Journal of Human Kinetics volume 104/2026, 209–229 DOI: 10.5114/jhk/209805
Section III – Sports and Physical Activity

Maximizing Performance in Limited Time: Effects of 30-min Superset and Repeated Sprint Training on Youth Basketball Players

by
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In youth basketball, limited practice time in most clubs demands time-efficient conditioning methods integrated into regular training. In this context, superset training (SST) and repeated sprint training (RST) offer viable strategies to develop key physical capacities, including explosive strength, aerobic fitness, speed and agility, efficiently. Therefore, this study investigated whether adding a weekly 30-min SST or RST session to the regular basketball practice over eight weeks could improve physical performance, and whether responses would vary across different chronological and biological age-groups. Sixty-two youth players from a basketball club academy (U-13 to U-18) were randomly assigned to the SST (N = 32) or the RST (N = 30) group. Baseline measurements from a familiarization period, when players only performed basketball training, served as reference for evaluating the intervention's impact, maintaining ecological validity. Explosive strength, aerobic fitness, speed and agility were assessed pre- to post-intervention. Compared to baseline, both SST and RST led to marked improvements in explosive strength ($p < 0.001$), aerobic fitness ($p \leq 0.004$), speed ($p < 0.001$) and agility ($p < 0.001$) pre- to post-intervention. Notably, the extent of improvements varied by chronological age in specific capacities. Incorporating a single weekly 30-min session of SST or RST into regular basketball practice can effectively enhance key performance capacities in youth basketball players. These findings suggest that even minimal, structured conditioning can elicit meaningful performance gains and distinct responses across age-groups. This underscores the need for interventions tailored to age-specific developmental requirements, offering a practical strategy for clubs facing limited training time.

***Keywords**: performance; strength; conditioning; team sports*

Introduction

Basketball alternates high-intensity actions with low- to moderate-intensity activities, requiring a combination of anaerobic capacity to meet explosive demands such as sprints, jumps or changes of direction alongside an aerobic component to facilitate recovery between intermittent efforts (Stojanović et al., 2018). Consequently, optimal performance is closely tied to the development of explosive strength, aerobic fitness, speed and agility (Gottlieb et al., 2021). In particular, for youth athletes implementing appropriate training routines tailored to different

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stages of growth and maturation is essential for progressively developing these physical capacities and preparing them for increasing training loads (Bergeron et al., 2024). In this context, youth development models recommend emphasizing neuromuscular strength and power throughout all developmental stages, particularly during pre-peak height velocity (PHV), and gradually increasing mechanical loading post-PHV for continued strength development (Bergeron et al., 2024; Lloyd et al., 2015, 2016). Although aerobic fitness is typically targeted more intensively post-PHV, anaerobic endurance, especially the phosphagen metabolic pathway, can contribute to improvements in aerobic fitness alongside speed and agility at any maturational stage (Lloyd et al., 2016; Mačinskas et al., 2023). Furthermore, training that focuses on motor skills control, specific sport techniques and movement patterns is crucial for the holistic development of these capacities across all stages (Bergeron et al., 2024; Lloyd et al., 2015, 2016).

In many youth basketball settings, however, multiple constraints such as limited training time, often lead coaches to prioritize technical and tactical skill development at the expense of structured strength and conditioning programs (Myer et al., 2016). Therefore, identifying time-efficient methods that support players' physical development across different stages of growth and maturation is crucial. Recent research has demonstrated that even minimal doses of conditioning work can yield significant adaptations (Viramontes et al., 2024), offering a practical solution to the time constraints inherent in many training schedules. In this context, Behm et al. (2023) emphasize that a single weekly session consisting of 6 to 15 repetitions at 30–80% of one repetition maximum (1RM) over an 8- to 12-week period can significantly enhance neuromuscular and strength adaptations in adults. Similarly, high intensity interval training (HIIT) is widely recognized as an effective and time-efficient method to improve aerobic fitness as well as speed and agility (Buchheit and Laursen, 2013). Notably, even short HIIT sessions (less than 30 min) performed consistently over a five-week period can yield substantial performance improvements, offering meaningful benefits for team sports (Thurlow et al., 2023).

In this context, superset training (SST) has emerged as an effective and time-efficient method for strength development, providing the necessary physiological, hormonal and metabolic stimulus for adaptation in young (Realzola et al., 2022) and adult (Fink et al., 2021; Miranda et al., 2020) populations. Compared to traditional strength training, SST achieves similar strength gains in less time while promoting greater caloric expenditure, higher perceived exertion and potential aerobic benefits (Fink et al., 2021; Realzola et al., 2022; Weakley et al., 2017). SST typically involves performing two consecutive exercises targeting agonistic and antagonistic muscle groups with minimal rest, incorporating both single- and multiple-joint movements (Weakley et al., 2017). Such structure is particularly advantageous for skill- and power-based sports like basketball, as it can be adapted to enhance sport-specific strength (Paz et al., 2019). Moreover, the adaptability of SST to target various stimulus, including neuromuscular and mechanical factors, enhances its suitability for athletes across different stages of growth and maturation (Bergeron et al., 2024; Lloyd et al., 2015, 2016). Similarly, repeated sprint training (RST) has been identified as a highly efficient method for developing aerobic fitness, speed and agility in sport settings, both in adults (Buchheit and Laursen, 2013) and youth (Rey et al., 2019). RST consists of short, explosive sprints (≤ 10 s) interspersed with brief recovery periods (≤ 60 s), thereby engaging both the anaerobic and aerobic energy systems (Thurlow et al., 2023, 2025). Research suggests that RST may be more effective than continuous or low-intensity interval methods in enhancing sport-specific capacities in team sports like basketball, while requiring minimal time investment (Gantois et al., 2019; Maggioni et al., 2019). Additionally, its ability to mimic the explosive movements commonly performed in basketball, along with its adaptability across different age-groups, makes it particularly valuable for preparing youth athletes to meet game demands (Caprino et al., 2012).

Given the critical periods for developing explosive strength, aerobic fitness, speed and agility in youth athletes (Lloyd et al., 2015), SST and RST potentially emerge as suitable, time-efficient strategies to optimize basketball-specific physical performance within constrained training schedules. In addition, investigating their effectiveness across different age groups could

help refine how these methods are applied, offering practical guidance on tailoring interventions to maximize their impact at various developmental stages. To our knowledge, no previous studies have directly compared these time-efficient methods in youth basketball players. Therefore, the main aim of this study was to investigate whether adding a single 30-min session per week of either SST or RST to the regular basketball practice over an 8-week period could promote meaningful improvements in aerobic fitness, explosive strength, speed and agility in youth basketball players. Furthermore, this study aimed to determine which age groups would benefit most from the specific SST and RST protocols. Therefore, the effects were evaluated based on both chronological and biological age (PHV).

Methods

Participants

A total of 66 youth basketball players (age: 15.39 ± 0.27 years; maturity offset: 1.37 ± 0.60 years; body height: 179.91 ± 7.38 cm; body mass: 66.61 ± 9.02 kg) from six different age-groups (i.e., U-13, U-14, U-15, U-16, U-17, U-18) participated in this study (Table 1). All participants were recruited from the academy from the Basquet Girona club (ACB-Liga Endesa).

The study was conducted during the competitive season, between February and March 2022. During the study period, participants followed their regular training schedule, consisting of three 90-min sessions per week and one competition on the weekend. The experimental sessions were scheduled during the first practice of the week, after a minimum of 24 h post-game (Monday or Tuesday). Inclusion criteria required participants to remain injury-free throughout the intervention, not to be on any medication that could affect outcomes, and to complete a minimum of seven out of the eight experimental sessions. In addition, to ensure comparable training exposure across participants and maintain high adherence, only players who attended a minimum of 85% of all training sessions and matches (equivalent to missing no more than three activities) during the study period were retained. Four players dropped out due to injury or illness.

All participants along with their legal guardians were fully informed about the potential risks and benefits of the study and provided written informed consent. The study was approved by the Research Ethics Committee of the Dr. Josep Trueta Hospital in Girona, Girona, Spain (approval code: 2020.193; approval date: 01 December 2020). The data collected were treated with utmost confidentiality and scientific rigor, in accordance with the Organic Law 15/1999 of the 13th of December on the Protection of Personal Data (OLPPD) and adhered to the ethical principles outlined in the Declaration of Helsinki Statement of 2008, updated in Fortaleza, October 2013 (World Medical Association, 2013).

Experimental Design

The study followed a quasi-experimental and randomized controlled trial design without a control group, incorporating two measurement points (pre-test and post-test). With the aim of preserving ecological conditions of training plans and routines, participants continued their regular practice routines and competition schedule throughout the study. The intervention involved adding a single 30-min session per week over an eight-week period, in which participants performed either SST or RST, with protocols adjusted to different age groups. This approach allowed for the practical integration of the intervention into real-world training settings (Chang et al., 2022), aligning with previous research approaches in applied sport contexts that also excluded control groups due to similar constraints in sports such as soccer and basketball (Rey et al., 2019; Viramontes et al., 2024). To further strengthen internal validity, familiarization data collected before the pre-test (September 2021) were used as an additional reference point, ensuring that changes observed between pre- and post-intervention could be more confidently attributed to the experimental protocols.

General Procedure

The experimental procedure had three phases (Figure 1). All assessments and procedures were conducted in the same sports official hall (Montfalgars Gym, Girona, Spain), at the same time of the day (6:00–8:00 PM) under consistent similar environmental conditions (15–18 ºC temperature, 70–80% humidity). Each testing day and prior to each experimental session, players completed a standardized 10-min warm-up (see supplementary material). Participants were

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instructed to avoid strenuous physical activity outside the scheduled training program and maintain their usual hydration, sleep, and dietary habits throughout the study. All participants were familiarized with the experimental procedure prior to the start of the intervention (September 2021).

Measures

Anthropometric Data

Standing height, sitting height and body mass were measured pre- and post-intervention using a Portable Seca® Stadiometer 213 (Seca® 213, Germany) and a Tanita BC-545 scale (Tanita®, Japan). Sitting height was measured with participants seated on the ground against the stadiometer (Massard et al., 2019). Maturity offset and age at PHV were calculated using the Moore Formula (Moore et al., 2015). Following the approach from Malina et al. (2024), participants were classified as early, circa (average) or late matures based on their age at PHV. Early maturers were defined as those with age at PHV more than one SD below the sample mean, late maturers as more than one SD above and circa maturers as within ± 1 SD. The cut-off values used for classification were < 13.35 years for early, 13.35–14.24 years for circa and > 14.24 years for late maturers, based on the sample mean age at PHV (13.80 ± 0.45 years).

Aerobic Fitness

The Yo-Yo intermittent recovery test assessed aerobic fitness following validated protocols (Krustrup et al., 2003). U-13 and U-14 teams performed level 1, while U-15 to U-18 teams completed level 2. Maximal oxygen uptake (VO_{2max}) was estimated based on the distance covered during the test (Krustrup et al., 2003).

Explosive Strength

Lower body explosive strength was evaluated using the jump height obtained in the CMJ test (Bosco et al., 1983). Measurements were taken using Chronojump® software (Version 1.6.1.0; Bosco Systems®, Barcelona, Spain). Participants completed two trials with a 2-min rest interval between jumps, and the best result was used for further analysis.

Speed

Linear speed was assessed using a 20-m sprint test (Gottlieb et al., 2021), with times recorded using two photocells (Witty gate, Microgate®, Bolzano, Italy). Each participant performed two trials with a 3-min rest interval in between, and the fastest time was used for analysis. Speed (m/s) was calculated by dividing the 20-m distance by the time taken to complete the sprint.

Agility

Agility was evaluated using two tests: the T-test (Semenick, 1990) and the V-cut test (Gonzalo-Skok et al., 2015). The T-test, measured forward, lateral and backward movements with timing recorded by a single photocell (Witty gate, Microgate®, Bolzano, Italy). The V-cut test assessed change of direction ability with two photocells (Witty gate, Microgate®, Bolzano, Italy). Each participant performed two trials with a 3-min rest interval between them, and the fastest time was used for analysis.

Training Intervention

After the pre-test, participants were randomly assigned to the SST group (N = 32; age: 15.35 ± 1.67 years; maturity offset: 1.43 ± 1.78 years; body height: 180.41 ± 12.67 cm; body mass: 68.20 ± 13.67 kg) or the RST group (N = 30; age: 15.46 ± 1.72 years; maturity offset: 1.34 ± 1.53 years; body height: 179.59 ± 10.69 cm; body mass: 68.21 ± 14.74 kg). To ensure balanced distribution across developmental stages, randomization was stratified by the age category, with participants within each age group (U-13 to U-18) randomly allocated to either intervention group. Each group then completed one 30-min session per week over the 8-week period.

The RST protocol consisted of 2 sets of 6 x 10 s all-out sprints with 20 s of active recovery between repetitions and a 6-min half-court shooting drill between sets (Buchheit and Laursen, 2013; Maggioni et al., 2019; Thurlow et al., 2025). Each sprint included four basketball-specific changes of direction to enhance neuromuscular and coordination demands (Thurlow et al., 2025). While court dimensions and work-to-rest ratios remained constant throughout the eight weeks, change-of-direction patterns were progressively varied; one set was used in weeks 1–4, and a different set in weeks 5–8, introducing new angles

and movement directions. This variation was introduced to increase movement variability and sustain neuromuscular load (Maggioni et al., 2019). The structure of the protocol remained consistent across age groups, but intensity was individually adjusted based on maximal effort to ensure that the load matched each participant's age-related capacity.

The SST protocol consisted of three sets of six basketball-specific multi-joint exercises (three paired supersets) at 30–50% 1RM, with the load adjusted to each participant's capacity through the level of effort (Hernández-Belmonte et al., 2022; Rodríguez-Rosell et al., 2018). In every set, each player performed 5 to 6 repetitions with a weight they could lift for 14 repetitions, ensuring an individualized power-oriented stimulus (Hernández-Belmonte et al., 2022). The exercises were chosen to reflect basketball-specific movement patterns to enhance sport-specific strength (Schelling and Torres-Ronda, 2016). The structure remained stable throughout the eight weeks, targeting fight actions (push-pull), acceleration (frontal and lateral) and jumping (bilateral and unilateral). However, the specific exercises changed mid-intervention; one exercise program was used in weeks 1–4 and a different one in weeks 5–8, while maintaining the same movement goals (e.g., push to pull, front to side acceleration, unilateral to bilateral jumping). While the exercises remained consistent across all participants, the intensity was adjusted by modifying the weight according to the age-specific capacity of each group. Incomplete rest periods (60 s) were used to increase metabolic stress and the overall training load (Realzola et al., 2022). Descriptions and images of the intervention are provided in the supplementary material.

Statistical Analyses

The exploratory analysis of the descriptive data and data distribution were examined using the Kolmogorov-Smirnov test (> 50) along with skewness and kurtosis values. Prior to the analysis, an overall descriptive exploration of the participants' data and the training intervention was conducted.

In order to isolate the effects of the intervention, the familiarization data (baseline measures from September 2021) were compared against the pre-test data (February 2022). Additionally, we compared the percentage change (delta; Δ) between familiarization and pre-test (when participants only followed their normal basketball schedule) versus the Δ change pre- to post-intervention (when 30 min of SST or RST were added to the normal basketball schedule over eight weeks).

To assess changes in performance before and after the training intervention, a two-way mixed-design ANOVA was conducted with time (pre vs. post) as a within-subject factor and the type of training (SST vs. RST) as a between-subject factor. Assumptions of normality and homogeneity of variances were verified using the Kolmogorov-Smirnov and Levene's tests, respectively. Significant main effects were followed by Bonferroni pairwise comparisons to identify specific differences. Additionally, to examine changes in performance outcomes (CMJ, VO_{2max}, 20-m sprint test, T-test, V-cut test) associated with each training type (SST and RST), separated paired *t*-tests were conducted for each group. Due to double paired *t*-test analysis, the significance threshold was corrected using the Bonferroni correction and set to $p < 0.025$. Cohen's effect size (ES) and 95% confidence intervals were calculated using pooled standard deviation and the *t*-value from the paired *t*-test. The effect size threshold was defined as follows: values less than 0.20 were considered trivial, between 0.20 and 0.59 small, between 0.60 and 1.19 moderate, between 1.20 and 1.99 large, and greater than 2.0 very large (Hopkins et al., 2009).

Separate one-way ANOVAs were conducted to analyze the effect of the age-group (based on chronological age) and the maturity group (based on PHV) on the Δ change in all performance measurements. When significant effects were found, Bonferroni post-hoc tests were used to compare changes among groups for each performance measure. Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS®, v. 25.0 for MacBook; SPSS Inc, Chicago) and JASP® (v. 0.18.3 for MacBook; JASP team®, Amsterdam). The level of significance was set at $p \leq 0.05$.

Results

All data presented a Gaussian distribution with low variances. The exploratory analysis of the descriptive data revealed no statistically significant differences among teams in the total practice

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volume, the number of basketball sessions per team, or the number of games played during the experiment ($p > 0.05$). Additionally, all age groups participated in the same intervention sessions.

The analysis comparing familiarization and pre-test data showed no significant difference in explosive strength ($p = 0.56$), aerobic fitness ($p = 0.58$) and agility ($p = 0.19$). Speed was significantly slower in the pre-test compared to the familiarization phase ($p < 0.001$). Furthermore, the comparison of Δ change between familiarization to pre-test and pre- to post-intervention revealed significantly greater improvements during the intervention across all performance outcomes ($p \leq 0.035$).

RST and SST

No significant group x time interaction effects were found across any of the performance measures, indicating that both training types (SST and RST) produced similar magnitude of improvement from pre- to post-intervention. Additionally, no significant group effects were found between SST and RST interventions in any of the performance measures. However, significant main effects of time (pre- to post-intervention) were detected for the CMJ ($F = 52.54$; $p < 0.001$), VO_{2max} ($F = 24.42$; $p < 0.001$), the 20-m sprint test ($F = 85.59$; $p < 0.001$), the V-cut test ($F = 65.40$; $p < 0.001$) and the T-test ($F = 45.67$; $p < 0.001$), reflecting performance improvements regardless of the training type (Figure 2). Independent analyses of each intervention (SST and RST) across all performance measures (CMJ, VO_{2max}, 20-m sprint, T-test and V-cut test) yielded significant results with small to moderate effect sizes in both SST and RST in all performance outcomes (Table 2).

Chronological Age

Significant pre- to post-intervention Δ changes were found based on the age-group for the CMJ ($F = 3{,}83$; $p = 0.005$), the 20-m sprint test ($F = 34{,}83$; $p = 0.023$), and the V-cut test ($F = 7{,}51$; $p < 0.001$). No significant effects were found for the T-test or VO_{2max}. Bonferroni post-hoc analysis (Figure 3) indicated that CMJ improvements were significantly higher in the U-13 age-group compared to U-14 ($p = 0.040$), U-15 ($p = 0.041$), U-17 ($p = 0.011$) and U-18 ($p = 0.007$) groups. Additionally, 20-m sprint speed improvements were significantly higher in the U-15 compared to the U-14 group ($p = 0.018$). Agility improvements, as measured by the V-cut test, were significantly greater in the U-13 group compared to U-14 ($p = 0.004$) and U-15 ($p = 0.003$) groups, as well as in the U-16 group compared to U-14 ($p = 0.001$), U-15 ($p < 0.001$), U-17 ($p = 0.017$) and U-18 ($p = 0.016$) groups.

Maturity Status

Maturity classification resulted in the following distribution: early maturers (N = 12), circa (N = 40) and late maturers (N = 10). No significant effects or interactions were found between maturity status and training on any of the performance tests ($p > 0.05$; see supplementary Figure 1).

Table 1. Baseline mean and standard deviations (SDs) with descriptive data from all the participants based on age-groups.

Team	N	Age (y)		APHV (y)		Maturity offset		Body height (cm)		Body mass (kg)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
U-13	10	12.90	0.27	13.75	0.42	−0.55	0.65	163.98	5.80	48.86	9.14
U-14	10	13.99	0.28	13.64	0.42	−0.41	0.79	173.04	11.89	58.07	9.19
U-15	12	14.95	0.24	13.96	0.42	1.04	0.71	181.58	7.96	63.31	11.87
U-16	9	15.80	0.25	13.58	0.44	1.68	0.41	183.04	4.40	70.80	7.96
U-17	11	16.90	0.25	13.80	0.57	3.09	0.46	186.55	7.86	76.22	9.50
U-18	10	17.80	0.30	13.98	0.37	3.38	0.59	191.24	6.34	82.38	6.43

APHV: age to peak height velocity; SD: standard deviation

Table 2. Paired *t*-test significance and effect size from the pre- vs. post-performance outcome for SST and RST.

SST		Pre		Post						
Test	N	Mean	SD	Mean	SD	t	*p*	Cohen's *d* ES	Lower ES	Upper ES
CMJ (m)	32	32.45	6.18	34.52	5.91	−5.59	< .001	0.99	0.56	1.41
VO_{2max} (mL·kg^{-1}·min^{-1})	32	51.06	4.51	52.86	5.12	−3.89	< .001	0.69	0.30	1.07
20-m sprint (m/s)	32	6,10	0.42	6.38	0.41	−6.57	< .001	1.16	0.71	1.61
T-test (s)	32	10.80	0.71	10.50	0.67	4.61	< .001	0.82	0.41	1.21
V-cut test (s)	32	7.43	0.44	7.18	0.41	4.85	< .001	0.86	0.45	1.26
RST		Pre		Post						
Test	N	Mean	SD	Mean	SD	t	*p*	Cohen's *d* ES	Lower ES	Upper ES
CMJ (m)	30	32.14	5.35	33.92	4.83	−4.68	< .001	0.86	0.43	1.27
VO_{2max} (mL·kg^{-1}·min^{-1})	30	51.94	4.99	53.34	5.16	−3.11	0.004	0.57	0.18	0.95
20-m sprint (m/s)	30	6.13	0.36	6.46	0.43	−6.51	< .001	1.19	0.71	1.65
T-test (s)	30	10.61	0.80	10.30	0.62	4.98	< .001	0.91	0.48	1.33
V-cut test (s)	30	7.32	0.50	7.03	0.53	6.91	< .001	1.26	0.77	1.74

SST: Superset training; RST: Repeated sprint training; ES: Effect size; SD: Standard deviation; VO_{2max}: maximal oxygen uptake; CMJ: Countermovement jump; Bonferroni correction significance threshold at p < 0.025

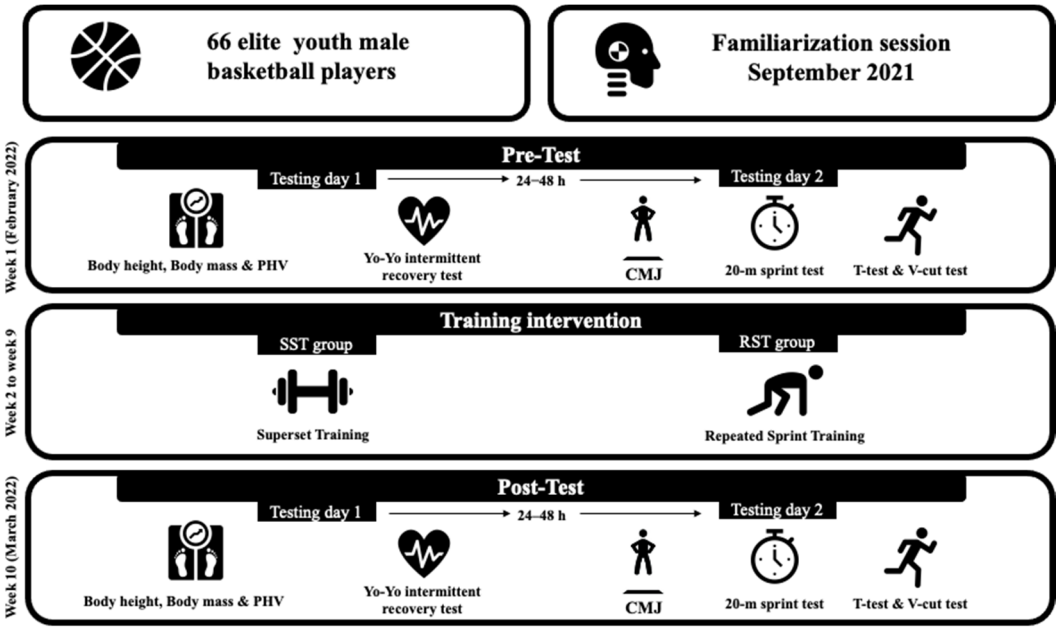

Figure 1. Experimental design of the training intervention.
PHV: Peak height velocity; CMJ: Countermovement jump; SST: superset training; RST: repeated sprint training

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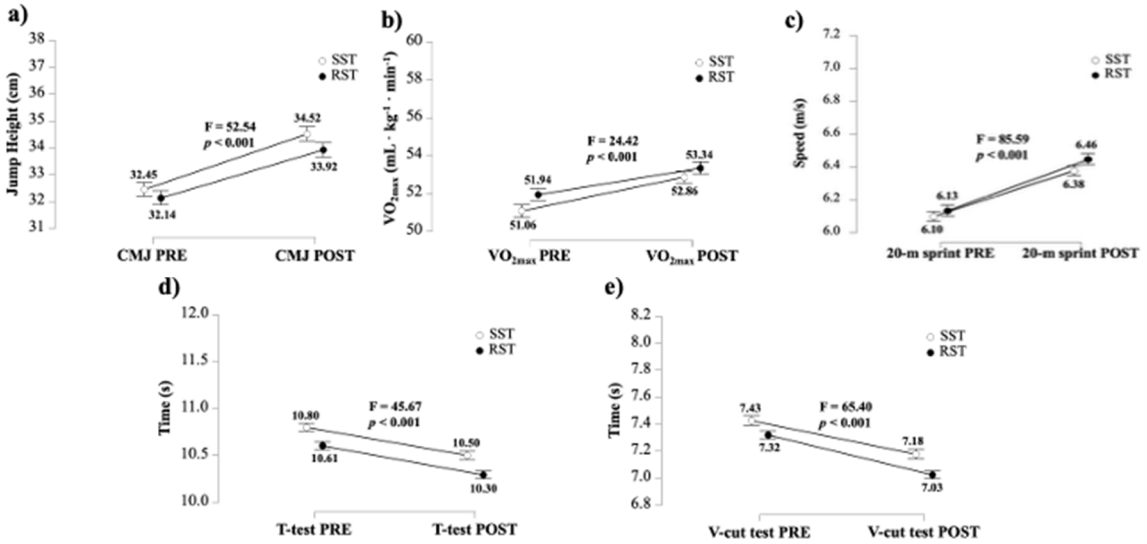

Figure 2. Main effects of time (pre vs. post) for each performance outcome based on two-way mixed-design ANOVA. F and *p* values refer to the significant main effect of time for the CMJ (a), VO_{2max} (b), the 20-m sprint test (c), the T-test (d), and the V-cut test (e). White dots correspond to superset training (SST) and black dots to repeated sprint training (RST).

VO_{2max}: maximal oxygen uptake; CMJ: Countermovement jump

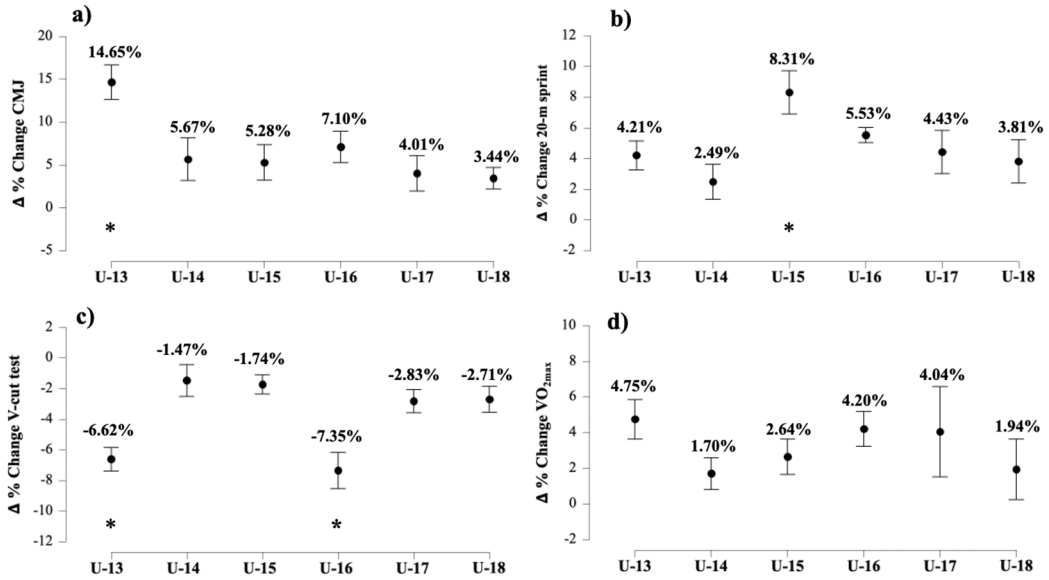

Figure 3. *Δ* change (%) with standard error of the differences post vs. pre for the CMJ (a), the 20-m sprint test (b), the V-cut test (c) and VO_{2max} (d) based on chronological age.

** shows significant difference*

Discussion

The main results showed statistically significant improvements in all performance measures (CMJ, VO_{2max}, 20-m sprint speed, V-cut test and T-test) following both SST and RST interventions. Moreover, the comparison with familiarization data (collected during basketball-only training before the intervention period) provides support that the observed improvements in performance outcomes were likely due to the intervention rather than the regular basketball practice itself. This is a particularly interesting finding in real-world settings, where structured strength and conditioning is sometimes sidelined due to time constraints. Notably, a clear chronological age-effect emerged: the U-13 group showed the greatest gains in explosive strength (CMJ), the U-15 group exhibited improvements in speed (20-m sprint), while agility improvements (V-cut test) were most pronounced in U-13 and U-16 groups. These different responses suggest that even minimal training doses can produce meaningful adaptations and underscore the necessity of designing training interventions adapted to the developmental stage of athletes (Calleja-González et al., 2018), even in environments with limited overall training time.

SST is widely recognized for its efficiency in enhancing strength and power in young and adult populations (García-Orea et al., 2023; Miranda et al., 2020; Realzola et al., 2022; Weakley et al., 2017). Most previous studies, however, have focused on strength-specific variables without extensively analyzing field assessments tied to performance outcomes. To the best of our knowledge, only one study (García-Orea et al., 2023) has assessed CMJ performance when comparing SST with traditional strength training gains in young adults, finding comparable improvements in CMJ performance (3.77% vs. 3.01%). Our findings suggest that SST can also yield significant improvements in the CMJ (6.94%; $p < 0.001$; ES = 0.99; moderate) in youth basketball players (Realzola et al., 2022). In addition, our study revealed significant improvements in VO_{2max} (3.57%; $p < 0.001$; ES = 0.69; moderate), the 20-m sprint test (4.67%; $p < 0.001$; ES = 1.04; moderate), the T-test (−2.70%; $p < 0.001$; ES = 0.82; moderate) and the V-cut test (−3.28%; $p < 0.001$; ES = 0.86; moderate).

Although further research is needed to clarify the mechanisms underlying these effects, SST appears to be well-suited to the limited training windows available in many youth basketball clubs. While improvements in explosive strength (CMJ) are consistent with the existing literature (Behm et al., 2023; Weakley et al., 2017), the benefits of SST to aerobic fitness, speed and agility, are less directly explained. These additional improvements may be explained by physiological and hormonal responses elicited by SST, which, although primarily impact explosive strength, could influence other performance domains (Fink et al., 2021; Miranda et al., 2020; Paz et al., 2019; Weakley et al., 2017). The alternating structure targeting agonist and antagonist muscle groups with minimal rest may improve neuromuscular efficiency through enhanced inter- and intra-muscular coordination and motor control, key components of speed and agility (Robbins et al., 2010). Additionally, the repeated execution of explosive actions with light loads likely stimulates fast-twitch muscle fibers recruitment and the rate of force development (RFD) (Cormie et al., 2011), both of which are critical for rapid acceleration and change of direction. Together, these adaptations may help explain the observed gains in speed and agility. Beyond neuromuscular improvements, the short recovery periods inherent in SST protocols likely increase cardiovascular and metabolic demands, potentially contributing to aerobic fitness improvements (Miranda et al., 2020; Realzola et al., 2022). The enhanced muscle fatigue resistance reported after SST protocols (Fink et al., 2021) may also support these aerobic gains. However, further sport-specific research is needed to establish a direct link between SST and aerobic performance in youth basketball players.

RST is commonly applied in team sports, including basketball, and is strongly associated with enhanced in-game intermittent and explosive actions (Caprino et al., 2012; Thurlow et al., 2023). Several studies with similar methodologies and training conditions have reported significant improvements in explosive strength (i.e., CMJ; 9.85%), aerobic fitness (i.e., VO_{2max}; 2.64%), speed (i.e., 10-m and 20-m sprints; 0.94%) and agility (i.e., T-test; 3.37%) in adult basketball athletes (Gantois et al., 2019; Maggioni et al., 2019). The findings from our study further support this, suggesting that youth basketball players may experience

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similar improvements from RST. Specifically, we observed increases in the CMJ (6.22%; $p < 0.001$; ES = 0.86, moderate), VO_{2max} (2.79%; $p = 0.004$; ES = 0.57, small), the 20-m sprint (4.27%; $p < 0.001$; ES = 1.37; large), the T-test (−2.78%; $p < 0.001$; ES = 0.91; moderate) and the V-cut test (−4.03%; $p < 0.001$; ES = 1.26; large). These observed improvements following RST likely result from the repeated high-intensity efforts involving accelerations, decelerations and changes of directions, which enhance stretch-shortening cycle function and neuromuscular coordination (Thurlow et al., 2023). These actions, performed with incomplete recovery, not only stimulate anaerobic pathways but also challenge the cardiopulmonary system (Buchheit and Laursen, 2013; Thurlow et al., 2023; Tortu et al., 2024). It is noteworthy that while VO_{2max} improvements were observed in both groups, the increase was slightly smaller in the RST group (2.79%) compared to the SST group (3.57%). This difference could be attributed to the distinct nature of each intervention. SST likely maintains a higher aerobic demand, elevating the heart rate and metabolic demands, while inducing muscle-specific anaerobic fatigue (Fink et al., 2021). In contrast, RST seems to provide a more pronounced anaerobic stimulus, impacting both muscular and cardiopulmonary systems (Buchheit and Laursen, 2013).

Although both SST and RST resulted in similar performance improvements, their structural differences likely engage distinct muscle activation patterns and metabolic demands. Shared training elements such as repeated high-intensity efforts, use of the stretch-shortening cycle, and neuromuscular requirements, may help explain overlapping outcomes. However, these findings also raise the possibility that comparable performance outcomes can arise from different underlying mechanisms, highlighting the complexity of training responses and the need for a deeper understanding of their underlying mechanisms (Gabbett and Oetter, 2025).

According to several authors (Bergeron et al., 2024; Lloyd et al., 2015, 2016), physical capacities develop in a non-linear fashion throughout growth and maturation, with marked improvements occurring around 13.6 ± 0.9 years in boys, typically corresponding with the PHV (Malina et al., 2024). Specific developmental stages (pre-PHV, circa-PHV and post-PHV) are considered key for developing explosive strength, aerobic fitness, speed and agility (Lloyd et al., 2015). For example, muscle strength development tends to accelerate post-PHV due to an increased muscle cross-sectional area, fiber type differentiation and higher levels of anabolic hormones such as growth hormone and testosterone (Lloyd and Oliver, 2019). However, neural factors, including inter- and intra-muscular coordination, are also crucial for muscle strength development, particularly in ages pre-PHV (Lloyd and Oliver, 2012, 2019). Despite the fact that in our study significant findings were observed based on chronological rather than biological age (PHV), U-13 players showed significant improvements in the CMJ following both SST and RST (Figure 3). This may be attributed to the neural specificity of SST and RST protocols, which appear to be particularly effective for younger athletes. Conversely, older athletes may require greater mechanical stress (e.g., progressive heavy resistance training) to achieve similar changes (Lloyd and Oliver, 2019).

In terms of aerobic fitness, although improvements generally manifest more robustly post-PHV (Lloyd et al., 2015), our findings suggest that both SST and RST can support aerobic development across various age groups. Trends in VO_{2max}, particularly among the U-13, U-16 and U-17 groups (Figure 3), suggest that even minimal training doses can potentially be beneficial across different age groups. This aligns with Mačinskas et al. (2023) who found enhanced aerobic fitness in basketball-trained boys, highlighting the role of sport-specific training in supporting aerobic fitness development regardless of the maturity level. However, further research is needed to confirm this trend and explore its implications more thoroughly. Speed and agility development is heavily influenced by the metabolic and physiological changes associated with the growth spurt, often leading to greater improvements post-PHV (Lloyd and Oliver, 2012). In the current study, speed improvements were more pronounced in the U-15 age-group, whereas agility improvements (assessed via the V-cut test) were notable in both the U-13 and U-16 age-groups. These findings suggest that a combination of age-appropriate metabolic challenges (i.e., progressing from the phosphagen metabolic pathway to anaerobic glycolysis) and neural stimulus (i.e., the RFD and the stretch-shortening cycle) along with

coordination-focused skills (i.e., acceleration-deceleration and changes of direction technique) may optimize agility development across different age-groups (Lloyd and Oliver, 2012). However, additional or alternative stimuli (e.g., running technique to mastery the running pattern) may be required to induce more significant speed adaptations in younger players (Arede et al., 2024; Barrera-Domínguez et al., 2024; Lloyd and Oliver, 2012).

Overall, the greater relative improvements observed in younger age groups align with the principles of the Long-Term Athletic Development (LTAD) framework (Lloyd et al., 2015). The neural-focused demands of SST and RST may have particularly matched the sensitive periods for neuromuscular development in younger athletes, enhancing their training responsiveness. These findings support the idea that time-efficient training doses like SST and RST could be particularly effective if aligned with the developmental characteristics of youth athletes.

Several limitations of this study should be acknowledged. First, the sample size was constrained, as only male players available at the club during the investigation were recruited. This small, single-gender sample limits the generalizability of the findings. Expanding the participants' pool including female athletes would provide a more comprehensive understanding of training doses and adaptations in youth basketball players. Second, due to sample size limitation and ethical reasons (as excluding a group from training was not feasible), we could not include a control group. Instead, baseline familiarization data from basketball-only training were used as a reference. While this approach has practical value in real-world setting, it may not completely isolate the intervention effects from those of regular training. Finally, the training methods were selected based on practical constraints and the specific context of the club. While the observed improvements highlight the short-term potential of low-frequency interventions, the long-term sustainability and scalability of such protocols under real-world limitations remain unclear. Future studies should compare these interventions with alternative training methodologies and examine the chronic effects over a longer period (beyond eight weeks) or with increased session frequency to determine optimal training protocols and effective strategies for periodization.

In conclusion, this study shows that integrating just one 30-min weekly session of either SST or RST into regular basketball practice can yield significant improvements in explosive strength, aerobic fitness, speed and agility in youth basketball players. While long-term conditioning programs remain essential for sustained athletic development, our findings indicate that even brief, targeted interventions, such as SST and RST, can elicit meaningful short-term performance improvements. This suggests that in settings with limited training time, incorporating structured, time-efficient conditioning is a valuable strategy for initiating performance gains without compromising the overall development plan.

Chronological age played a key role in the observed improvements, with younger age-groups (U-13) showing the greatest explosive strength gains (CMJ), while speed and agility gains were more distributed across different age-groups (U-15 for speed, U-13 and U-16 for agility). These differential performance outcomes underscore that even minimal, time-efficient training doses can be strategically adapted to support age- and development-specific needs.

Although these results are promising for short-term interpretation, it remains uncertain whether such low training frequency would sustain or enhance performance gains over longer periods. It is suggested that beyond an initial adaptation window, a higher frequency or increased stimulus variability may be necessary to support continued development. Understanding how these time-efficient protocols can be periodized, scaled or rotated over longer cycles could offer valuable solutions to optimize long-term athletic progression in youth athletes, particularly in youth settings where training time is limited.

Author contributions: Conceptualization: A.S., A.P.-P., J.C.-G. and V.L.-R.; methodology: A.S., A.P.-P., J.C.-G. and V.L.-R.; software: A.S.; validation: A.P.-P., J.C.-G., T.C. and V.L.-R.; formal analysis: A.S.; investigation: A.S.; resources: A.S., A.P.-P. and V.L.-R.; data curation: A.S.; writing—original draft preparation: A.S.; writing—review & editing: A.S., A.P.-P., J.C.-G., T.C. and V.L.-R.; supervision: A.P.-P.,

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J.C.-G., T.C. and V.L.-R.; project administration: A.P.-P., J.C.-G. and V.L.-R.; funding acquisition: A.P.-P. All authors have read and agreed to the published version of the manuscript.

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***Funding Information*:** This research was funded by Grant PID2021-124162OA-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by "ERDF A way of making Europe", by the European Union.

Institutional Review Board Statement: This study was conducted following the principles of the Declaration of Helsinki, and approved by the Research Ethics Committee of the Dr. Josep Trueta hospital in Girona, Girona, Spain (approval code: 2020.193; approval date: 01 December 2020).

Informed Consent: Informed consent was obtained from all participants included in the study.

Conflicts of Interest: The authors declare no conflict of interest.

***Acknowledgments*:** We would like to express our sincere gratitude to the basketball players and families of Basquet Girona for their participation in this project. We also extend our appreciation to the club and coaches for allowing us to integrate our interventions into their regular basketball schedule. Special thanks to Mr. Jesús Escosa, Technical Director of the Basquet Girona Club, for making this project possible and for his support in developing the idea.

Received: 07 March 2025

Accepted: 22 August 2025

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SUPPLEMENTARY MATERIAL

Supplementary Table 1. Intervention warm-up protocol.

Supplementary Table 2. Superset Training Part 1: from January 31st to February 25th. Incomplete recovery (5–10 s) between repetitions and full rest (30 s–1 min) between sets. All repetitions are performed at maximal speed. Number in brackets represents the level of effort. Example: 5 (14) is 5 reps with a weight the player could perform 14.

Supplementary Table 3. Superset Training Part 2: from February 28th to March 25th. Incomplete recovery (5–10 s) between repetitions and full rest (30 s–1 min) between sets. All repetitions are performed at maximal speed. Number in brackets represents the level of effort. Example: 5 (14) is 5 reps with a weight the player could perform 14.

Supplementary Table 4. Repeated Sprint Training Part 1: from January 31st to February 25th.

Supplementary Table 5. Repeated Sprint Training Part 2: from February 28th to March 25th.

Supplementary Figure 1. Δ change (%) with standard error of the differences post vs. pre for the CMJ (a), VO_{2max} (b), the 20-m sprint test (c), the T-test (d) and the V-cut test (e) based on biological age (PHV group).

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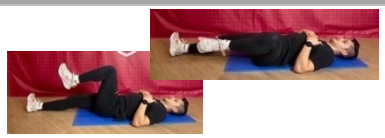
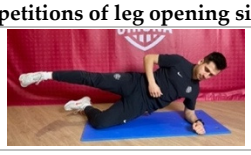
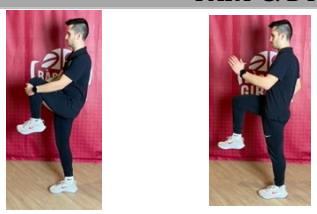
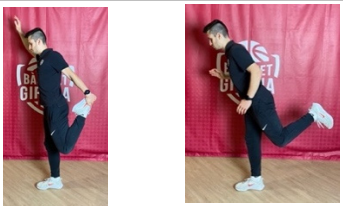
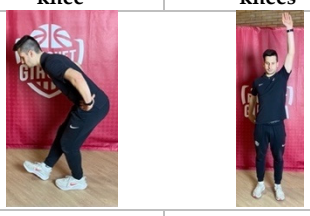
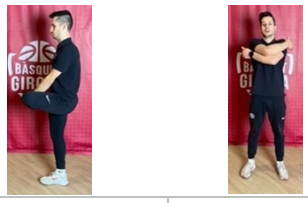
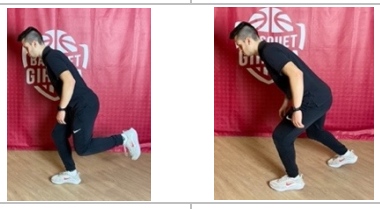
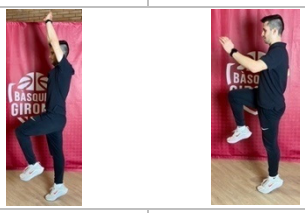
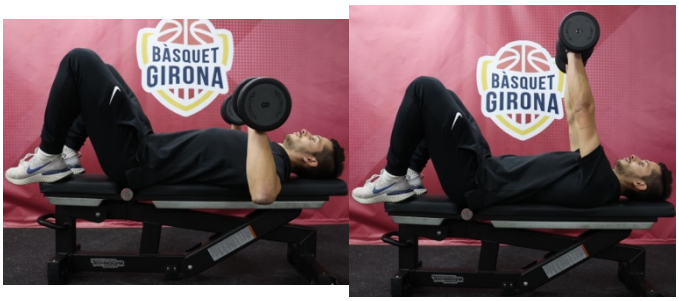
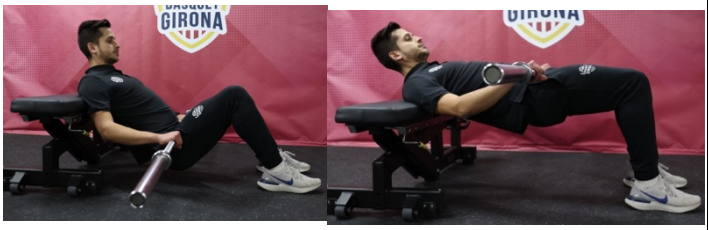
Supplementary Table 1. Intervention warm-up protocol.

PART A: FLOOR ACTIVATION		
		
10 leg extensions hamstring	**10 in/out leg catches and release**	**10 repetitions of leg opening side**
		
5+5 side to side Legs move back mobility	**10 each side Dead bug opposite leg-arm extension**	**10 each side Push knee against the ground glute/core activation**
10 push-ups	**10 dynamic pyramids**	**5+5 superman plank extension opposite leg-arm**
PART B: ACTIVATION IN A STANDING POSITION		
5 squat jumps	**5 back lunges (each leg)**	**5 repetitions of the deadlift (each leg)**
PART C: DYNAMIC STRETCHING (ONE EXERCISE EACH HALF COURT)		
		
Walking hold knee / **Running high knees**	**Walking quad stretch** / **Running But kicks**	**Walking Groin stretch** / **Running side to side defense**
		
Walking Hamstring push heel ground / **Arms up-down dynamic running**	**Walking glute hold leg up** / **Open-close arms dynamic running**	**Running one-leg landing** / **Running changing directions left to right**
		
Walking calf raises / **Running lay-up jumps**	**3-repetition sequence: jumping + landing + sprinting + back running to the start position**	

Supplementary Table 2. Superset Training Part 1: from January 31st to February 25th. Incomplete recovery (5–10 s) between repetitions and full rest (30 s–1 min) between sets. All repetitions are performed at maximal speed. The number in brackets represents the level of effort. Example: 5 (14) is 5 reps with a weight the player could perform 14.

Goal: Actions with a ball & passing	
Exercise 1	**Exercise 2**
Dumbbell chest press	Wall chest pas ball throw
	
3 x 5 (14) reps	5 reps
Goal: acceleration	
Exercise 1	**Exercise 2**
Bilateral hip thrust	Deadlift step on the bench with a dumbbell curl
	
3 x 5 (14) reps	3 x 5 (14) reps each leg
Goal: unilateral lay up	
Exercise 1	**Exercise 2**
Step up on the bench	Squat push one leg up + military press
3 x 5 (14) reps each leg	3 x 4 (12) reps 2 each leg

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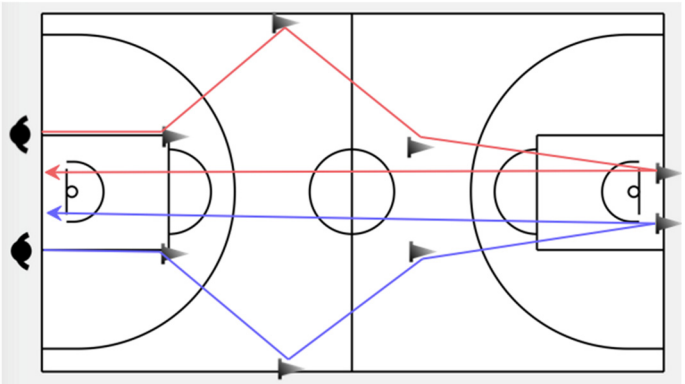
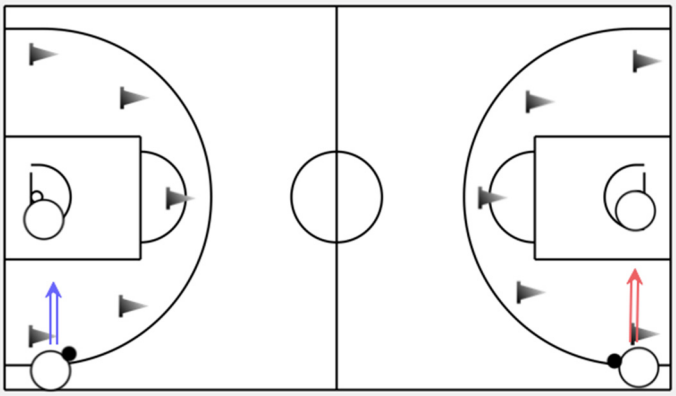
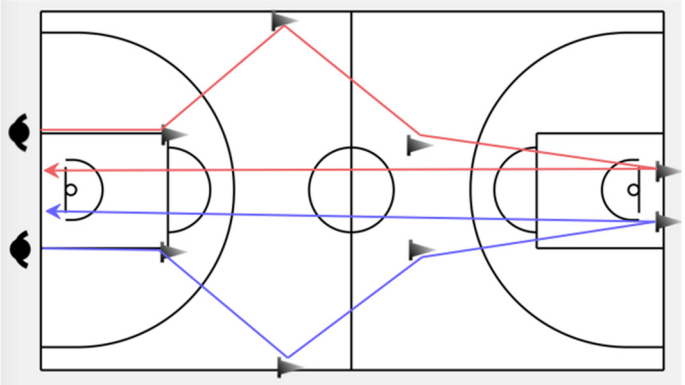
Supplementary Table 3. Superset Training Part 2: from February 28th to March 25th. Incomplete recovery (5–10 s) between repetitions and full rest (30 s–1 min) between sets. All repetitions are performed at maximal speed. The number in brackets represents the level of effort. Example: 5 (14) is 5 reps with a weight the player could perform 14.

Goal: fight pull	
Exercise 1	**Exercise 2**
One hand row dumbbell	Biceps dumbbell with a band around the hips + step back
3 x 6 (14) reps each arm	3 x 6 (14) reps 3 each leg
Goal: side acceleration	
Exercise 1	**Exercise 2**
Side lunge dumbbell	Side acceleration with a band around the hips + core ball rotation
3 x 5 (14) reps each leg	3 accelerations each side
Goal: bilateral jump	
Exercise 1	**Exercise 2**
Squat	Drop jump
3 x 5 (14) reps	3 drop jumps

Supplementary Table 4. Repeated Sprint Training Part 1: from January 31st to February 25th.

Six 10-s sprints with 20-s active recovery (walking to the starting position)

6-min active recovery (dynamic shooting in pairs: a shot, I take my own rebound and I pass to my teammate) from 5 positions (score 5 each position) + 2 free throws.

Six 10-s sprints with 20-s active recovery (walking to the starting position)


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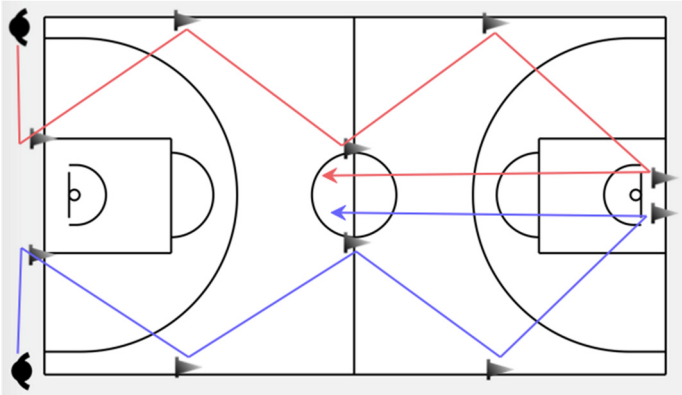
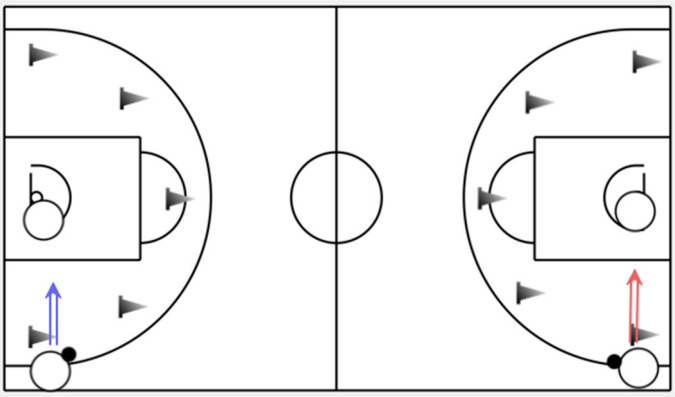
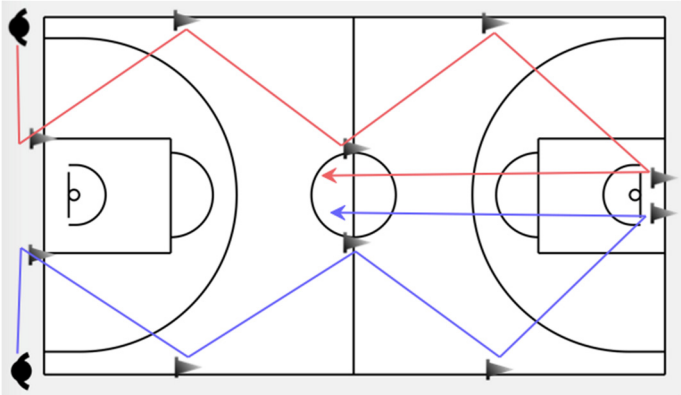
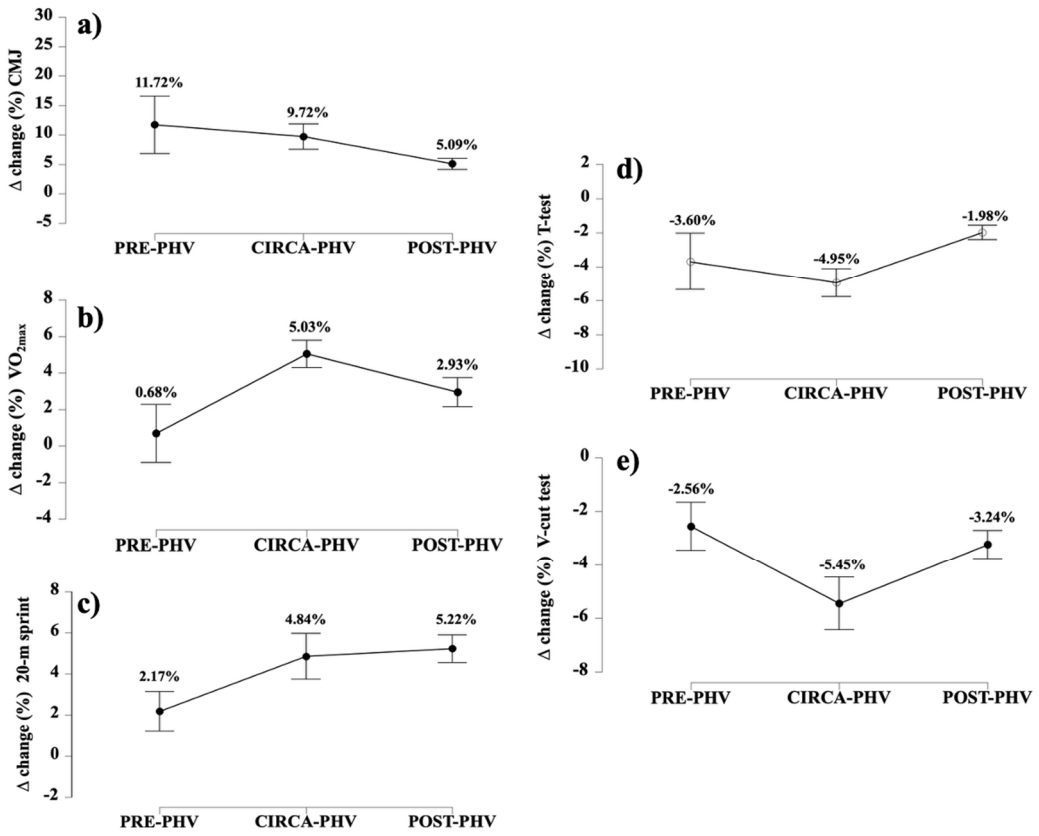
Supplementary Table 5. Repeated Sprint Training Part 2: from February 28th to March 25th.

Six 10-s sprints with 20-s active recovery (walking to the starting position)

6-min active recovery (dynamic shooting in pairs: a shot, I take my own rebound and I pass to my teammate) from 5 positions (score 5 each position) + 2 free throws.

Six 10-s sprints with 20-s active recovery (walking to the starting position)




Supplementary Figure 1. *Δ* change (%) with standard error of the differences post vs. pre for the CMJ (a), VO_{2max} (b) the 20-m sprint test (c), the T-test (d) and the V-cut test (e) based on biological age (PHV group).

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