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The effect of a weekly flywheel resistance training session on elite U-16 soccer players' physical performance during the competitive season. A randomized controlled trial

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Short title: flywheel resistance training in youth footballers

Abstract

This study investigated the effects of a weekly flywheel resistance training session over a 10-week period during the competitive season on U16 soccer players' physical performance with special attention to change of direction ability (e.g. deficit [COD_{def}]). Twenty elite young soccer players were recruited and assigned to an experimental (EG, n = 10) or control (CG, n = 10) group in this randomized controlled trial. Unilateral countermovement jumps with dominant (CMJ_d) and non-dominant (CMJ_{nd}) leg, 10, 20, and 30-m linear sprint test and change of direction sprint test in 5+5 (COD10) and 10 + 10 m (COD20) were performed before and after 10-week flywheel training period. Significant within-group differences were found in CG in COD10 (p=0.01; effect size [ES]=large) and COD_{def}10 (p=0.03; ES=small) with dominant leg, while differences in EG were observed in CMJ (p=0.001-0.01; ES=moderate-large) and in all COD and COD_{def} variables (p=0.001-0.04; ES=large). However, neither group reported significant variation in the linear sprint test (p>0.05; ES=trivial-moderate). Between-groups analysis revealed differences in favour of the EG in CMJ (p=0.03-0.05) and COD and COD_{def} variables (p=0.001-0.05). These findings suggest a weekly flywheel training session is suitable for improving jumping and COD abilities in U16 elite soccer players in season.

Keywords: football, eccentric, fitness, team sport, non-linear sprint

Introduction

Soccer is a highly demanding team-sport in which players are required to perform a great number of accelerations, decelerations and changes of direction (COD), as well as quick and decisive jumps and sprints (Ade, Fitzpatrick, & Bradley, 2016). These high-intensity actions occur mainly during decisive moments of match-play (Faude, Koch, & Meyer, 2012), for instance the actions preceding goals. Additionally, considering the multidirectional nature of soccer, players must be prepared not only to sprint over linear courses, but also to perform rapid COD (Chaouachi et al., 2012), mainly attending to external stimuli (e.g., ball trajectory, opponents' and teammates' movements) (Born, Zinner, Düking, & Sperlich, 2016). Time-motion analysis has revealed that soccer players perform ~100 turns of 90–180° during games (Bloomfield, Polman, & O'Donoghue, 2007) – therefore, players must be highly prepared to perform such a high neuromuscular demand consistently and effectively. One of the main goals of strength and conditioning specialists is to enhance the sport-specific physical abilities of their players in order to allow them to better cope with on-field performance demands (Ade et al., 2016).

The COD deficit (COD_{def}) has emerged as a suitable approach to comprehensively assess the efficiency of a COD maneuver (Loturco et al., 2018). COD_{def} refers to the additional time that a COD requires when compared to a linear straight sprint test over the same distance (Nimphius, Callaghan, Spiteri, & Lockie, 2016), and it has been proposed as a practical tool to better isolate and identify the player's ability to perform COD without being influenced by player's acceleration and linear speed qualities (Loturco et al., 2018). In this regard, studies have only evaluated the influence of the initial level of physical condition (acceleration or sprint) or the effects of playing position on COD_{def} (Freitas et al., 2019; Loturco et al., 2019). According to the present information, faster and more powerful athletes are less efficient when changing direction, presenting a greater COD_{def} (Loturco et al., 2018). However, the current literature is very limited on this specific argument, because previous studies have used only cross-sectional designs, while no studies have implemented longitudinal training programs to improve COD_{def}. Since soccer players must perform rapid and forceful movements to cope with match performance demands and to create an advantage over opponents (Taber, Bellon, Abbott, & Bingham, 2016), it is necessary to understand which training methods are the most effective for optimizing players' COD ability across all age-categories.

It is well established that resistance programs which incorporates flywheel exercises are one of the most effective methods for improving sport-specific performance in sporting populations (Madruga-parera et al., 2020). In this regard, flywheel devices have gained a lot of popularity because of their ability to optimize the load of the eccentric phase during resistance exercises, which led to beneficial adaptations based on common physiological and mechanical background, such as a preferential upregulation of satellite cell activity and transcriptional pathways in fast-twitch muscle fibers, the increased protein synthesis that favor the hypertrophic effects and the higher number of attached cross-bridges which explain the greater work efficiency of the eccentric contraction (Beato & Dello Iacono, 2020; Maroto-Izquierdo et al., 2017). This processes seem to justify the supposed superiority of this methodology compared to traditional resistance exercises (Nuñez & Sáez de Villarreal, 2017; Raya-González, Castillo, & Beato, 2020). Specifically, previous researchers have investigated the effects of flywheel resistance training programs in young soccer players. For instance, de Hoyo et al. (2015) found improvements in countermovement jump (CMJ) performance after a 10-week flywheel half-squat and leg curl training program with a weekly frequency of 1-2 sessions with under 19 (U19) elite male soccer players. Likewise, an 11 week protocol substantially improved COD ability in professional under 19 (U19) soccer players after weekly multi-exercise flywheel resistance training sessions were combined with vibration training (Tous-Fajardo, Gonzalo-Skok, Arjol-Serrano, & Tesch, 2016). Finally, Suarez-Arrones et al. (2018) reported improvement in acceleration, 30 and 40 m linear sprint performance after a multi-exercise flywheel resistance training program for a complete season (2 sessions per week for 27 weeks) in professional young soccer players. Although there are some studies focused on young players, to our knowledge, no studies have been carried out using a randomized controlled trial with U16 soccer players in season.

Players in the Under 16 (U16) age-category are in a sensitive stage of their formative training process, where greater competitiveness exists due to being part of a professional academy team (Castillo et al., 2019). At this stage, the selection and identification of talented players is determined not only by the player's skill level but also by physical fitness, which allows players to be more competent during matches (Castillo et al., 2019). Thus, to improve physical fitness, it seems essential to optimize on-field performance while reducing injury risk (Hägglund, Waldén, & Ekstrand, 2013). This may be particularly important during this stage, which is characterized by non-linear changes in growth and large differences in musculoskeletal maturity (Faigenbaum et al., 2009) – especially from a muscle mass and force production capability perspective (Castillo et al., 2020). Thus, the application of flywheel resistance training programs in U16 soccer players could be suitable to ameliorate their ability to perform high-intensity actions (Raya-González, Castillo, et al., 2020), enhancing their on-field performance (Taber et al., 2016), and consequently, facilitating their progression towards elite soccer levels (Castillo et al., 2019). However, the impact of these programs must be comprehensively controlled to avoid negative effects such as injuries or overtraining syndrome, which could affect young soccer players during their talent development stage.

Despite the promising effects of flywheel training in young soccer players and the importance of neuromuscular performance in team sports, there is a lack of published research around flywheel training programs with U16 soccer populations (Raya-González, Castillo, et al., 2020). Therefore, the aim of this study was to analyze the effect of adding a weekly flywheel resistance training session for 10-weeks within the regular soccer periodization of U16 soccer players' physical performance with special attention to COD performance (COD_{def}). The authors hypothesized that training with the flywheel devices will improve the physical performance indicators in young soccer players.

Methods

Experimental design

A randomized controlled trial design was used to assess the effects of a 10-week flywheel training program (a single weekly session) in young soccer players’ physical performance with specific attention towards investigating COD_{def}. At baseline and post-training, physical fitness was assessed in a single session. In this sense, jump testing (i.e., CMJ) was performed in a performance lab (18ºC, 60–70% relative humidity), whereas sprinting and change of direction ability was assessed on an artificial grass field where the team performed their usual training sessions and players wore their own soccer boots. All tests were carried out in the afternoon between 5 – 7 pm. Likewise, players were instructed to take their last meal 3 h before the beginning of the tests, not to drink any caffeinated beverages or to perform intense physical exercise. Also, the strength and conditioning specialist supervised all testing and gave verbal encouragement during all protocols (Raya-González, Bishop, et al., 2020).

Participants

Initially, twenty-four young elite soccer players from an elite Spanish soccer club agreed to participated in the study. An *a priori* power analysis (G*Power, v3.1.9.2, Universität Kiel, Germany) indicated a sample size of at least 20 was required to achieve power (1-β) of 0.84 with an effect size (ES) of 0.35 (moderate effect) and alpha of 0.05. Players were included in the study if they belonged to the same soccer academy for the last 2 years, took part in at least 80% of training sessions during the 10-week period, had experience of at least 4 years on systematic soccer training and were not injured during the previous 2 months. Additionally, Goalkeepers were not included in the study due to the characteristics of their training and role during the game. Participants were randomly allocated (single-blinded; http://www.randomizer.org/) to either the experimental group (EG, n = 11) or to the control group (CG, n = 11). Finally, twenty soccer players were included in the further analysis, since one participant did not attend 80% of training and other was injured during the intervention (Figure 1). All participants were informed of the procedures, potential risks and benefits of the study before giving their written consent. The study was performed in accordance with the Declaration of Helsinki (2013) and approved by the Ethics Committee of the University (Code: UI1-PI008).

Figure 1 near here, please

Procedures

During the 10-week intervention period (from February to April), players performed their regular weekly in-season routine, with the EG including flywheel training (one session per week). To have a more ecological approach, the strength training session was placed in the middle of the week (Wednesday) (Nonnato, Hulton, Brownlee, & Beato, 2020), in accordance with the habitual coaches' scheduled routines (Coratella et al., 2019). The weekly program (i.e., microcycle) was planned by the coach and strength and conditioning specialist and was comprised by 4 training sessions and 1 official match (Table 1).

Table 1 near here, please

Participants were accustomed to battery test due to their assessment routines previously carried out in the club during preseason. Moreover, players were fully familiarized with the flywheel device and exercise technique thanks to the 4 sessions along the 2 weeks prior to the baseline physical assessment. Players' physical performances were carried out in a single testing session following this order: CMJ, linear sprinting and COD tests in order to minimize the accumulation of fatigue (Raya-González, Bishop, et al., 2020). For unilateral assessments, the dominant leg was considered as the one in which each player obtained the best result (Raya-González, Bishop, et al., 2020). Before testing sessions, a standardized 15-minute warm-up was performed, consisting of 7-minutes of slow jogging and strolling locomotion, followed by 8-minutes of jump and progressive acceleration and sprint actions over 10 and 30-m distances.

Countermovement Jump (CMJ). Players performed 3 maximal unilateral CMJ with each leg (dominant, CMJ_d and non-dominant, CMJ_{nd}), separated by 45 s of passive recovery (Raya-González, Bishop, et al., 2020). Players were instructed to perform a downward movement followed by a complete, explosive extension of the lower limbs, maintaining their hands on their hips (Sáez de Villarreal, Suarez-Arrones, Requena, Haff, & Ferrete, 2015). Additionally, players were randomized to start the test with a different leg. A photocell system (Optojump, Microgate™, Bolzano, Italy) was used to measure jump height (cm) calculated as: $h = gt/8$ (h, height, cm; g, acceleration due to gravity, 9.81 $m \cdot s^{-2}$; t, flight time of the jump, s) (Young, 1995). The highest jump (cm) with each leg was used for subsequent analysis. The intraclass correlation coefficients (ICCs) and the coefficients of variation (CVs) for the jump tests were 0.97 (0.91–0.99) and 3.1% (2.4-4.5) for CMJ_d and 0.99 (0.98–1.00) and 1.4% (1.1-2.0) for CMJ_{nd}.

Linear sprinting test. Players completed 2 maximal 30-m sprints interspersed with a 120-s passive standing rest. Four pairs of photoelectric cells (Microgate™ Polifemo, Bolzano, Italy) were used to record the sprint time at 10 (SPR10), 20 (SPR20) and 30 m (SPR30). The starting position was placed 0.5-m behind the first timing gate, with players starting when ready (eliminating reaction time). The fastest time was considered for the subsequent analysis. The ICCs and the CVs for the sprint tests were 0.74 (0.48–0.89) and 2.6% (2.0-3.8) for SPR10, 0.84 (0.63–0.93) and 1.6% (1.3-2.4) for SPR20, and 0.90 (0.77–0.96) and 1.3% (1.0-1.9) for SPR30.

Change of Direction (COD) Sprint Test. Participants were evaluated over a 10-m and 20-m COD sprint tests using 2 pairs of photoelectric cells (Microgate™ Polifemo, Bolzano, Italy). Four maximum 5+5-m sprints (COD10) and 10+10-m sprints (COD20) with a COD turn of 90º (i.e., two trials with the dominant leg on the outside during the turn and two trials with the dominant leg on the inside) were performed (Núñez et al., 2018), and 2-minutes of passive recovery were allowed between trials. The best time obtained in each COD test was selected for the subsequent analysis. To calculate the COD_{def}, an adapted formula was used as in previous study (Nimphius et al., 2016): COD10 – SPR10 or COD20 – SPR20. The ICCs and the CVs for the COD test were 0.99 (0.97–1.00) and 0.5% (0.4-0.8) for $COD10_{d}$, 0.87 (0.70–0.95) and 1.7% (1.3-2.5) for $COD10_{nd}$, 0.74 (0.43–0.89) and 1.9% (1.5-2.8) for $COD20_{d}$ and 0.93 (0.83–0.97) and 1.0% (0.8-1.5) for $COD10_{nd}$.

Training program

Soccer players belonging to the EG underwent a 10-week training program using a flywheel device (K-Box 4, Exxentric™, Stockholm, Sweden). Flywheel exercises were performed prior to the regular soccer session, once a week (Wednesday) in an indoor performance lab (18ºC, 60–70% relative humidity). Each flywheel session was structured in a brief warm-up (i.e., low intensity running, joint mobility and dynamic stretching and a submaximal set of 8 repetitions of the lateral squat) and 2-4 sets of 8-10 repetitions of the lateral squat (Table 2) with an inertia of 0.025 $kg \cdot m^2$. During each repetition, players were instructed to perform the concentric phase as fast as possible and to delay the braking action until the last third of the eccentric phase (Sabido, Hernández-Davó, Botella, Navarro, & Tous-Fajardo, 2017) and in each set players started the flywheel program with a different leg. 3-minutes of recovery between sets were allowed (Núñez et al., 2018) with each resistance flywheel session lasting around 20-minutes.

Table 2 near here, please

Well-being monitoring

The Hooper questionnaire was used in the team environment to analyze well-being state at the beginning of training sessions (Romaratezabala, Nakamura, Castillo, Gorostegi-Anduaga, & Yanci, 2018). The Hooper questionnaire, consisting of 4 items (fatigue, sleep, soreness and stress) (Hooper & Mackinnon, 1995), was administered every Friday before the regular soccer session. The scale ranged from 1 (very, very low) to 7 (very, very high) for fatigue, stress, and soreness categories, while for the sleep categories values ranged from 1 (very, very good) and 7 (very, very bad) (Romaratezabala et al., 2018). Additionally, the Hooper index was calculated as the sum of values reported for each item (Romaratezabala et al., 2018). The strength and conditioning specialist applied the questionnaire, and the answers were recorded individually for each player. Participants were familiarized with this questionnaire during the preseason period.

Statistical analysis

Descriptive statistics are presented as mean ± standard deviation (SD). The normality of the distribution and the homogeneity of variances were tested using the Shapiro-Wilk and Levene tests, respectively. A Paired-samples *t*-test was used to evaluate within-group differences, and an analysis of covariance (ANCOVA) was performed to detect possible between-group differences, assuming baseline values as covariates. Additionally, an independent samples *t*-test was used to compare well-being state between groups (CG and EG) during the intervention period. Statistical significance was set at $p < 0.05$. Effect sizes (ES) were calculated using Cohen's ES and were interpreted as follow: < 0.2, trivial; 0.20 to 0.49, small; 0.50 to 0.80, moderate and > 0.80, large (Cohen, 1988). The data analysis was carried out using the Statistical Package for Social Sciences (SPSS 25.0; SPSS Inc., Chicago, IL, USA).

Results

Changes in jump and sprint performances for both groups after the intervention period are shown in Table 3. Within-group analysis did not report significant differences for the CG in CMJ and linear sprinting performances ($p = 0.29$ to 1.0; ES = -0.03 to 0.15, trivial), while significant improvements were observed for the EG in jumping ability (i.e., CMJ_d and CMJ_{nd}) ($p = 0.001$ to 0.01; ES = 0.75 to 1.28, moderate to large). Between-groups differences were found in CMJ_d (F = 4.32; $p = 0.05$) and CMJ_{nd} (F = 5.59; $p = 0.03$) but were not found in SPR10 (F = 0.69; $p = 0.42$), SPR20 (F = 4.33; $p = 0.06$) and SPR30 (F = 3.94; $p = 0.07$).

Table 3 near here, please

Table 4 presents the changes observed in COD and COD_{def} performance after the intervention period in both groups. Within-group analysis showed improvements in $COD10_d$ ($p = 0.01$; ES = -1.30, large) and $COD_{def}10_d$ ($p = 0.03$; ES = -0.26, small) for

CG and improvements in all COD and COD_{def} variables analyzed in the study for EG (p = 0.001 to 0.04; ES = -2.20 to -0.97, large). Between-groups analysis revealed differences in favour of the EG in $COD10_d$ (F = 4.25; p = 0.05), $COD10_{nd}$ (F = 19.15; p = 0.001), COD_{def10d} (F = 14.58; p = 0.001), $COD_{def10nd}$ (F = 11.01; p = 0.004), COD_{20d} (F = 5.10; p = 0.037), $COD20_{nd}$ (F = 12.88; p = 0.002), COD_{def20d} (F = 5.79; p = 0.027), and $COD_{def20nd}$ (F = 10.19; p = 0.005).

Table 4 near here, please

In the Hooper questionnaire, the EG obtained greater values in all items (fatigue = 2.90 ± 0.57, sleep = 2.10 ± 0.74, soreness = 3.10 ± 1.20, stress = 1.50 ± 0.53 and Hooper index = 9.60 ± 2.10) compared to the CG (fatigue = 2.80 ± 0.63, sleep = 1.90 ± 0.99, soreness = 2.70 ± 0.95, stress = 1.30 ± 0.48 and Hooper index = 8.70 ± 1.42), but no significant differences were observed between groups (p = 0.27 to 0.71; ES = 0.16 to 0.63, trivial to moderate).

Discussion

The aim of this study was to analyze the effect of adding a weekly flywheel resistance training session over a 10-week period on U16 soccer players' in-season physical performance, with special attention to COD performance and COD_{def}. Although previous studies have focused on young soccer players (de Hoyo et al., 2015; Suarez-Arrones et al., 2018; Tous-Fajardo et al., 2016), this is the first investigation to evaluate the effects of a single weekly flywheel session on physical performance outcomes in U16 players in season. Significant within-group changes in CMJ, COD and COD_{def} performance for dominant and non-dominant limbs were found for EG, whereas no changes in sprinting performances were observed. For CG, no within-group changes were found in CMJ and sprinting performance, although improvements were noted for certain COD variables ($COD10_d$ and $COD_{def}10_d$). Moreover, between-groups analysis revealed differences in favour of the EG in CMJ, COD and COD_{def} variables.

The present study highlights that a single additional session of flywheel lateral squat training may enhance unilateral CMJ performance of elite young soccer players. These improvements could be explained by the capacity of the eccentric training to trigger multiple functional changes (e.g., improvements in stiffness of the muscle-tendon unit and strength production), which have shown to be particularly effective for rebounding activities (Hody, Croisier, Bury, Rogister, & Leprince, 2019). It has been previously reported that flywheel training improves CMJ performance regardless of whether training was performed bilaterally or unilaterally (Gonzalo-Skok et al., 2017). Although unilateral training has many purposes and should be considered for its enhancement of jumping ability, as successfully implemented previously (Gonzalo-Skok et al., 2017), it has not always been effective (Sabido et al., 2017). In contrast to our findings, adult handball players reported no enhancement of CMJ performance after weekly flywheel lunge training sessions (Sabido et al., 2017). Our results may be explained by the fact that young athletes improve their physical capacities during such a sensitive stage of the maturation process (Faigenbaum et al., 2009). As such, de Hoyo et al. (2015) noted an increase in the CMJ performance in U19 soccer players after a 10-week flywheel resistance training program. Subtle but significant differences between this last study (2 weekly bilateral training sessions) and our program (1 weekly unilateral training session) highlight that different approaches can be utilized with young elite players to improve their jumping performance. In this sense, a greater understanding of the load variables in flywheel resistance training programs is necessary to optimize it's application (Sabido et al., 2017).

The lack of significant improvements observed in sprint performance coincide with previous investigations (de Hoyo et al., 2015; Tous-Fajardo et al., 2016). After applying a weekly multi-exercise flywheel protocol for 11 weeks, no changes in 10-30 m sprint time were found in elite U18 soccer players (Tous-Fajardo et al., 2016). Similarly, de Hoyo et al. (2015) also reported no significant improvement in sprint time over 10 and 20 m distances in U19 elite soccer players after the completion of a 10-week (1-2 weekly sessions) flywheel leg curl and half-squat protocol. In contrast with our findings, Suarez-Arrones et al. (2018) reported improvements in 10, 30, and 40 m sprint performance with U18 soccer players. Such improvements were found after 27-weeks of bi-weekly flywheel multi-exercise training programs. The disparity between results may be explained by the higher total volume (27 vs. 10 weeks) and exposure (54 vs. 10 training sessions). Therefore, multi-exercise programs with a higher weekly frequency and a longer duration are necessary to improve sprint performance. Likewise, further studies should investigate the effect of training on soccer players with a higher physical fitness, as they have been shown to have less adaptation potential (Faude, Steffen, Kellmann, & Meyer, 2014).

Flywheel training is an attractive and time efficient method for enhancing COD ability (Coratella et al., 2019; Tous-Fajardo et al., 2016) both from an acute (Raya-González, Castillo, et al., 2020) (Beato, McErlain-Naylor, Halperin, & Iacono, 2020) and chronic (Beato & Dello Iacono, 2020; Maroto-Izquierdo et al., 2017) performance perspective. The flywheel demands more complex movement patterns during training (i.e., rapid decelerations and re-accelerations) that closely represent COD tasks in soccer (Coratella et al., 2019; de Hoyo et al., 2015). Our investigation showed that 10 weeks of flywheel lateral squat training achieves significant improvements in COD performance over different distances (10 and 20 m with one 90º COD) with each leg. Possibly, specific neural patterns derivated to the eccentric training, such as the preferential recruitment of high threshold motor unit and greater cortical activity, or the reduced need of motor units to generate the same amount of force during a submaximal exercise, have favored these improvements (Douglas, Pearson, Ross, & McGuigan, 2018). In agreement with our results, Tous-Fajardo et al. (2016) reported that weekly multi-exercise flywheel resistance training sessions (anteroposterior / lateral / rotational movements) combined with vibration exercise improve COD ability in U18 elite soccer players. Likewise, a previous investigation conducted by Coratella et al. (2019) involving adult semiprofessional soccer players highlighted that a weekly bilateral flywheel squat protocol produced significant improvements in COD performance. This is the first study which has assessed the effects of a training program on COD_{def} ability, reporting significant improvements over 10 and 20 m with both dominant and non-dominant legs. The positive effects reported could be due to 2 key factors: firstly, the aforementioned influence of the eccentric load generated by the flywheel, and secondly, the lateral squat, which has similarities to COD movement patterns. Although our findings confirm that flywheel training can enhance COD and COD_{def} performance, further research is necessary with adult male and female soccer players and young soccer players to optimize training processes and outcomes.

When a training program is prescribed, it is essential to know not only its effects on performance, but the impact on quality of life measures it may have (Mujika, Halson, Burke, Balagué, & Farrow, 2018). In this regard, the Hooper questionnaire was administered each week as a method to monitor if the experimental groups well-being was altered throughout the study. The analysis reported no significant between-groups differences, showing that the present protocol can be used effectively to enhance performance in U16 soccer players without altering the players reported well-being state. Despite some recommendations for the use of inertial intensities of 0.05-0.11 kg·m^2 (Beato & Dello Iacono, 2020), the present study justifies its use of an inertia of 0.025 kg·m^2 with younger athletic populations to achieve jump and COD enhancements. Since the use of higher inertial loads could be perceived as too demanding for youth athletes (Piqueras-Sanchiz et al., 2019), the current research highlights that a lower inertial load can be effective with elite young soccer players. Regarding training frequency and volume, 2-3 weekly sessions for a duration of 5-10 weeks appear optimal for inducing positive adaptations (Coratella et al., 2019), however some positive adaptations can be obtained with only one session a week, especially during the soccer season as reported in the current study. A benefit of weekly flywheel training in this investigation was that although it included a greater training load it did not induce additional stress and fatigue levels.

This study is not without limitations. First, the characteristics of the sample enrolled (i.e., male young soccer players) are specific to this type of population. Therefore, it remains to be seen whether these findings can be extended to adult female or male soccer players with a higher training experience. Second, the limited size of the sample enrolled where only players from the same team were included. However, the enrollment of players on the same team has ruled out some possible confounders such as the possible influence of playing and training styles and different weekly training load. Further research with senior and female soccer players following a multicenter research trial would highlight the reproducibility of our findings.

Conclusions

In conclusion, the inclusion of one flywheel training session per week, over 10 weeks, can effectively enhance jump and COD performance without affecting reported well-being state in U16 elite soccer players in-season. In particular, CMJ, COD and COD_{def} performance for dominant and non-dominant limbs were improved following the training period. The training protocol reported in this study can be used by practitioners to enhance soccer performance with their players. However, different training configurations, including a greater number of exercises, frequency and volume, appears necessary to obtain larger improvements in jumping performance as well as significant changes in sprint performance in young soccer players.

Implementing a weekly flywheel session with an inertial intensity of 0.025 kg·m^2 can enhance physical performance in U16 soccer players. Specifically, the use of a progressive loading periodization strategy may be particularly effective for enhancing physical performance without worsening the players' well-being state. These findings suggest that the proposed flywheel resistance training program is an ecologically valid method which could be implemented safely by strength and conditioning practitioners within elite environments during the competitive season.

Disclosure Statement

There are no funding sources and no conflicts of interest surrounding this scientific investigation.

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Figure and table legends

Figure 1. CONSORT diagram of participant's recruitment, allocation, follow-up and analysis.

Table 1. An in-season weekly program for an elite youth soccer team.

Table 2. Flywheel training program over 10 weeks.

Table 3. Jump and sprint performances before (baseline) and after (post-training) the 10-week intervention period in both groups.

Table 4. Performance on change of direction and change of direction deficit before (baseline) and after (post-training) the 10-week intervention period in both groups.