U13	12	3 + match
U14	14	3 + match
U15	12	4 + match
U16	11	4 + match
Reserve	9	4 + match

4.3. Training programme

Three to four times a week for 16 weeks, the experimental group followed the following integrated programme, structured in four phases with a total duration of 85 minutes per session (Table 2):

Table 2. Structure of the integrated programme (experimental group).

Component	Duration	Content
Proprioception + technical movements	15 mins	Balance exercises on unstable surfaces combined with specific technical skills (control, passing: feet, head)
Physical training + technical skills	15 mins	Training combining, depending on the focus for the month (weeks 1–4, 5–8, 9–12 or 13–16): aerobic work, explosive strength, speed or recovery/maintenance, always combined with a technical skill (see periodisation, Table 2a)
Small-sided positional games with cognitive challenges	45 mins	Position-based game formats (e.g. 4v4+3, 6v6+3) targeting intermittent intensity depending on the focus
Functional core training	10 mins	Dynamic core stability and anti-rotation exercises, with weight shifts similar to those encountered in the game

The control group, meanwhile, followed a more conventional training programme over the same period: continuous and/or interval running, analytical strength training, technical exercises and game situations at an equivalent weekly volume, but without the specific components of the integrated programme (position-based games, proprioception, physical training combined with technical skills, and functional core training).

4.3.1. Proprioception and associated technical movements (15 mins)

This first component aims to progress from simple postural stability towards proprioceptive situations combined with increasing technical and perceptual demands, in line with the month's physical focus.

Table 3. Periodisation of the proprioception component + technical skills (15 mins) over 16 weeks.

Month	Weeks	Proprioceptive content	Associated technical movement
1	S1–S4	One-legged balance on stable ground followed by two jumps onto hoops whilst maintaining balance (5–10 s × 4–6)	Directed ball control (dominant/non-dominant foot) whilst maintaining balance, followed by a short pass to a partner without losing alignment
2	S5–S8	Dynamic balance on an unstable surface with disturbances (light tugs by a partner, light contact)	Control + shot or pass whilst under external imbalance (duel simulator)
3	S9–S12	Proprioceptive reactivity: landing from jumps on an unstable surface, rapid changes of support, stabilisation in < 1–2 s	Immediate directional control + explosive start or quick pass whilst moving (perception-to-action transition)
4	S13–S16	Consolidation: maintaining acquired skills on a variety of unstable surfaces, combined exercises whilst slightly fatigued, reduced volume (2–3 times instead of 4–6)	Control, passing and shooting in varied conditions (fatigue, light opposition) — focus on retention rather than progression

Examples of exercises used: one-legged balance with a hop, plus control of a ball passed by a partner (foot, chest, head); zigzag dribbling; jump reception (mini-hurdles 20–30 cm) followed by 2 seconds of stabilisation and then a directed pass; 1v1 duels, plus controlled reception and on-target shooting.

4.3.2. Physical training combined with technical skills (15 mins)

The associated physical training (second part of the session, Table 2) aims to develop three physical qualities – aerobic endurance, explosive strength and speed – plus a recovery/maintenance cycle at match intensity and reduced volume, always combined with a technical skill, following a fixed weekly schedule repeated over the 16 weeks: Session 1 = interval training (basic aerobic conditioning), Session 2 = explosive strength training, Session 3 = speed training.

What varies from month to month is not the order of the sessions but their qualitative focus: each month combines a dominant physical aspect (aerobic capacity, explosive strength, speed or recovery/maintenance) with a dominant training load parameter (volume, intensity or recovery), which shapes the three sessions of the week (Table 2a).

Table 2a. Periodisation of integrated physical training (15 mins) over 16 weeks.

Month	Weeks	Physical focus	Training load parameter	Session 1 (Interval)	Session 2 (Strength)	Session 3 (Speed)
1	S1–S4	Aerobic	Volume	Pure interval training (aerobic)	Strength training on an aerobic base	Speed on an aerobic base
2	S5–S8	Strength	Intensity	Intermittent + explosive strength	Pure strength	Speed + explosive strength
3	S9–S12	Speed	Recovery	Intermittent + speed	Explosive strength + speed	Pure speed
4	S13–S16	Recovery / Maintenance	Workout (reduced volume and match intensity)	Extensive low-volume interval training (active recovery)	Light strength training, with a focus on technical skills	Submaximal speed, running technique

4.3.3. Small-sided games with cognitive demands (45 mins)

The format and tactical instructions for small-sided games with cognitive demands vary each month to target the dominant energy system and the technical skill practised beforehand, whilst maintaining a fixed session structure.

Table 4. Periodisation of small-sided positional games (45 mins) over 16 weeks.

Month	Dominant	Format(s)	Dimensions / player-to-pitch ratio	Work/recovery time	Dominant tactical approach
1	Aerobic	6v6+3 support players, continuous play: ball possession	Large area (~250–300 m² per player)	Long sets of 4–6 mins / active recovery 1–2 mins	Ball retention, wide movement, extended playing time
2	Explosive strength	4v4+3, quick transitions	Reduced playing area (~100–150 m² per player)	Intense short bursts of 2–3 mins / recovery 2–3 mins	One-on-ones, immediate attack-to-defence transitions, counter-pressing
3	Speed	3v3 or 4v4 in very small areas, with transition zones	Very small, with fast transition corridors	Very short bursts of 30–60 seconds (repeated) / long recovery periods of 2–3 minutes	Vertical movement, accelerating after regaining possession, direct play
4	Ball retention / Control	6v6+3 or 8v8 in free play, minimal tactical constraints	Large pitch (~200–250 m² per player)	Sets of 3–5 mins / active recovery 2–3 mins, sub-maximal intensity	Maintenance of acquired technical and tactical skills,

Examples:

- **Month 1**: **Width and Depth** (unpredictable player): 6v6+3 over a large area with the instruction ‘10-man possession: find the free (unpredictable) player to attack the depth’.
- **Month 2**: **Numerical and Positional Superiority**: 4v4+3 wildcards in support in a confined area (e.g. 24x16m). Two teams of 4 players, plus 3 wildcards (one low support player for build-up, one high support player, and one central player at the heart of the play).
  - Procedure**:** The team in possession uses the 3 wildcards to create a 7-against-4 situation. Players must constantly adjust their positioning to keep passing lanes open.

- Physical exertion**:** The sequence of short sprints and changes of direction places significant demands on aerobic capacity and agility.

- **Month 3**: **Rational Use of Space**: Players must never be on the same horizontal or vertical line as the player in possession of the ball. Positioning themselves at different heights (in a staggered formation) creates a network of diagonal passes, making it extremely difficult for the defender to intercept.

- Example exercise: Sectorised Position Rondo (5v5 + 1 Joker).

- Set-up: A large square divided into 4 equal mini-squares.

- Procedure: The attacking players have designated zones of responsibility. Strict rule: no more than two players may be in the same sub-square or on the same line. The central joker links the play. If a player drops back towards the ball, a teammate must compensate by moving deeper to balance the structure.

- **Month 4: Transition and Counter-Pressing**: 6v6+3 or 8v8 with large pitches, sub-maximal intensity and a reduced workload. Match-like conditions: maintaining match intensity whilst keeping the training session's workload reduced and appropriate.

- In positional play, the way we attack dictates the way we defend. If the team maintains the correct possession distances (players close enough to link up, but spread out enough to advance), it is ideally structured to pounce on the opposition as soon as possession is lost.

- Example exercise: Positional play with transition goals.

- Set-up: A standard possession area. Outside this area, set up 4 mini-goals (or gates).

- Procedure: Team A retains possession. If Team B wins the ball back, they have only 4 seconds to score in one of the small goals. Team A must therefore apply fierce pressure *immediately* upon losing possession to stifle the build-up play.

- Athletic link**:** The intensity of the reaction to losing possession and the constant restarts directly stimulate specific endurance and the ability to repeat intense efforts.

4.3.4. Functional core training (10 mins)

The core training used in the integrated programme prioritises dynamic and anti-rotational exercises, with load transfers that closely mimic the demands of the game (unstable footing, trunk rotations and sideways support, unstable footing on different sides combined with leg movements), rather than traditional static core training. This component also follows a periodisation programme based on progressive complexity.

Table 2b. Periodisation of functional core training (10 mins) over 16 weeks.

Month	Focus	Type of core training	Examples
1	Aerobic / Volume	Anti-extension and anti-rotation core training, static to semi-dynamic	Plank with slight shifts in weight distribution; side plank with alternating shoulder taps
2	Strength / Intensity	Dynamic core exercises with load and resistance	Trunk rotations with shoulder touches; plank with unilateral pull
3	Speed / Recovery	Reactive core training, mimicking sporting movements, in motion	Closed-chain core work with rapid changes of support (lateral mountain climbers)
4	Recovery / Maintenance	Static core stabilisation, low load	Standard front and side planks (15–30 s); light dynamic core work without additional resistance

4.3.4. Assessment of aerobic fitness

Aerobic capacity was assessed using the Yo-Yo Intermittent Recovery Test, Level 1, in accordance with the standardised protocol by Krustrup et al. (2003), before and after the intervention, always under the same conditions (time, surface, warm-up, supervision). The total distance covered (in metres) served as the primary indicator of intermittent aerobic capacity (Bangsbo et al., 2008).

5. Statistical analysis

The data were analysed using a repeated-measures ANOVA (group × time), supplemented by Tukey's HSD post-hoc tests where the interaction proved significant. The effect size was estimated using Cohen's d. An analysis by age subgroup was carried out to test hypothesis H3. The significance threshold was set at $p < 0.05$. As comparisons between the control group and the four categories of the experimental group involved a large number of tests (12 in total, on pre- and post-test values and gains, for the four categories of the experimental group), a Bonferroni correction was applied to limit the risk of false positives, supplemented for comparison by a less conservative Benjamini–Hochberg (FDR) correction. t-tests, ANOVA and Tukey's post-hoc test were carried out using Python (pandas, NumPy, SciPy, stats models); the Bonferroni and Benjamini-Hochberg corrections were calculated using the stats models. stats. multitest. multiple tests function.

5.1. Results: Analysis and interpretation

5.1.1. Results of physical tests: Yo-Yo Intermittent Recovery Test 1

VMA (U13)					
Prenoms	Postes	YO YO 1(m)	VMA 1 (Km/h)	YO YO 2 (m)	VMA 2 (Km/H)
Yousref	2	760	14,5	1720	16
Yassir	8	760	14,5	2760	18
Serraiddine	11	1600	16	2760	18
Alaeddine	3	1000	15	1760	16,5
Rayan	3	1880	16,5	2760	18
Adam	2	1600	16	2760	18
Med Islam 1	7	2240	17	2400	17,5
Mohamed	8	2000	16,5	2760	18
Mouslim	9	1200	15,5	2760	18
Yousref	4	1100	15	2400	17,5
Med Islam2	10	1560	16	2700	18
Saad	8	1100	15	2120	17

VMA (U14)					
Pré noms	Postes	YO YO 1 (m)	VMA 1 (Km/h)	YO YO 2 (m)	VMA 2 (Km/h)
Yousref	5	1440	16	2600	17,5
Yassine	2	1240	15,5	3000	18,5
Abderrahmane	4	2240	17	3400	19
Haytam	9	1060	15	2900	18
Imrane	11	1440m	16,5	2200	17
Adam	3	1240	15,5	1400	16
Salim	9	1300	15,5	3000	18,5
Mohammed rayan	6	2000	17	3160	18,5
Adam	2	1580	16	2400	17,5
Hamza	8	1640	16	3100	18,5
Mohammed	10	1460	16	2120	17
Ahmed	7	1540	16	3440	19
Oussama	10	2240	17	3360	19
Rayan	4	1240	15,5	2200	17

VMA (U15)					
PRENOMS	Postes	YO YO 1 (m)	VMA 1 (Km/h)	YO YO 2 (m)	VMA 2 (Km/h)
aymane	DC	2540	17,5	4000	19,5
mouad	DC	3400	19	3640	19,5
amine	AL	3200	18,5	3640	19,5
jihad	AL	1580	15,5	3640	19,5
mohamed	MD	2080	17	3640	19,5
salahdine	MD	2120	17	4000	19,5
saad	AT	2440	17,5	1560	19
ismal	MO	2120	17	2440	17,5
mohamed	AL	2880	18	3440	19,5
chahid	AT	2520	17,5	3560	19
aymane	MD	2000	16,5	3060	18,5
Noureddine	DC	1280	15,5	2320	17

VMA (U16)					
Prenoms	Postes	YO YO 2 (m)	VMA 1 (Km/h)	YO YO 2 (m)	VMA 2 (Km/h)
Mohammed	2	2760	18	4000	19,5
Ismail	3	2090	17	3640	19,5
Yousref	4	3760	19	4000	19,5
Rayan	6	2080	17	4000	19,5
Anas	8	3360	19	4000	19,5
Issam	11	2480	17,5	4000	19,5
Sohail	10	2090	17	4000	19,5
Amine	5	2520	17,5	4000	19,5
Rayan	2	2080	17	4000	19,5
Rayan	9	1160	15,5	3060	18,5
Khalil	3	1920	16,5	4000	19,5

VMA (U15/U16 Temoins)						
Prenoms		Postes	YO YO 1 (m)	VMA 1 (Km/h)	YO YO 2 (m)	VMA 2 (Km/h)
Khalil	Belghiti	3	2260	17	2880	18
hossam	Berradi	2	1800	16,5	2400	17,5
Hamza	Bakkari	4	2110	17	2240	17
Taha	El Akaoui	10	2160	17	1960	16,5
Zakaria	Hamoud	7	2600	17,5	3440	19
Taha	wandji	9	3000	18	3600	19
Mohammed	Kharouani	11	2260	17	2260	17
Amine	Douma	4	1740	16,5	1720	16
Owayss	El Hilali	4	2260	17	2560	17,5

5.1.2. Initial homogeneity of the groups

First observation: an ANOVA carried out on the pre-test values reveals a significant difference between the five groups (comparison to be recalculated on the reduced dataset), which is logical, since age directly influences initial intermittent aerobic capacity (Bangsbo et al., 2008). The control group, however, is at a level comparable to that of the U15s ($p = 0.665$) and U16s ($p = 0.585$), but above the U13s and U14s ($p < 0.001$ in both cases). Overall, when comparing the pooled experimental group ($n = 49$) with the control group ($n = 9$), no significant difference was found in the pre-test (comparison to be recalculated using the reduced dataset), which allows, despite the variations by category, an overall comparison between the two conditions.

5.1.3. Intra-group comparison (pre-test vs post-test)

Paired t-tests show that the distance covered in the YYIR1 increased in a statistically significant manner across all five groups, including the control group (Table 5).

Table 5. Intra-group comparison of pre-test vs post-test (mean ± standard deviation) by category.

Group	n	Pre-test (m)	Post-test (m)	Δ (%)	t	p	Cohen's d
U13	12	1,400 ± 486	2472 ± 400	+76.5	8.21	< 0.001	2.37
U14	14	1547 ± 371	2,751 ± 588	+77.8	9.25	< 0.001	2.47
U15	12	2,347 ± 619	3,245 ± 756	+38.3	3.80	0.003	1.10
U16	11	2,391 ± 713	3,882 ± 293	+62.4	8.46	< 0.001	2.55
Control	9	2,243 ± 383	2562 ± 637	+14.2	2.65	0.029	0.88

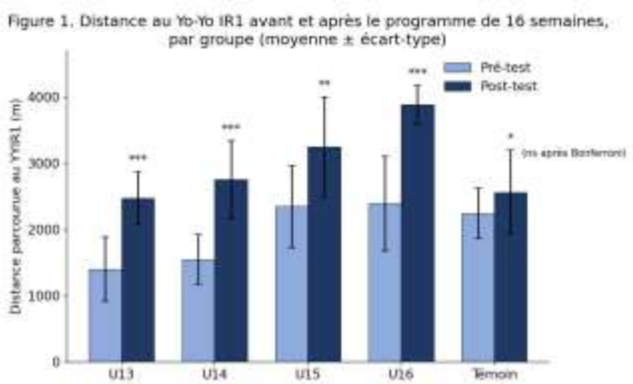

Figure 1. Distance covered on the YYIR1 before and after the 16-week programme, by group (mean ± standard deviation). *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$ (unadjusted test; see section 3.5 for results after Bonferroni correction).

A bar chart with standard deviation (Figure 1) remains useful for a quick overview, showing the group summary, but masks the actual variation between players, the sample size, or any outliers. Figure 1a therefore complements this interpretation by showing, player by player, the individual trajectory between pre- and post-test.

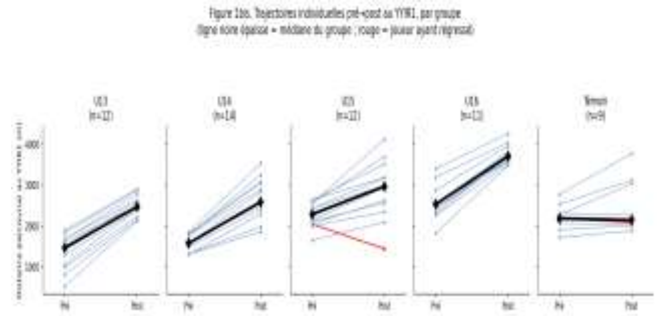

Figure 1bis. Individual pre-post trajectories for YYIR1, by group. Each thin line represents a player; the thick black line indicates the group median; the red lines highlight players whose distance decreased between the pre- and post-tests.

Two things are evident here that were not shown in Figure 1: the outlier value of one U15 player, who regressed significantly and dragged down the effect size for the entire category; and a fairly marked heterogeneity within the control group, where several players showed barely any progress – a nuance that the group mean alone did not reveal.

In the experimental group, it is the U14s (+77.8 per cent; d = 2.47) and the U13s (+76.5 per cent; d = 2.37) who show the greatest improvement, closely followed by the U16s (+62.4 per cent; d = 2.55 – the largest effect size in the entire sample). The U15s (+38.3 per cent; d = 1.10) showed less improvement, dragged down by the outlier value of one player who regressed (Figure 1bis). The control group, for its part, also showed improvement (+14.2 per cent; t = 2.65; p = 0.029), but with the smallest effect size of the group (d = 0.88), which is roughly in line with what would be expected from a standard 16-week fitness programme.

5.1.4. Inter-group comparison (before and after the 16 weeks)

The ANOVA applied this time to the post-test values confirms that the categories remain significantly different from one another (comparison to be recalculated on the reduced dataset), which is hardly surprising: age and level of development naturally create a hierarchy of absolute distances. This heterogeneity, present both before and after the intervention, suggests that it is better to consider relative values (%) rather than raw metres when comparing the categories with one another. On this basis, the average gain for the pooled experimental group (+1,161 m, or +61.2 per cent) clearly exceeds that of the control group (+319 m, or +14.2 per cent); the statistical significance of this difference (t-test, p-value, Cohen's d) remains to be recalculated on the reduced dataset, but the magnitude of the difference suggests a large effect according to Cohen's conventions.

5.2. Comparison of the control group with each category of the experimental group

Table 6 sets out, category by category, how the control group compares with the experimental groups before and after the intervention.

Table 6. Comparison of the control group with each experimental group, in the pre-test, post-test and gain measures (ns = not significant, $p \geq 0.05$; * = significant, $p < 0.05$).

Group	Pre vs Control (p)	Post vs Control (p)	Gain vs Control (p)	Gain (m) vs Control (+319 m)
U13	0.0004 *	0.693 (ns)	0.0006 *	+1,072 m
U14	0.0003 *	0.474 (ns)	0.0001 *	+1,204 m
U15	0.665 (ns)	0.041 *	0.063 (ns)	+898 m
U16	0.585 (ns)	< 0.001 *	0.0001 *	+1,491 m

A fairly consistent pattern emerges. Despite differences in initial levels linked to age (the U13 and U14 groups started at a lower level than the control group), the four experimental groups (U13, U14, U16 and, to a lesser extent, U15) made significantly greater progress than the control group in absolute terms. The U13 and U14 groups eventually caught up with the control group's level without statistically exceeding it ($p = 0.693$ and $p = 0.474$): given their initial lag, this is already a notable improvement. The U15 and U16 age groups, on the other hand, significantly outperformed the control group in the post-test ($p = 0.041$; $p < 0.001$). For details of the gains, see Table 6.

5.3. Sensitivity analysis: correction for multiple comparisons

It must be made clear that the previous analyses are based on a large number of repeated tests (5 paired t-tests in 3.2, 12 independent t-tests in 3.4), and this automatically increases the risk of wrongly concluding that an effect exists. A sensitivity analysis was therefore required, using a Bonferroni correction (adjusted α threshold = 0.05 divided by the number of tests) and, for comparison, a Benjamini–Hochberg (FDR) correction, which is slightly less stringent. A Tukey HSD post-hoc test was also applied to the post-test ANOVA to determine precisely which pairs of groups actually differ.

As for intra-group comparisons (Table 7, 5 tests, adjusted $\alpha = 0.01$), the improvements observed in U13, U14, U15 and U16 still hold up after the Bonferroni correction. The progress observed in the control group, however, no longer meets the Bonferroni threshold (corrected $p = 0.146$), although it remains significant under the less conservative FDR (Benjamini–Hochberg) correction (corrected $p = 0.029$) — a borderline result that should be interpreted with caution.

Table 7. Pre-post within-group comparison with Bonferroni correction.

Group	Raw p-value	Corrected p (Bonferroni)	Significant at α = 0.01?	Unadjusted significance (α = 0.05)?
U13	< 0.001	0.000025	Yes	Yes
U14	< 0.001	0.0000025	Yes	Yes
U15	0.0030	0.0150	Yes	Yes
U16	< 0.001	0.0000335	Yes	Yes
Control	0.0292	0.1460	No	Yes

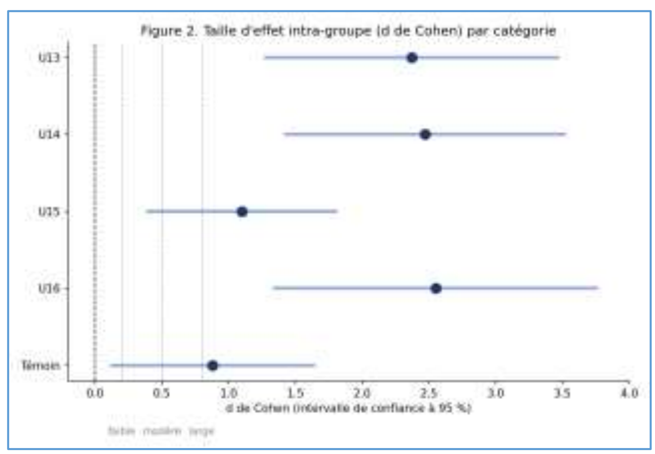

Figure 2. Intra-group effect size (Cohen's d, 95% confidence interval) by category. The vertical markers indicate Cohen's (1988) conventional thresholds for small (0.2), moderate (0.5) and large (0.8) effects.

Tukey's post-hoc test (Table 8) provides further detail: the control group differs significantly from the other groups only in relation to the U16s in the post-test, and remains statistically indistinguishable from the U13s, U14s and U15s at this stage. This result should be interpreted in the light of the differences in initial ability that were already present even before the programme began (see 3.1 and 3.4).

Table 8. Tukey HSD post-hoc test on post-test values (selected pairs; see text for all 10 comparisons).

Comparison	Difference (m)	Tukey's q	p (Tukey)	Significant?
U13 vs U15	-773	5.09	0.0082	Yes
U13 vs U16	-1,410	9.07	< 0.001	Yes
U14 vs U16	-1130	7.54	< 0.001	Yes
U16 vs Control	+1,320	7.89	< 0.001	Yes
U15s vs Témoin	+683	4.16	0.0504	No (limit)
U13 vs Control	-91	0.55	0.999	No
U14 vs Control	+189	1.19	0.959	No

Finally, when comparing the control group with each category after adjustment (Table 9, 12 tests, adjusted α = 0.0042), most of the significant results hold up: the pre-test scores, the gains for the U13, U14 and U16 groups, and the post-test scores for the U16 group. Only one result changes: the apparent superiority of the U15s over the control group in the post-test, which was significant in the unadjusted test (p = 0.041), does not withstand either the Bonferroni correction (corrected p = 0.497) or the FDR correction (corrected p = 0.071). It must therefore be presented as a trend, not as an established result.

Table 9. Comparison of the control group versus each experimental category (pre, post, gain), with Bonferroni and Benjamini-Hochberg (FDR) corrections for multiple comparisons.

Group / phase	Unadjusted p	Bonferroni p	FDR (BH) p	Unadjusted significance	Bonferroni significance	FDR significance
U13 – pre	0.0004	0.0048	0.0010	Yes	Yes	Yes
U13 – post	0.6933	1.000	0.6933	No	No	No
U13 – gain	0.0006	0.0072	0.0012	Yes	Yes	Yes
U14 – pre	0.0003	0.0036	0.0009	Yes	Yes	Yes
U14 – post	0.4738	1.000	0.6317	No	No	No
U14 – gain	0.0001	0.0012	0.0004	Yes	Yes	Yes
U15 – pre	0.6650	1.000	0.6933	No	No	No
U15 – post	0.0414	0.4968	0.0710	Yes	No	No
U15 – gain	0.0632	0.7584	0.0948	No	No	No
U16 – pre	0.5846	1.000	0.6933	No	No	No
U16 – post	< 0.001	0.0001	0.0001	Yes	Yes	Yes
U16 – gain	0.0001	0.0012	0.0004	Yes	Yes	Yes

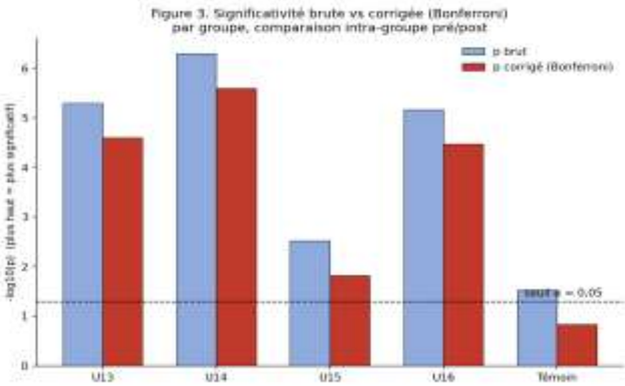

Figure 3. Raw vs. corrected (Bonferroni) significance by group, intra-group pre/post comparison, expressed as -log10(p) (the higher the bar, the more significant the result). The dotted line indicates the conventional threshold $\alpha = 0.05$.

Overall, this sensitivity analysis reinforces rather than undermines the central conclusion: the superiority of the integrated programme among the U13, U14 and U16 age groups holds up under strict statistical correction. Two caveats are worth noting. Firstly, the gain observed in the control group itself is no longer statistically robust after correction, which, paradoxically, tends to favour the integrated programme: in this sample, conventional training does not guarantee a reliable aerobic effect over 16 weeks. Secondly, the superiority of the U15s over the control group in the post-test should be interpreted with caution, as a trend rather than a statistically established result.

6. Discussion

These results confirm H1: the 16-week integrated programme, focusing on positional play with cognitive demands plus rituals (proprioception coupled with technical skills, associated physical training, and functional core strengthening), does indeed improve the intermittent aerobic capacity of young elite footballers. And this result still holds after correction for multiple comparisons (section 3.5), which is no small feat: the average gain in the experimental group remains significantly higher than that of the control group, whose improvement — though significant in the raw test results — does not withstand a strict Bonferroni correction. In other words, in this sample, the control group's conventional training does not guarantee a solid aerobic improvement over 16 weeks, whereas the integrated programme produces significant and robust gains in three out of four age groups (U13, U14, U16).

6.1. Comparison with the literature

The magnitude of the gains observed in the experimental group is not surprising in light of the literature: in fact, it is at the upper end of the range. Hill-Haas et al. (2011) and Halouani et al. (2017) have already shown that small-sided games provide an aerobic stimulus at least equivalent to conventional interval training methods in young players, which partially confirms H2: the control group also showed improvement in the raw test results, but this improvement was no longer significant after Bonferroni correction, unlike that of the U13, U14 and U16 groups in the experimental group. This difference in favour of the integrated programme is likely due to its combined nature: positional games involve intermittent exertion close to ventilatory threshold 2, replicating the physiological demands of a match (Owen et al., 2021; Riboli et al., 2020); the associated physical training aims for the same objective, whilst proprioception combined with technical skills and functional core training improve postural efficiency and the quality of footwork – two factors that could reduce the energy cost of repeated actions during a match (Clemente et al., 2022; Nobari et al., 2023).

6.2. Effect of age and maturation

H3 is also confirmed: the magnitude of the gains varies significantly according to age, and this variation holds up in sensitivity analysis. The U13, U14 and U16 age groups show the greatest improvements and effect sizes, which remain robust after Bonferroni correction; this suggests that young, developing players are particularly receptive to this type of intermittent, coordination-based stimulus, in line with research on significant aerobic plasticity around puberty (Clemente et al., 2021; Sarmento et al., 2020). The more modest gain observed in the U15s (+38.3 per cent; $d = 1.10$) should, however, be interpreted with caution: this is also the category where an outlier (a player showing a marked decline, see Figure 1bis) pulls the effect size down, which explains why its superiority over the control group does not withstand corrections for multiple comparisons (section 3.5).

The comparison of the control group with each experimental category, even after correction (section 3.5, Table 9), points in the same direction: the U13s and U14s, having started at a level significantly lower than the control group, eventually catch up with it without statistically exceeding it – a genuine catch-up based on a gain significantly greater than that of the control group and which holds up after the Bonferroni correction. The case of the U16s is undoubtedly the most compelling argument in favour of the programme: starting at a level comparable to the control group ($p = 0.585$), they significantly outperformed it in the post-test ($p < 0.001$, robust after correction), with the strongest gain across the entire sample. The U15s, on the other hand, should be treated with greater caution: their apparent lead over the control group in the post-test ($p = 0.041$, unadjusted) does not withstand either the Bonferroni or FDR tests; a larger sample will be required to determine whether the effect is genuine or not.

6.3. Ecological approach and transfer to performance

These results are consistent with the rationale behind ecological approaches to training, which favour integrating technique, tactics and physiology within a single task rather than working on them separately (Araújo & Davids, 2016; Coutinho et al., 2022). The fact that the control group, at an equivalent training volume, also made progress — albeit much more modestly — suggests that it is not simply the training volume that makes the difference, but rather the integrated and specific nature of the stimulus provided.

6.4. Limitations and future directions

This study has its limitations, which must be acknowledged. Firstly, the groups were not perfectly matched at the pre-test (significant differences exist between certain categories and the control group), which means that relative gains should be prioritised over absolute values; an ANCOVA controlling for pre-test levels would be a useful addition in future research. Furthermore, the sample sizes remain modest (9 to 14 players depending on the group, with a minimum of 9 for the control group), which limits the statistical power of certain comparisons: this is probably why the effect observed in the U15s, although significant in absolute terms, does not withstand correction. A larger sample size would help distinguish between a genuine lack of statistical power and a genuine absence of effect. Finally, biological maturation was not measured directly (bone age, growth spurt), even though it undoubtedly accounts for some of the variability between categories. Future research would benefit from following players over a longer period, directly measuring internal load during positional games (heart rate, RPE), matching groups by maturity rather than chronological age, using a Level 2 test for the older age groups, and working with larger samples to maintain sufficient statistical power once the corrections have been applied.

7. Conclusion

This controlled longitudinal study shows that a 16-week integrated programme focusing on positional games with cognitive demands, combined with rituals (proprioception combined with technical skills, associated physical training and functional core strengthening) significantly improves the intermittent aerobic capacity of young elite footballers, with an average gain (+61.2 per cent) more than four times greater than that of conventional training (+14.2 per cent). Once rigorous statistical corrections have been applied (Bonferroni, Benjamini-Hochberg), this effect remains significant among the U13, U14 and U16 age groups, whilst the gain in the control group loses its statistical significance; this, in essence, strengthens rather than weakens the case for the integrated programme. This finding is consistent with research demonstrating the effectiveness of small-sided games as an aerobic stimulus in young footballers (Buchheit & Laursen, 2013; Hill-Haas et al., 2011; Halouani et al., 2017). In practical terms, these findings suggest that this type of programme should be incorporated into the planning of physical preparation in youth academies, particularly for the U13, U14 and U16 age groups, whilst caution should be exercised for the U15s, whose advantage over the control group remains an unconfirmed trend after correction for multiple comparisons. More broadly, these findings are consistent with the principles of ecological approaches to training, which aim for optimal transfer to competitive performance (Araújo & Davids, 2016; Coutinho et al., 2022).

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