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In-season autoregulation of one weekly strength training session maintains physical and external load match performance in professional male football players

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ABSTRACT

The aim of this study was to compare the effects of autoregulating strength training volume based on an objective (external load match performance) versus a subjective (self-selected) method in professional male football players. Sixteen players completed a 10-week strength training programme where the number of sets was regulated based on football match high-intensity running distance (HIR >19.8 km/h, AUTO, $n = 7$), or self-selected (SELF, $n = 9$). In addition to traditional physical performance assessments (30-m sprint, countermovement jump, leg-strength, and body composition), external load match performance was assessed with five matches in the beginning and in the end of the study period. Both groups performed ~ 1 weekly bout of ~ 6 sets in leg extensor exercises during the 10-week period, and maintained physical performance during the competitive season, with no group differences detected after the training period. Non-overlap of all pairs (NAP) analysis showed weak-to-moderate effects in external load match performance from before to after the study period, suggesting that players maintained or improved their performance. In conclusion, no group differences were observed, suggesting that both external load autoregulated and self-selected, low-volume in-season strength training maintained physical, and external load match performance in professional male football players.

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Resistance training; Athlete monitoring; GPS; Soccer

Introduction

Physical fitness is an important component of football performance and several studies have addressed the issue of optimizing strength training to prepare for match performance (Cross et al., 2019; Rønnestad et al., 2011; Styles et al., 2016; Suchomel et al., 2016). General recommendations for highly strength-trained athletes suggest performing strength training ≥ 2 times per week with a total of ~ 10–30 sets per muscle group, per week (Beato, Maroto-Izquierdo, et al., 2021; Schoenfeld et al., 2021). However, timing of in-season strength training is challenging, as professional teams often participate in numerous competitions, regularly playing several matches per week. With focus on adequate recovery, travel, and other match preparations, strength and conditioning coaches in team sports must compromise their strength training focus due to these time constraints (McQuilliam et al., 2022; Rønnestad et al., 2011; Silva et al., 2015). Thus, high strength training volumes are often not achievable or not prioritized during the competitive season. Intriguingly, as little as one strength training session per week during the competitive season has been reported to maintain initial pre-season gains in strength, jump and sprinting performance, compared to de-training effects observed without in-season strength training (Rønnestad et al., 2011; Silva et al., 2015). Contrastingly, a higher training volume should be prioritized if the overall aim is to improve physical performance (Beato, Maroto-Izquierdo, et al., 2021; Silva et al., 2015). Nevertheless, the aim of in-season strength training is often not to improve players physical capabilities, but rather to maintain strength and physical performance, in addition to reduce the risk of injury (Beato, Maroto-Izquierdo, et al., 2021; McQuilliam et al., 2022; Suchomel et al., 2016). Naturally, the effect of in-season strength training programming can therefore differ from strength training interventions that are performed during pre-season training periods (Silva et al., 2015). Thus, the inclusion of one session per week is often practiced during the competitive season (Beato, Maroto-Izquierdo, et al., 2021; Rønnestad et al., 2011; Silva et al., 2015).

Where team sport players previously were treated collectively, researchers and practitioners have acknowledged the need for individualization also within team sports (Boullosa et al., 2020). For example, differences in dose-response, fitness-level, recovery status, and so on, plays an important role for training prescription and programming (Boullosa et al., 2020; Ravé et al., 2020; Wing, 2018). Several methods have been applied to optimize individual training load adjustment, including autoregulation. Autoregulation refers to adjustment of training based on measurements of physical performance (objective autoregulation) or the athletes perceived capability to perform (subjective autoregulation) (Greig et al., 2020). Current practice of objective autoregulation methods in

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strength training seem to mainly focus on in-session measurements for adjustments in training intensity or volume (Zhang et al., 2021). For example, velocity-based autoregulation applies thresholds for velocity during each repetition (e.g., lifting within a certain velocity target or ending the set after a given velocity reduction between repetitions). Alternatively, subjective autoregulation can be applied by measures of rating of perceived exertion (RPE), reps in reserve (RIR), readiness scores or self-selection of training load and intensity, hereby adjusting for individual factors such as sleep, stress, fatigue etc (Greig et al., 2020; Lopes Dos Santos et al., 2020). In addition, alternative measures of readiness, such as pre-session assessment of neuromuscular fatigue or heart rate responses have also been applied to regulate training (Lacome et al., 2018; Silva et al., 2018).

As football players do most of their training on the field, with tracking systems widely applied as a player monitoring tool, it's interesting to note the limited research investigating the link between these external workload variables and individual adjustment of strength training intensity and volume. High intensity running (>19.8 km/h; HIR) and sprint running distances have become increasingly important in modern day football and are among the most applied performance measures from tracking systems when assessing both training and match performance (Akenhead & Nassis, 2016; Bush et al., 2015). Interestingly, a meaningful relationship is shown between HIR distance and post-match fatigue (Beattie et al., 2021), and a recent review has shown HIR distance to be associated with increased fatigue 24 hours post-match, with increased creatine kinase and lower countermovement (CMJ) peak power output (Hader et al., 2019). Furthermore, HIR distance exposure has been related to soft tissue injuries, while simultaneously being suggested as a tool in injury prevention strategies (Beato, Drust, et al., 2021). Despite these findings, the use of tracking systems as an objective marker in regulating strength training load seems unexplored. Hence, the aim of this study was to compare the effects of in-season strength training volume autoregulated based on football match HIR distance with self-selection of strength training volume, in professional male football players. Furthermore, in addition to typical pre-post assessments, we also included measures of external load match performance before and after the study period to explore possible changes in physical match performance following the strength intervention period. Based on the findings by Hader et al. (2019), we hypothesized that autoregulating strength training with an objective marker would induce superior changes in physical and external load performance compared to self-selection of strength training volume.

Methods

Design

This study was conducted over 15 weeks during the second half of the regular season (Figure 1). Within this period, the team performed a 10-week strength training intervention. During the intervention, players alternated training between a micro-dose strength training programme (grey strength icons) and a regular-dose programme (black strength icons). Physical performance (black arrows, 30-m sprint, CMJ and leg press strength and power) and body composition (blue arrows, via dual-energy X-ray absorptiometry: DXA) were tested pre- and post-intervention. During the study period, the team played 18 matches (football-icons), 5 matches at the beginning ("baseline") and 5 matches at the end of the study period ("follow-up"), were included to explore the effects in external load match performance after the study-period (green football icons).

Participants

A professional football club, playing in the Norwegian 2nd tier was invited to participate in the study. Initially, 30 out-field players were eligible for participation in the study. Nine players did not participate in pre-testing, due to injuries and not being a part of the senior team squad. Thus, 21 players were randomly assigned to an external load autoregulated group (AUTO-group, $n = 10$) or a subjectively regulated group (SELF-group, $n = 11$). During the intervention period, five players were injured and were unable to participate in the post tests (n = 3 AUTO, $n = 2$ SELF). Sixteen players between 16 and 30 years (AUTO [$n = 7$: 24.1 ± 4.7 yrs, 181.4 ± 5.1 cm, 76.6 ± 7.1 kg], SELF [$n = 9$: 23.7 ± 3.9 yrs, 185.0 ± 6.9 cm, 77.4 ± 8.4 kg]) consisting of 12 defensive players (AUTO: $n = 3$, SELF: $n = 6$), 5 midfielders (AUTO: $n = 3$, SELF: $n = 2$) and 2 attackers (AUTO: $n = 1$, SELF: n = 1) completed the intervention period and all pre- and post-laboratory measurements. Written informed consent was

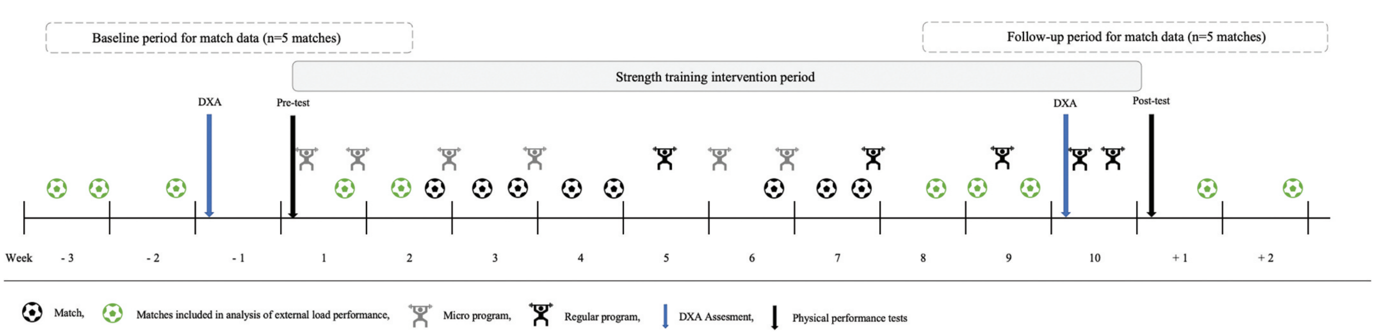

Figure 1. Overview of the intervention period. Football-icons: Matchday; Green football-icons: match data included in analysis of external load performance; Blue arrow: Dual X-ray absorptiometry (DXA) Body composition assessment; Black arrow: Physical performance tests; Strength icon: strength training session for both groups; Black strength training icon: AUTO-group performed the regular strength training program; Gray strength training icon: AUTO-group performed the micro strength training program.

obtained from all players before the study commenced. The study was performed according to the Helsinki declaration of 1975, approved by the local ethical committee at the University of Agder, Kristiansand, Norway, and Norwegian Center for Research Data (approval reference: 464080).

Experimental procedure

During the intervention period all players performed two different strength training programmes: *Regular* and *Micro*. Each program was designed to be feasible in-season sessions with exercises that players were well familiarized with prior to the present study. For the AUTO-group, the micro programme was applied in more congested periods (i.e., ~2 matches per week) while the regular programme was applied in normal weeks (e.g., ~1 match per week). SELF-group was able to self-select both programme and number of sets during the same sessions. Exercises included in the respective programmes are presented in Table 1. All players performed 1–3 sets per exercise of the regular programme, and 1–2 sets per exercise with the micro programme. The players performed one to two strength training sessions per week, with an aim of performing two sessions per week as often as the football training and match schedule allowed for. The head coach decided when strength training sessions could be implemented, and the training schedule was similar for both groups (Figure 1).

The regulation of training volume in the AUTO-group was based on HIR distance, and the SELF-group self-selected their number of sets based on a subjective feeling of readiness to train. For the AUTO-group, the calculation of a player's HIR distance was dependent on time between the strength training session and the last match, and match participation. Specifically, if a strength training session was performed <3 days after a match, and the player had ≥ 60 playing time, HIR distance from that specific match was used to calculated training volume. In all other circumstances, the accumulated HIR distance the previous 72 hours prior to the strength training session was applied to calculate the player's HIR distance.

The selection of HIR distance as a variable to regulate strength training volume was based on the findings from Hader et al. (2019), which demonstrated that HIR distance represented the most sensitive post-match monitoring variable associated with markers of neuromuscular fatigue across 165 semi-professional to elite level soccer players.

To calculate the specific thresholds applied in the AUTO-group of the present study, repository HIR distance data from the team's field activity (i.e., training and matches) during the ongoing season (243 data points) was applied. By design, we aimed to divide the players into three "groups", which regulated the players to low (1 set), moderate (2 sets) or high (2 sets in micro programme, 3 sets in regular programme) strength training volumes. Accordingly, an upper and lower HIR distance threshold of 687 m and 421 m, was calculated, which corresponds to the team's previous field activity HIR distance data's mean ±0.5 SD (554 ± 133 m). This distribution of our repository data in the present study and threshold categorization, was in our interpretation comparable to the distribution of the data across players in Hader et al. (2019). Thus, for the AUTO-group in the present study, the strength training volume was regulated to either 1, 2 or 3 sets (2 sets in the micro-programme), when the player had a HIR distance >687 m, between 421–687 m or <421 m, respectively.

Before every strength training session, the AUTO-group received information on which programme and specific number of sets to perform, according to the HIR criteria. The SELF-group performed training on the same days as the AUTO-group. The SELF-group were instructed to reflect on their subjective feeling and readiness to train and base selection of programme and set number on their subjective rating of readiness. For example, if they felt fresh and ready to train, they were encouraged to select a higher training volume. Thereafter, players selected the programme and number of sets accordingly. Typically, strength training sessions were conducted the day after a match and/or ~4 days prior to upcoming match-days (Figure 1). The SELF-group selected their desired programme and number of sets before initiating each training session, to ensure that they chose the self-selected appropriate training volume prior to exercising in the same environment as the AUTO-group. The same researcher supervised all training sessions for all athletes.

Testing procedure

Physical performance testing was completed over one test-day, pre- and post-intervention, whereas body composition was

Table 1. Strength training programmes during the intervention period.

Programme/Exercise	Sets	Reps	RIR	Rest	Comment
MICRO-DOSE					
A1 Back squats	1–2	6	1–2	2–3 min	Full range of motion
A2 Assisted band jumps		4			Bodyweight, pause 2 s at bottom
B1 Hip Thrust	1–2	6	1–2	2–3 min	Instructed to jump as high as possible
B2 Depth jump		4			
REGULAR-DOSE					
Back squats	1–3	6	1–2	2–3 min	Full range of motion
Hip Thrust	1–3	6	1–2	2–3 min	
Bulgarian split squat	1–3	6	1–2	2–3 min	Sets x reps per side
Seated calf raises	1–3	6	1–2	2–3 min	
Side-plank	1–3	8		2–3 min	Sideways w/knee kicks (8 knee kicks). Sets x reps/side. ~15 s per side.
Pallof-press	1–3	8		2–3 min	Standing in cable machine. Sets x reps/side. Hold ~3 s per side.

Exercises included in the specific programs. All participants performed the same programs. RIR: Reps in reserve. A1 and A2, or B1 and B2: superset between exercises, 1 and 2 were performed without a rest period.

completed on a separate test day, with no moderate to hard physical activity the previous 48 h prior to testing. The physical performance test-battery consisted of 10-min self-paced warm-up on a treadmill, 30-m linear sprint, CMJ, and Keiser leg press. All players were familiar to the test battery and had previous experience from similar test protocol movements. The test session duration was ~ 1 hour and all players performed the tests in the same order pre- and post-intervention between 08:00 and 15:00. Physical performance post-testing was completed 70.0 ± 0.0 days after pre-testing and at the same time of day (±1.0 hours). Body composition was assessed ±7.0 days in relation to physical performance testing, and post-assessments were completed 68.6 ± 3.8 days after the initial assessment and at the same time of day (±40 min) between 08.00 and 12.00.

Body composition (DXA)

Height was measured without shoes to the nearest 0.5 cm using a wall-mounted centimetre scale (Seca Optima, Seca, Birmingham, UK). Body mass was measured in underwear to the nearest 0.1 kg with an electronic scale (Seca 1, model 861, Birmingham, UK). Body composition was assessed using dual-energy X-ray absorptiometry (DXA) (GE-Lunar Prodigy, Madison, WI, USA, EnCore software version 15) and performed according to best practice recommendations, were the players arrived in a fasting state without any fluid intake on the morning of the scan (Nana et al., 2015). The same technician performed all scans on all players. This protocol is categorized with excellent reliability scores (CV < 0.8%) for both total body and regional (i.e., legs) body composition measures (Shiel et al., 2018).

30-m sprint

30-m Sprint test was performed on an indoor synthetic surface. Players performed 2–4 maximal sprints during the test with 4 min passive rest between each attempt. The timing started when the front foot left the ground at 0 cm and wireless dual-beam timing gates were used to measure time at each 5-m interval (Musclelab, Ergotest innovation AS, Langesund, Norway). The sensors at 5-, 10-, 15-, 20-, 25- and 30-m were placed 120 cm above the ground. The trial with the best 30-m time was included in post-test analysis and maximum speed was calculated from the 5-m split-times. TE of 0.03–0.05 s is reported for 10–30 m sprint times and 0.18 m/s for max speed (Lindberg et al., 2022).

Counter movement jump (CMJ)

CMJs were performed with hands on the hips, and the depth of the squatting motion was self-selected. The players completed 2–3 sets of 3 jumps performed 30 s apart, followed by 2–3 min passive rest. The CMJs were measured using an AMTI force plate sampling at 1000 Hz (Advanced Mechanical Technology, Inc Waltham Street, Watertown, USA) with custom-written MATLAB (The MathWorks, Natric, MA) script used to process the data. The mean jump height and power of the two single best attempts was included in post-test analysis. Jump height was calculated through the impulse – momentum theorem and registered with a minimum of 1 decimal (e.g., 0.1 cm). Power was calculated as time average (mean) instantaneous power (product of force and velocity) from the entire push-off phase for each respective jump, that is, from peak force, obtained at the deepest position, until take-off. The power was obtained as watts (Lindberg et al., 2021). A TE of 1.7 cm and 121 W is reported for CMJ height and power, respectively (Lindberg et al., 2022).

Keiser leg press

Lower limb strength and power was assessed using a Keiser AIR300 horizontal pneumatic leg press device with an A420 software (Keiser Sport health equipment INC., Fresno, CA, USA). Average force and velocity in each repetition were derived from the Keiser software with the manufacturer's standard "10-repetition force-velocity test" with incremental loads (Lindberg et al., 2021). The incremental test was performed in the seated position with a 90° knee-joint angle, starting at 41 kg and increasing to 250 kg at the tenth repetition with increased and standardized increments of approximately 20–30 kg for each attempt. If the participant exceeded 250 kg, the test continued with 60-s rest between attempts until failure. The rest period was 10–20 s for the initial 5 loads and 20–40 s for the last 4 loads. The players were encouraged to push as explosively as possible until failure. Keiser leg press does not cause ballistic action due to the pneumatic semi-isotonic resistance, and the entire push-off was performed with maximal intentional velocity. The leg press was performed as a concentric only action without countermovement, as the pedals are resting in a predetermined position prior to each repetition. A linear regression was fitted to the average force and velocity data to calculate individual force–velocity variables. Theoretical maximal force and theoretical maximal velocity were defined as the intercepts of the linear regression for the corresponding force and velocity axis. The theoretical maximum power was calculated as theoretical maximal force · theoretical maximal velocity/4 (Lindberg et al., 2021) and was retained for further analysis. Test-retest analysis of the Keiser leg press have revealed a CV of 4.2% for both Pmax and Fmax (Lindberg et al., 2021)

External load match data

HIR distance from training and external load match performance was assessed with a tracking system from Catapult Sports (Vector S7, Firmware 8.10, Catapult Sports, Melbourne, Australia). Catapult Vector uses the Doppler shift methods for GPS positional calculations, while inertial measurement analysis is performed based on Kalman filtering algorithms (Luteberget et al., 2017). Each player wore a tracking device, located between the scapulae in a custom vest supplied from the manufacturer. Data was collected via a 10 Hz global navigation satellite system and an inertial measurement unit including a three-dimensional accelerometer, magnetometer, and gyroscope sampling at 100 Hz. Devices were turned on ~15 min prior to training/matches, and all players used the same designated device throughout the study period. A total of 10 matches were included to explore the effect of external load match performance after the intervention period. Five matches played over 28 days at the beginning of the study period were used as a baseline reference for match performance (baseline-period), while the five last matches, played over 29 days, at the end of the intervention period were used to assess the effect of the intervention (follow-up-period). All included matches were played on an artificial grass surface with kick off between 15:00–20:00. To be included in the analysis of external load match performance, the players had to participate in a minimum of two matches with ≥60 min of playing time in both the baseline- and follow-up period. Eight ($n = 5$ AUTO, $n = 3$ SELF) of the 16 players completing the intervention period, fulfilled these inclusion criteria for external load match data. Average number of connected satellites and horizontal dilution of precision was 14.8 ± 1.7 and 0.9 ± 0.2 during the baseline period and 13.7 ± 1.1 and 1.0 ± 0.1 during the follow-up period, respectively.

Match data were extracted from the tracking devices post-match and edited in Catapult OpenField (Catapult Sports, Melbourne, Australia) software (version 1.17.2) to only include data from playing time in the match. Locomotive variables from the matches included distance per min, peak speed, HIR distance (19.8–25.2 km/h), sprint running distance (>25.2 km/h) and number of HIR and sprint efforts. PlayerLoad™, high intensity events, accelerations, decelerations and change of directions were applied as previously reported by Luteberget and Spencer (Luteberget & Spencer, 2017). Accelerations, decelerations and change of directions are a summary of identified movements in the respective direction with an intensity >2.5 m/s where the sum of accelerations, decelerations and change of directions is displayed as high intensity events. External load variables were re-calculated and expressed relative to player's playing time. All external load variables have shown acceptable reliability (Crang et al., 2022; Luteberget et al., 2017).

Factor influencing match performance

Level of the opposition and match score are factors that potentially can influence the team's performance (Bradley et al., 2013; Lago et al., 2010; Lago-Peñas, 2012; Moalla et al., 2018). To address these potential confounders, we used table ranking and final match score to classify match difficulty and match outcome. Final table ranking of the included season was used to classify match difficulty, where the match was ranked as hard, moderate, or easy when facing a top 6, middle 5 or bottom 5 team, respectively. Match score was classified as "win/loss" when there was a ≥ 2 goal difference, or even (draw/single goal difference), in the final score. The included team ended among the middle-ranked teams. The matches were classified as easy ($n = 1$) and hard ($n = 4$) in the baseline period, and easy ($n = 2$), moderate ($n = 1$) and hard ($n = 2$) in the follow-up period. Two matches, 1 in each period, were classified as "win", with the remaining 8 matches classified as "even".

Statistics

Descriptive results were calculated using Microsoft Excel (version 16.67, 255 Microsoft Corp. Redmond, WA, USA) and are reported as Mean ± SD. The main statistical analysis was conducted in Jeffreys's Amazing Statistics Programme (JASP) version 0.16.1. Differences between the AUTO- and SELF-group were assessed at pre-test and post-test using Mann–Whitney U test, while the within group differences in pre- to post-test changes were analysed using Wilcoxon signed-rank test. Between group differences from pre- to post-test was analysed with a Friedmans test.

Differences in external load match performance variables between the baseline and follow-up period were analysed using non-overlap of all pairs (NAP). NAP is a nonparametric technique for measuring nonoverlap or "dominance" for two phases. It does not include data trend. NAP is appropriate for nearly all data types and distributions, including dichotomous data. NAP has good power efficiency, approximately 91–94% that of linear regression for "conforming" data, and greater than 100% for highly skewed, multi-modal data. NAP is equal to the empirical AUC (Area Under the Curve) from a ROC test. Strengths of NAP are its simplicity, its reflection of visual nonoverlap, and its statistical power. In many cases it is a better solution than tests of Mean or even Median differences across phases (Parker & Vannest, 2009). Effect sizes for NAP values are reported according to Parker and Vannest's recommendations: 0–.65 = week effects, .66–.92 = moderate effects, .93–1.0 = large or strong effects (Parker & Vannest, 2009).

Results

The AUTO-group ($n = 7$) completed 1.1 ± 0.1 strength training sessions per week, while the SELF-group ($n = 9$) completed 1.0 ± 0.1 strength training sessions per week. On average, the AUTO-group and SELF-group completed 5.8 ± 1.2 and 6.4 ± 1.4 sets in leg extensor exercises (hip, knee, and ankle extensors) per strength training session, respectively.

Mean number of strength training sessions in total across 10 weeks were 10.6 ± 0.8 (Regular 5.0 ± 0.0, Micro 5.6 ± 0.8) for AUTO-group and 10.6 ± 1.0 (Regular 5.3 ± 1.1, Micro 5.2 ± 1.6) for the SELF-group. Mean number of sets in leg extensor (ankle, knee and hip) exercises per session were similar between the groups for both the regular (AUTO: 8.2 ± 1.8, SELF: 8.9 ± 2.0) and micro programme (AUTO: 3.6 ± 0.4, SELF: 3.8 ± 0.4). Mann-Whitney U test confirmed that there were no group differences in training volume (number of strength-training sessions, sessions with the regular and micro programme, or number of sets completed) between the groups. The AUTO-group was regulated based on their HIR distance and an overview of sessions regulated (regular/micro) to high (3/2) moderate (2/2) or low (1/1) volume strength training can be found in Table 2.

A calculation of HIR-distance was additionally performed for the SELF-group to explore if HIR-distance was associated with their subjective regulation of strength training volume. On average, 4.7 ± 1.3 of the SELF-group's strength sessions across the 10-week intervention were self-selected in accordance with the AUTO-group's criteria, while 5.9 ± 1.6 was not.

The pre- and post-test results are presented in Table 3 with percent change in physical performance from pre- to post-test presented in Figure 2. No differences in physical and body composition measures were found between the groups at pre- or post-test. When comparing post- to pre-test measures, no significant differences was evident in the physical performance measures for the respective groups, or when analysing all players as one group. For body

Table 2. Autoregulated strength training sessions for the AUTO-group (*n* = 7).

	High volume training (HIR: <421)		Moderate volume training (HIR: 421–687)		Low volume training (HIR: >687)	
	Total	Mean ± SD	Total	Mean ± SD	Total	Mean ± SD
Strength sessions (n)	27	3.9 ± 1.9	29	4.1 ± 1.2	18	2.5 ± 2.8
Regular (n)	12	1.7 ± 0.8	13	1.9 ± 0.9	10	1.4 ± 1.5
Micro (n)	15	2.1 ± 1.2	16	2.3 ± 1.0	8	1.1 ± 1.4

Number of strength training sessions/programs in total across all AUTO-group participants, and that was regulated to a high, moderate or low training volume.

Table 3. Physical performance and body composition at pre- and post-test.

	Pre-test			Post-test			Change from pre- to post-test		
Test variable	SELF (*n*=9)	AUTO (*n*=7)	Combined (*n*=16)	SELF (*n*=9)	AUTO (*n*=7)	Combined (*n*=16)	SELF (*n*=9)	AUTO (*n*=7)	Combined (*n*=16)
Physical performance tests									
10 m (s)	1.53 ± 0.07	1.52 ± 0.05	1.52 ± 0.06	1.52 ± 0.06	1.49 ± 0.03	1.51 ± 0.05	−0.01 ± 0.04	−0.02 ± 0.05	−0.02 ± 0.04
30 m (s)	3.95 ± 0.17	3.91 ± 0.11	3.93 ± 0.14	3.92 ± 0.16	3.88 ± 0.10	3.90 ± 0.13	−0.03 ± 0.08	−0.03 ± 0.08	−0.03 ± 0.08
30 m max speed (m/s)	8.75 ± 0.43	8.88 ± 0.32	8.81 ± 0.38	8.78 ± 0.42	9.06 ± 0.38	8.89 ± 0.42	−0.03 ± 0.18	0.17 ± 0.18	0.08 ± 0.19
CMJ (cm)	39.3 ± 6.2	42.3 ± 3.6	40.6 ± 5.3	40.9 ± 7.1	43.5 ± 6.1	42.0 ± 6.6	1.7 ± 3.6	1.19 ± 3.94	1.46 ± 3.64
Relative CMJ power (W/kg)	31.8 ± 3.7	32.8 ± 4.1	32.2 ± 3.8	31.6 ± 3.7	32.0 ± 3.9	31.8 ± 3.7	0.2 ± 2.3	−0.8 ± 1.8	−0.5 ± 1.8
Leg press Pmax (W)	1487 ± 309	1667 ± 405	1566 ± 353	1488 ± 362	1650 ± 431	1559 ± 388	1 ± 193	−17 ± 113	−7 ± 158
Relative leg press Pmax (W/kg)	19.2 ± 2.7	21.5 ± 4.2	20.2 ± 3.5	19.3 ± 4.0	21.2 ± 4.5	20.1 ± 4.2	0.2 ± 2.3	−0.3 ± 1.2	0.0 ± 1.9
Leg press Fmax (N)	2794 ± 377	3071 ± 640	2915 ± 509	2898 ± 368	3037 ± 647	2959 ± 494	104 ± 146	−34 ± 302	44 ± 230
Relative leg press Fmax (N/kg)	36.2 ± 3.8	40.0 ± 7.4	37.8 ± 5.8	37.8 ± 3.7	39.3 ± 6.9	38.4 ± 5.2	1.6 ± 2.3	−0.6 ± 4.0	0.6 ± 3.2
Body composition assessment									
Body mass (kg)	77.4 ± 8.4	76.6 ± 7.1	77.0 ± 7.6	76.9 ± 7.9	76.9 ± 6.1	76.9 ± 6.9	−0.5 ± 1.7	0.3 ± 1.8	−0.2 ± 1.7
Total Lean mass (kg)	65.9 ± 5.9	66.5 ± 6.9	66.2 ± 6.1	65.4 ± 5.7	66.9 ± 6.5	66.1 ± 5.9	−0.5 ± 1.6	0.4 ± 1.2	−0.1 ± 1.4
Total Fat mass (kg)	8.6 ± 3.9	7.4 ± 1.7	8.1 ± 3.1	8.5 ± 2.9	7.4 ± 1.7	8.0 ± 2.5	−0.1 ± 1.5	0.0 ± 0.8	−0.1 ± 1.2
Total fat (%)	11 ± 3	10 ± 2	11 ± 4	11 ± 3	10 ± 3	11 ± 3	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.1
Legs total mass (kg)	27.3 ± 3.5	27.7 ± 2.4	27.4 ± 3.0	27.4 ± 3.4	28.1 ± 2.4*#	27.7 ± 2.9*	0.1 ± 0.7	0.4 ± 0.4*#	0.3 ± 0.6*
Legs lean mass (kg)	22.4 ± 2.4	23.2 ± 2.3	22.8 ± 2.3	22.6 ± 2.3	23.6 ± 2.2*#	23.0 ± 2.3*	0.1 ± 0.7	0.4 ± 0.3*#	0.2 ± 0.6*
Legs fat mass (kg)	3.3 ± 1.5	2.9 ± 0.7	3.1 ± 1.2	3.3 ± 1.1	2.9 ± 0.9	3.1 ± 1.0	0.0 ± 0.6	0.0 ± 0.3	0.0 ± 0.5
Legs fat (%)	12 ± 4	11 ± 3	12 ± 4	12 ± 3	11 ± 3	12 ± 3	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.1

*Different from pre-test (*p* = <0.05). # between group difference from pre- to post-test (*p* = <0.05). CMJ: Countermovement jump, Pmax: maximum power (W and W/kg total body mass) extrapolated from Keiser leg press power profile, Fmax: maximum force (N and N/kg total body mass) extrapolated from Keiser leg press power profile, Body composition assessment from dual-energy X-ray absorptiometry, %: percentage. Note: negative change in 10 and 30 m time indicate improved performance.

composition, a statistically higher leg mass and legs lean mass was shown at post- compared to pre-test, for the AUTO-group (z = −2.197, p = 0.031 and z= −2.197, p = 0.034) and when analysing all players as one group (z = −2.094, p = 0.039 and z= −2.275, p = 0.024). Comparingly, a between group difference was observed from pre- to post-test in leg mass (x^2 = 4.000, df = 1, p = 0.046) and legs lean mass (x^2 = 4.000, df = 1, p = 0.046).

Match data

With no differences between the AUTO- and SELF-group in physical performance after the intervention period, the influence on match data was assessed by merging the eight players that met the inclusion criteria for external load match data in to one group. Players appeared in 4.1 ± 1.1 matches (33 observations) with 89.2 ± 12.9 min playing time in the baseline period and in 4.5 ± 0.8 matches (36 observations) with 91.9 ± 7.4 min playing time in the follow-up period. External load match performance variables from the respective periods and NAP results are presented in Table 4. Overall, a moderate effect (NAP 0.66–0.92) was found for six of the included variables, while a weak effect (NAP 0–0.65) was found for the remaining five variables.

Discussion

The aim of this study was to assess the difference between objectively regulating strength training volume based on football match external load, compared to a subjective regulation method allowing the players to self-select their training volume. A novelty was to include and explore the change in external load match performance after an intervention period. Contrary to our hypothesis, our main finding was that there were no meaningful group differences in physical performance, or body composition after the intervention period. NAP analysis of external load match performance showed week to moderate effects, however, with the difference from the baseline to the follow-up period being lower than typical match-to-match variabilities suggesting that self-selection of strength training volume may be as effective as objectively regulating professional football players in-season training volume.

We did not observe any difference between the AUTO- and SELF-group in physical performance or body composition after the intervention period. However, compared to pre-test, assessment of body composition showed a 0.2–0.4 kg higher leg mass and legs lean mass for the AUTO-group and when assessing both groups together. This was however, the only significant differences observed, and with a SD of 2–3 kg among participants, the practical effect of this significant change should not be exaggerated. The lack of observed difference between the

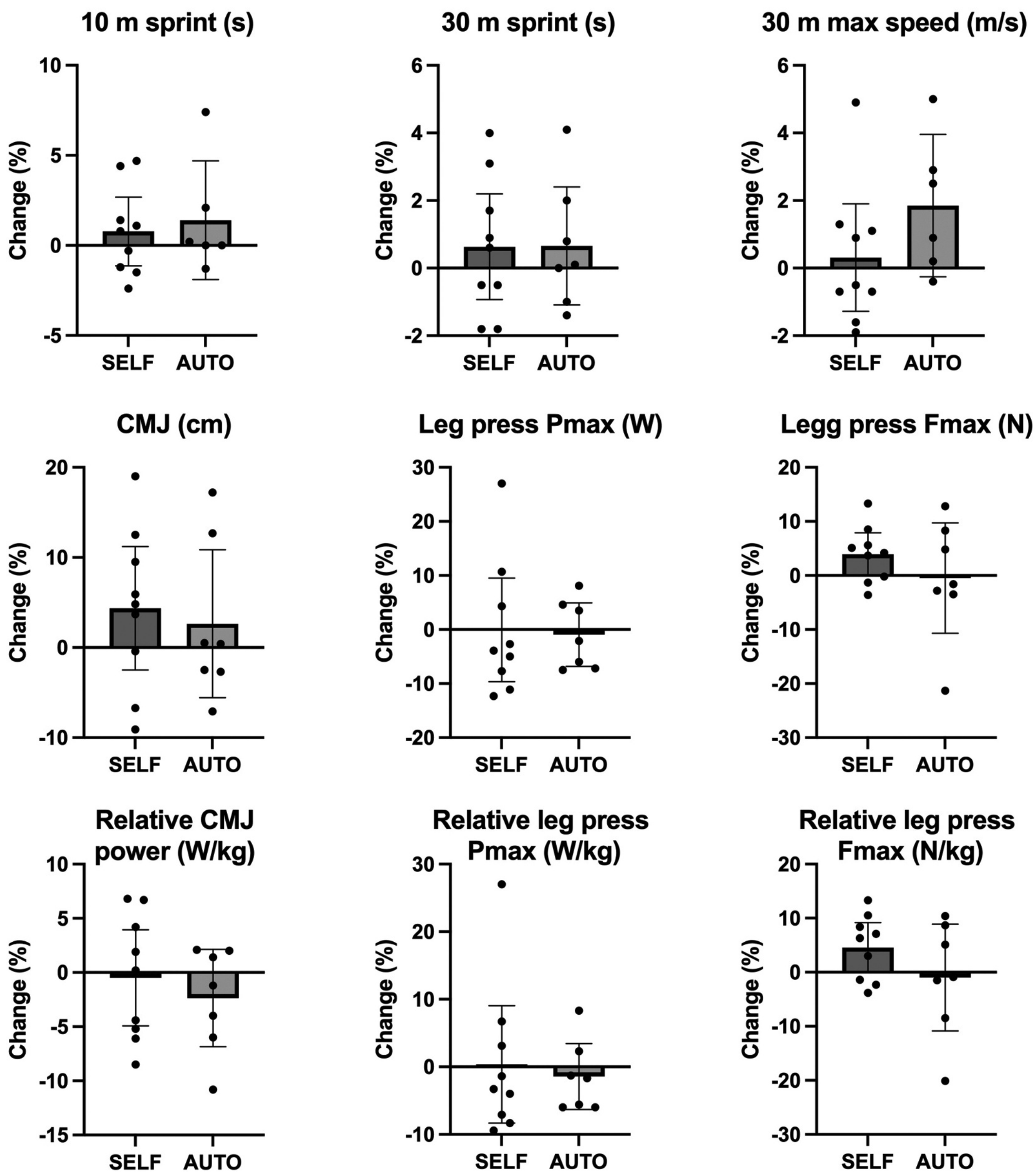

Figure 2. Mean ±95% CI % change in physical performance tests, including individual changes from pre- to post test. 10 and 30 m; Time to 10 m and 30 m during sprint tests, Max Speed: Maximum speed (m/s) during 30-m sprint testing, CMJ: Countermovement jump, Pmax: maximum power (W and W/kg total body mass) extrapolated from Keiser leg press power profile, Fmax: maximum force (N and N/kg total body mass) extrapolated from Keiser leg press power profile.
Note: positive change in 10- and 30-m time indicates improvement from pre- to post test.

Table 4. External load match performance variables during baseline and follow-up period.

Variable	Baseline period	Follow-up period	NAP (90% CI)
Distance per min (m/min)	116.6 ± 12.1	119.3 ± 9.5	.67 (.43–.92)
Peak Speed (m/s)	8.18 ± .47	8.43 ± .46	.65 (.41–.90)
PlayerLoad™ per min (au/min)	11.79 ± 1.59	11.87 ± 1.25	.60 (.35–.85)
HIR distance (19.8–25.2 km/h) (m/min)	6.43 ± 2.58	7.31 ± 1.71	.71(.47–.96)
Sprint distance (>25.2 km/h) (m/min)	1.37 ± .93	1.78 ± .89	.72 (.48–.97)
Efforts HIR (19.8–25.2 km/h) (#/min)	.43 ± .16	.48 ± .12	.67 (.43–.92)
Efforts Sprint (>25.2 km/h) (#/min)	.07 ± .05	.09 ± .05	.76 (.51–1.00)
High intensity events (>2.5 m/s) (#/min)	1.22 ± .26	1.34 ± .24	.65 (.41–.90)
Accelerations (>2.5 m/s) (#/min)	.27 ± .08	.31 ± .24	.74 (.50–.90)
Decelerations (>2.5 m/s) (#/min)	.26 ± .08	.25 ± .09	.41 (.16–.65)
Change of directions (>2.5 m/s) (#/min)	.69 ± .18	.78 ± .17	.64 (.40–.89)

All values except Peak speed are relative to playing time (i.e., per min). Au; arbitrary units, #; number. HIR; High intensity running.

groups is likely explained by the low training volume and similarities in the undertaken strength training. In accordance with general recommendations suggested to improve physical performance, we aimed for two strength training sessions per week (Beato, Maroto-Izquierdo, et al., 2021; McQuilliam et al., 2022; Schoenfeld et al., 2021). However, due to the real-world challenges with timing of in-season strength training previously reported (McQuilliam et al., 2022; Rønnestad et al., 2011; João R.; Silva et al., 2015), the present study ended up with ~ 1 session per week. Therefore, the overall volume of training being regulated is low and such low volumes may be well within the recoverable load for most players. Hence, autoregulating strength training load in-season may not be needed with such low training volumes. A potential reason for the lack of difference in strength training volume between the AUTO- and SELF-group could be that the SELF-group was also utilizing undertaken HIR distance when selecting training volume. However, when comparing the HIR distance and undertaken training volume for the players in the SELF-group, our results show otherwise. We hypothesize that autoregulation methods can be more important with a larger number of sessions or training weeks that also could differentiate the overall volume of undertaken training between the groups. Potential differences following an intervention period with higher strength training volumes should be assessed by future studies.

Although previous studies mainly included in-session objective markers during strength training to regulate training load (Zhang et al., 2021), we applied an objective football-related field measure shown to be associated with fatigue (Hader et al., 2019) and compared this to a subjective regulation method. While the SELF-group was instructed to reflect on subjective feeling and readiness, we did observe tendencies suggesting that some players were more likely to consistently select a high or low strength training volume. Personal preferences, with some players keener of strength training, and other players potentially favouring other aspects of their strength and conditioning training (therefore selecting a low volume), may explain this observation. Contrastingly, the application of HIR distance for the AUTO-group is unaffected by players personal preferences when prescribing training volume. Following this augment, applying a subjective regulation in periods with higher training volume could result in larger individual differences and potential de-training effects due to a low stimulus for some players. On the other hand, the individual aspect is important, and an objective marker might not be sensitive enough to capture every aspect of a player's ability to perform. Therefore, a combination of objective and subjective regulations might be preferable (Greig et al., 2020; Zhang et al., 2021).

Our findings align with the previous findings indicating a maintained physical performance with ~ 1 strength training session per week (Beato, Maroto-Izquierdo, et al., 2021; Rønnestad et al., 2011; Silva et al., 2015). However, "one session" can be imprecise, as the total volume (e.g., number of sets per muscle) of undertaken training differ between studies. For example, the players in the current study performed ~ 6 sets of leg extensor exercises per session, while Rønnestad et al. (2011) performed 3 sets per session. Nonetheless, 3 and 6 sets are lower than the typical recommendations for strength trained athletes of ~ 10–30 sets per muscle group, per week (Beato, Maroto-Izquierdo, et al., 2021; Schoenfeld et al., 2021). While strength and conditioning coaches report that they prescribe of ≥ 2 sessions per week (McQuilliam et al., 2022), adherence is typically lower. For example, professional players were reported to have 1.5 ± 0.9 strength training sessions per micro cycle (time between matches) (Cross et al., 2019). However, they were only asked to report from 7-day turnaround cycles without any substantial travel. In real-world conditions, involving the complexity of congested match schedules, travels, national team appearances, change of coach, training philosophy, match importance/preparations, and so on (Malone et al., 2019; McQuilliam et al., 2022; Rønnestad et al., 2011), up to 10 sets/~1 session per week seems to represent the real-world practice when timing strength training sessions during the competitive period (João R. Silva et al., 2015).

When performing training interventions, there is an underlying assumption that a change in physical performance relates to the players performance in training and matches. However, training intervention studies have typically been isolated to laboratory-testing, and potential performance-enhancing effects are simply assessed by evaluating the pre-post changes, with some studies also including a follow-up test to identify longitudinal effects after the intervention (Iaia et al., 2015; Rønnestad et al., 2011). Therefore, a secondary aim for this study was to address external load match performance at the same timepoints as the physical performance tests. Additionally, we intended to assess the relationship between changes in physical- and external load performance. However, with few players fulfilling the inclusion criteria for match data, and limited changes due to the overall low training volume, we were unable to explore this aim. Nevertheless, we included a baseline and follow-up period and used NAP analysis to assess changes in external load match performance between the periods. While 33 and 36 match observations from baseline and follow-up period were included in NAP analysis, the data is only a representation from 8 of 16 players fulfilling the strength intervention. Nonetheless, and unlike traditional approaches, NAP analysis allows every observation at both periods to be assessed for each individual player before combining all players and display an overall "effect" from the baseline to the follow-up period. While a weak to moderate effect is shown in these external load variables, it is important to notice the actual difference in external load output during each period, and the practical importance. For example, sprint distance has a moderate effect (NAP = 0.72) and increases from 1.37 m/min to 1.78 m/min between the baseline to the follow-up period. With ~90 min playing time, this difference equals ~40 m. This is less than a half football field, and importantly lower than the match-to-match variations for sprint distance (Carling et al., 2016; Gregson et al., 2010). Additionally, this was an in-season study including 1–2 weekly matches and focus on football field training, all contributing to stimuli relevant for external load match performance. Thus, our findings should not be interpreted as an effect per se, but rather be interpreted together with the physical performance results following the intervention period, supporting the evidence for a maintained physical- and external load match performance following a strength intervention period with ~ 1 low volume strength training session per week.

While we highlight the scarcity of in-season intervention studies, we acknowledge that there are several limitations to our design. Performing in-season studies involving professional players limits the experimental control over the design and researchers influence. For example, the number of strength training sessions was influenced by the philosophy of the head coach and match importance, resulting in increased focus on field training with technical and tactical focus in this specific period. Furthermore, the inclusion of a control-group is unrealistic when working with this population. Therefore, the effects of performing 1 vs 2 strength training sessions per week or simply performing football specific field training in our participants are unknown. While we randomly assigned players to the AUTO- or SELF-group, there is a possibility that the selection of such small groups might influence the results as individuals may respond differently to specific autoregulation methods. Furthermore, the AUTO- and SELF-group performed strength training in the same facility and at the same time, which could have influenced the self-selection of training volume in the SELF-group. However, the SELF-group always selected their training volume before either group initiated training sessions to minimize the likelihood of such an interaction between groups. In addition, the players were used to having individualized strength training prescriptions provided by the coaching staff, and therefore did not place focus on what training other players performed. Nevertheless, the SELF-group was dependent on the players being honest with themselves and actively reflecting on their readiness before selecting training volume. Thus, a player could repeatedly select a low volume if they desired. We could have implemented a RPE or wellness scale in an attempt to control this regulation. However, both scale-measurements and the applied regulation of the SELF-group is dependent on factors such as standardizations (e.g., when and how is data collected) and athlete buy-in for the implementation to work as intended (Abbott & Taber, 2021). While we emphasize the possibility for the players to "cheat", these are professional players always competing for a spot among the 11 players starting a match, and are likely aware that an insufficient training volume can lead to detraining. Thus, autoregulating training volume based on self-selection represents a real-world practical example, allowing the players to self-regulate themselves to be optimally prepared for match performance.

The effects of a subjective vs an objective autoregulation method should however also be assessed in periods with higher training volume before concluding. The AUTO-group in the present study was regulated on an objective marker by the application of HIR distance that is previously shown to be closely associated with markers of neuromuscular fatigue across 165 soccer players with different positional demands (Hader et al., 2019). In addition, the chosen thresholds in the present study represents a three-way division of HIR distance from a similar HIR distribution across players as the athletes in Hader et al. (2019). However, we acknowledge that such collective calculation of the thresholds across athletes to regulate training volume has its limitations. Match HIR distance is subject to the influence of positional demands (Buchheit et al., 2020) and thereby variations in HIR distance loads, which, in turn, can affect the optimal prescription of strength training volume. Unfortunately, we were unable to address position-specific differences due to the small sample size. Therefore, we recommend that future research explores individual regulations based on personalized reference points, as opposed to the utilization of absolute values as observed in the present study. Furthermore, HIR distance is only one external load measure as highlighted by Hader et al. (2019). Additionally, external load is only one aspect of player monitoring and further studies should aim to explore other external load measures as well as the inclusion of internal load measures to objectively regulate strength training. In addition, it could be speculated that external on-field load measures such as HIR distance better reflect a combination of the most relevant load and associated fatigue than typical pre-session assessment of neuromuscular fatigue measures (Boullosa et al., 2020). However, typical readiness variables such as CMJ or a combination of such off-field measurements could potentially be better markers of overall fatigue and readiness. Finally, we aimed to explore the relationships between changes in physical and external load performance following an intervention period. This is however challenging during an in-season phase with limited control and a number of contextual factors influencing the variability of match performance. We do however believe that external load measures in addition to traditional physical performance assessments after periods of intensified training (e.g., intervention periods, pre-season, etc.) can provide valuable information. However, it is important to ensure accuracy and standardization of the measurements. As such, standardized small-sided games can serve as a measure in this regard and we encourage future studies to explore the inclusion of external load during such conditions. In summary, our findings with weak to moderate effects in external load match performance is to be expected. Thus, the relationship between a change in physical performance and how this relates to external load performance remains to be determined.

Conclusion

Our findings demonstrated that objective autoregulation of strength training volume based on football match HIR distance did not differentiate from allowing players to self-regulate based on their subjective readiness to train during a 10-week intervention period. This is likely explained by a low, and similar volume in the strength training undertaken. Furthermore, no meaningful change was observed in external load match performance. Future studies are however, needed to assess the difference in these two autoregulation methods during periods with higher strength training volumes. To conclude, this study demonstrates that an in-season strength training regime, applying either an objective or subjective autoregulation method with ~ 6 sets of leg extensor exercises, performed once a week, can maintain professional football players physical- and external load match performance during a competitive period.

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Data availability statement

Data that supports the findings of this study are available from the corresponding author (Byrkjedal, PT.), upon reasonable request.

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