ORIGINAL ARTICLE

Physiological adaptations to soccer specific endurance training in professional youth soccer players

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Background: Improved oxygen uptake improves soccer performance as regards distance covered, involvements with the ball, and number of sprints. Large improvements in oxygen uptake have been shown using interval running. A similar physiological load arising from interval running could be obtained using the soccer ball in training.

Objectives: The main aim was to study physiological adaptations to a 10 week high intensity aerobic interval training program performed by professional youth soccer players, using a soccer specific ball dribbling track.

Methods: Eleven youth soccer players with a mean (SD) age of 16.9 (0.4) years performed high intensity aerobic interval training sessions twice per week for 10 weeks in addition to normal soccer training. The specific aerobic training consisted of four sets of 4 min work periods dribbling a soccer ball around a specially designed track at 90–95% of maximal heart frequency, with a 3 min recovery jog at 70% of maximal heart frequency between intervals.

Results: Mean Vo_{2max} improved significantly from 63.4 (5.6) to 69.8 (6.6) ml kg^{-1} min^{-1}, or 183.3 (13.2) to 201.5 (16.2) ml $kg^{-0.75}$ min^{-1} ($p<0.001$). Squat jump and counter movement jump height increased significantly from 37.7 (6.2) to 40.3 (6.1) cm and 52.0 (4.0) to 53.4 (4.2) cm, respectively ($p<0.05$). No significant changes in body mass, running economy, rate of force development, or 10 m sprint times occurred.

Conclusion: Performing high intensity 4 min intervals dribbling a soccer ball around a specially designed track together with regular soccer training is effective for improving the Vo_{2max} of soccer players, with no negative interference effects on strength, jumping ability, and sprinting performance.

Due to its acyclical nature and intensity, soccer is classified as a high intensity intermittent team sport.[1] During competitive soccer match play, elite players cover a distance of about 10–12 km[2–5] at an average intensity close to the anaerobic threshold, being 80–90% of maximal heart frequency (Hf_{max}) or 70–80% of maximal oxygen uptake (Vo_{2max}).[3 6 7] It is estimated that aerobic metabolism provides 90% of the energy cost of soccer match play.[1] Therefore, it is a prerequisite in the modern game for the elite soccer player to have high aerobic endurance fitness. Pate and Kriska[8] have described a model that incorporates the three major factors that account for inter-individual variance in aerobic endurance performance, namely Vo_{2max}, lactate threshold (LT), and work economy (C), with numerous studies supporting this model.[7 9–13] The physiological elements of this model can be used when studying the physiological profiles of soccer players and the physiological adaptations to specific training interventions.

Vo_{2max} is considered to be the most important component of endurance performance.[14 15] Small alterations in LT occur in response to running interventions when LT is expressed as a percentage of Vo_{2max}.[7] Minor changes have been shown for running economy (C_R) after running interventions, although C_R is positively influenced by maximal strength training based on maximal mobilisation of force and rate of force development (RFD).[16]

The mean Vo_{2max} of elite soccer players is normally reported to be between 55 and 68 ml kg^{-1} min^{-1}.[14 17–24] These moderate to high values are similar to those found in other team sports,[25] but are substantially lower than elite endurance performers where values close to 90 ml kg^{-1} min^{-1} have been found.[15] Individual values higher than 70 ml kg^{-1} min^{-1} for modern soccer players have been recently reported.[7 15 24]

The importance of Vo_{2max} in soccer has been reflected by rank correlation of the most successful teams in the Hungarian 1st Division Championship.[26] Wisløff *et al*[24] supported this aerobic power-success relationship by demonstrating a clear difference in Vo_{2max} between the top team Rosenborg (67.6 ml kg^{-1} min^{-1}) and a lower placed team Strindheim (59.9 ml kg^{-1} min^{-1}) in the Norwegian elite division. The observation of a high correlation between Vo_{2max} and distance covered during match play supports the adoption of training regimes that raise the Vo_{2max} of soccer players to high levels.[7 27 28] Smaros[28] reported that in addition to the strong correlation with the total distance covered in the game ($r = 0.89$), Vo_{2max} also influenced the number of sprints attempted during a match. It has been recently shown that by improving the mean Vo_{2max} of youth soccer players by 11% over an 8 week period, a 20% increase in total distance covered during competitive match play was manifested, along with a 23% increase in involvements with the ball and a 100% increase in the number of sprints performed by each player.[7]

In activities that involve dynamic work with large muscle mass utilisation, as in playing soccer, it is generally assumed that Vo_{2max} is primarily limited by maximal cardiac output.[29] Whereas untrained subjects are limited peripherally, trained individuals are primarily limited centrally, with the maximal

Abbreviations: 1RM, one repetition maximum; C, work economy; CMJ, counter movement jump; C_R, running economy; Hf, heart frequency; Hf_{max}, maximal heart frequency; LT, lactate threshold; RFD, rate of force development; SD, standard deviation; SJ, squat jump; Vo_{2max}, maximal oxygen uptake stroke volume of the heart being accepted as the major limiting factor of Vo_{2max}.[30 31] Increased stroke volume has recently been shown up to the level of Vo_{2max}.[32]

Hoff and Helgerud[15] thus argue that continuous interval training for 3–8 min with a working intensity of 90–95% of Hf_{max} should increase Vo_{2max} by increasing the maximal cardiac output by improving stroke volume. Recently, Helgerud *et al*[7 33] showed the effectiveness of such a training regime, significantly increasing mean Vo_{2max} and C_R of soccer players using running and treadmill running as training modes, respectively. Similar physiological load could be obtained by using a specifically designed soccer track where the subjects dribble a soccer ball instead of regular running.[34] This might however raise different problems in terms of the subjects and coaches' control of intensity, control of the ball, etc, that might influence training execution and response.

The main aim of this study was to intervene in a professional youth soccer team using high intensity interval training with the players dribbling a soccer ball around a specifically designed track. An improvement in Vo_{2max} of similar magnitude as that attained by Helgerud *et al*[7] for youth players and by Helgerud *et al*[33] for Champions League players was hypothesised, with no adverse effects on sprinting and jumping ability. A secondary aim of this study was to present normative physiological data on professional youth soccer players.

METHODS

Subjects

Sixteen male youth soccer players from Celtic Football Club's U-17's Youth Academy squad (Glasgow, Scotland, UK) participated in the study. The players studied were all full time professional soccer players and trained on a daily basis. Seven of the players tested are of international standard for their age group. Each subject reviewed and signed consent forms in accordance with the Declaration of Helsinki and the Human Research Review Committee at the Norwegian University of Science and Technology prior to the study. Subjects were informed about the test protocols, but without being informed about the aim of the study. The players' physical characteristics are presented in table 1.

Testing

Each player's mass and height were recorded upon entering the laboratory. The players then performed a 10 min warm up on a treadmill (Technogym RunRace, Gambettola, Italy) at an intensity of approximately 60–70% of Vo_{2max}. Squat jump (SJ) height with no arm swing, counter movement jump (CMJ) height with no arm swing, and RFD were determined using a force platform (Kistler, Winterthur, Switzerland). Jumping height was determined as the centre of mass displacement calculated from force-time characteristics and body mass. The best jump from three attempts was recorded. A 2 min rest period was allowed between efforts. Hands were placed on the hips during the jump tests. RFD was calculated from an SJ performed from a position with a 90° angle in the knee joint (between femur and tibia). RFD was calculated as the force from 10 to 90% of peak external force registered from the force platform divided by the time used to exert that force. The same start and peak force window from the pre-test was used to obtain changes in RFD at the post-test.[35] One repetition maximum (1RM) strength was then obtained as the maximal weight the subjects were able to raise in a half squat (90° angle in the knee joint between femur and tibia). Testing was carried out using 5 kg stages and 1–2 min between each trial. 1RM was normally determined using three to five trials.

Then 5 min after completion of the strength testing, each player commenced treadmill testing of C_R and Vo_{2max}. C_R was measured at 9 km h^{-1} at a treadmill inclination of 5.5%. The average value of oxygen uptake (Vo_{2max}) between 4 and 4.5 min was used to calculate C_R. The velocity of the treadmill was then increased by 1 km h^{-1} every minute to a level that brought the subject close to exhaustion after approximately 5–6 min. Inclination of the treadmill was kept constant at 5.5%. Heart frequency (Hf) was determined using short range radio telemetry (Polar Accurex Plus, Polar Electro, Kempele, Finland). The highest Hf measured throughout the test was recorded as Hf_{max}. Vo_{2max}, minute ventilation, and breathing frequency were measured using a Cortex Metamax II device (Cortex, Leipzig, Germany), a portable metabolic test system that has been previously validated.[36]

On the following day, each player's sprint acceleration was assessed over a 10 m distance.[37] After a 15 min warm up, each player carried out three maximal sprints from a static position (0 m behind first photocell), with each trial separated by 3 min of rest. The sprint tests were performed on an indoor running track and 10 m sprint time was recorded using photocells (Newtest Powertimer, Oulu, Finland).

Training intervention

The aerobic training intervention consisted of interval training, comprising four bouts of 4 min work periods dribbling a soccer ball (Mitre ISO League, Mitre, Wilmslow, Cheshire, UK) around a specially designed track[34] (fig 1) on an artificial field-turf pitch. Training cones used in the dribbling circuit were 0.3 m high and 0.15 m wide. Hurdle height was set at 0.5 m. Working intensity was at 90–95% of each player's Hf_{max}, with work periods separated by 3 min of jogging at 70% of Hf_{max}. All players wore a Polar Team System heart rate belt and monitor (Polar Electro) throughout the interval training. The interval training was performed two times a week at the end of the soccer training session, on the same days and time of day throughout the intervention period. No emphasis was placed on improving strength, sprinting, or jumping performance throughout the intervention period. The 10 week intervention period was carried out directly after the off-season intermission period, encompassing the 6 week pre-season preparation period and the first 4 weeks of the competitive season.

Allometric scaling

Oxygen uptake is a measure of power and, in order to be independent of absolute body mass, should be expressed in ml per kg lean body mass raised to a power of 0.67.[38] Vo_{2max} expressed as ml kg^{-1} min^{-1} implies 1 : 1 linearity between oxygen uptake and body mass, which is not the case.[39] When expressing Vo_{2max} as ml kg^{-1} min^{-1}, light individuals are over-estimated in terms of work capacity and heavy individuals are under-estimated. The opposite is true when evaluating the oxygen cost of running at sub-maximal workloads. When comparisons amongst people of different body mass are made for running, oxygen uptake should be expressed as ml $kg^{-0.75}$ min^{-1}.[13 39] Expressing Vo_{2max} in relation to the power 0.67 or 0.75 may not be critical as long as the unit approximates the theoretical value and not the traditional body mass.[13]

Table 1 Physical characteristics of players (n = 11)

Age (years)	Height (cm)	Mass (kg)	Hf_{max} (beats min^{-1})
16.9 (0.4)	177.0 (6.4)	70.6 (8.1)	199 (8)

Values are mean (SD).

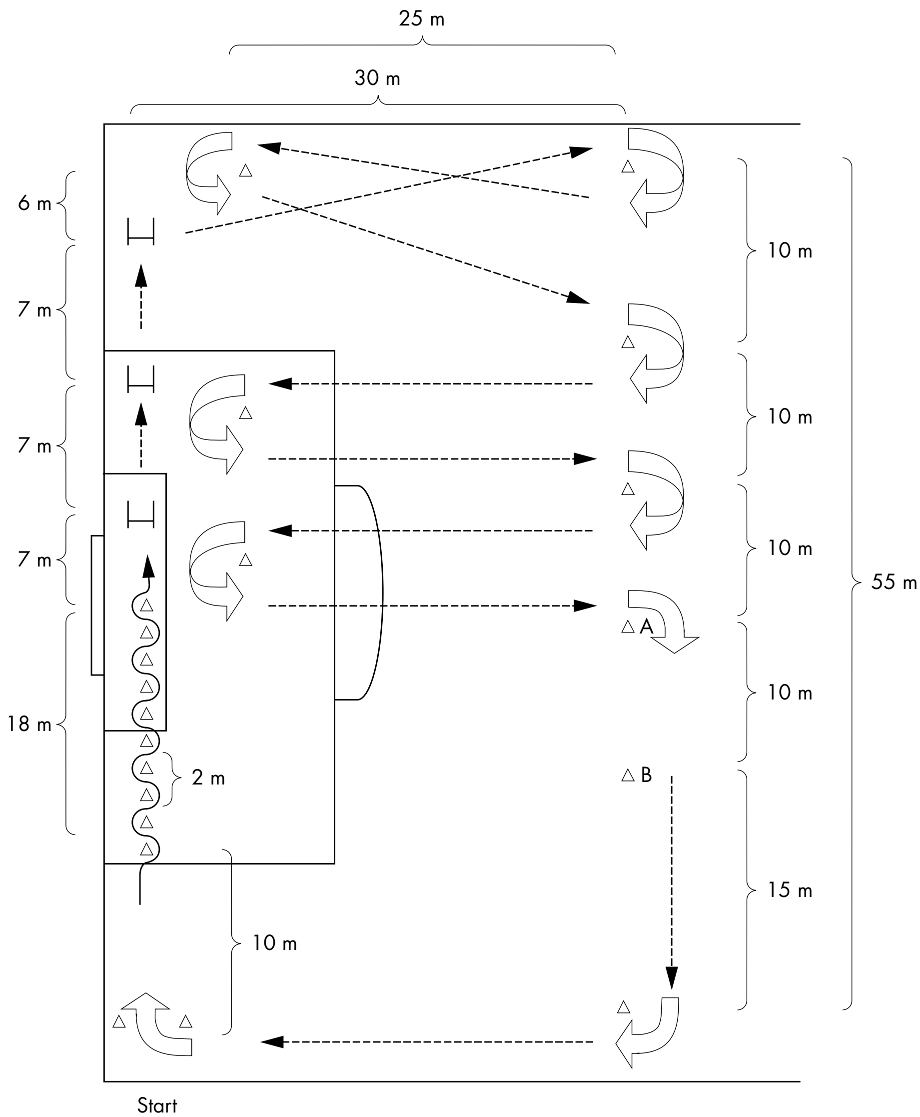

Figure 1 Soccer specific dribbling track used for high intensity interval training sessions. Players dribble a soccer ball around the track, lift the soccer ball over the hurdles, and jump over the hurdles. Players dribble backwards with the soccer ball between points A and B.

Statistical analysis

All results are reported as means and standard deviations (SD) calculated by conventional procedures. Differences from pre- to post-training were calculated using a *t* test, with results accepted as significant at $p<0.05$. Changes from pre- to post-training in Vo_{2max} and C_R given in per cent are calculated on the basis of the unit ml $kg^{-0.75}$ min^{-1}.

RESULTS

During the 10 week, twice a week intervention, the players in this study completed 16 (80%) of the scheduled 20 interval training sessions. Four sessions were uncompleted due to the players competing in a 1 week tournament and mid-week competitive matches. Five players of the 16 assessed pre-intervention were withdrawn from the study due to injuries not connected with the training intervention (three players) and unavailability at the post-intervention session (two players).

The 10 week aerobic training intervention manifested significant improvements in Vo_{2max} (table 2) of 9% ($p<0.001$). The mean Vo_{2max} increased from 4.45 (0.37) to 4.87 (0.45) l min^{-1}, which equates to a change from 63.4 (5.6) to 69.8 (6.6) ml kg^{-1} min^{-1}, or 183.3 (13.2) to 201.5 (16.2) ml $kg^{-0.75}$ min^{-1}. Mean body mass was unchanged after the intervention period.

When treadmill running at 9 km h^{-1} at an inclination of 5.5%, C_R was unchanged by the intervention. However, mean Hf at this workload decreased significantly from 162 (14) to 154 (14) beats min^{-1} ($p<0.05$).

No significant changes in RFD and 10 m sprint performance were evident. SJ and CMJ height increased from 37.7 (6.2) to 40.3 (6.1) cm and 52.0 (4) to 53.4 (4.2) cm, respectively ($p<0.05$).

DISCUSSION

The training intervention used in this study elevated mean Vo_{2max} by 6.4 ml kg^{-1} min^{-1} or 9.0%. Mean Vo_{2max} increased from a typical soccer player value of 63.4 (5.6) to 69.8 (6.6) ml kg^{-1} min^{-1}, or 183.3 (13.2) to 201.5 (16.2) ml $kg^{-0.75}$ min^{-1}. Removing the goalkeeper's Vo_{2max} value from the pre- and post-intervention results shows an improvement in mean Vo_{2max} from 64.7 (3.9) to 70.9 (5.7) ml kg^{-1} min^{-1}, or 186.3 (9.2) to 204.0 (14.8) ml $kg^{-0.75}$ min^{-1} for the outfield players ($n = 10$).

Table 2 Pre- and post-training intervention physiological results (n = 11)

	Pre-training	Post-training
Body mass (kg)	70.6 (8.1)	70.2 (8.2)
Vo_{2max}		
l min^{-1}	4.45 (0.37)	4.87 (0.45)**
ml kg^{-1} min^{-1}	63.4 (5.6)	69.8 (6.6)**
ml $kg^{-0.75}$ min^{-1}	183.3 (13.2)	201.5 (16.2)**
C_R (9 km h^{-1}, 5.5% inclination)		
ml $kg^{-0.75}$ m^{-1}	0.85 (0.06)	0.85 (0.05)
Hf (beats min^{-1})	162 (14)	154 (14)*
Strength		
1RM half squat (kg)	–	129.1 (11.4)
Relative strength (kg $kg(bm)^{-1}$)	–	1.85 (0.12)
Relative strength (kg $kg(bm)^{-0.67}$)	–	7.49 (0.39)
Sprint test		
10 m (s)	1.96 (0.07)	1.96 (0.06)
Force platform tests		
RFD (N s^{-1})	3553 (1492)	3654 (1487)
SJ (cm)	37.7 (6.2)	40.3 (6.1)*
CMJ (cm)	52.0 (4)	53.4 (4.2)*

*$p<0.05$, **$p<0.001$, significantly different from pre-intervention value.

Helgerud *et al*[7] used 4 min intervals at 90–95% Hf_{max} with youth soccer players over an 8 week training period and promoted a Vo_{2max} increase of 11%, an increase from 58.1 (4.5) to 64.3 (3.9) ml kg^{-1} min^{-1}. Although the players in the present study had a mean Vo_{2max} score greater than the post-intervention values found by Helgerud *et al*,[7] large improvements in Vo_{2max} were still attained. The training intervention of Helgerud *et al*[7] manifested improvements in Vo_{2max} of 0.67% per training session, compared to 0.56% in the present study. The somewhat greater efficiency of Helgerud's intervention may be due to the lower initial aerobic fitness levels of the Norwegian junior players in that experiment.

The initial and post-intervention mean Vo_{2max} values of the Scottish youth players assessed in the present study are greater than those of Norwegian youth players of similar age[7] and also of Spanish Premier Liga soccer players.[40] Indeed, the Vo_{2max} of the Scottish players in this study are comparable to elite Norwegian Champions League soccer players, who possessed a mean (SD) Vo_{2max} of 200.2 (8.4) ml $kg^{-0.75}$ min^{-1}, which are the highest oxygen uptake values reported for a soccer team.[24] It is suggested that the modern 75 kg soccer player should have a Vo_{2max} above 70 ml kg^{-1} min^{-1}, or 205 ml $kg^{-0.75}$ min^{-1}.[15] Five players in this study attained a Vo_{2max} greater than 205 ml $kg^{-0.75}$ min^{-1} after the intervention period, with none of the players possessing this level of aerobic fitness pre-intervention.

The first 6 weeks of the intervention period in this study encompassed the pre-season training regime, and it is plausible that some of the improvements in Vo_{2max} manifested were attributable to the players returning to pre-season in a de-trained state, due to the 6 week summer intermission period. It is also plausible that improvements in Vo_{2max} in this study may have resulted from the conventional soccer training the players participated in (for example, small-sided game play, technical/tactical training), although it should be noted that the only endurance training that the players performed over the pre-season period in this training study were the high intensity aerobic interval sessions. Some studies have not reported large changes in Vo_{2max} of soccer players after pre-season training. For example, Bangsbo[1] reported only small increases in Vo_{2max} after a 5 week pre-season training period in professional soccer players.

The authors of this study are aware that this study would have benefited from data from a control group. The use of controls is difficult, if not impossible, when dealing with professional soccer clubs and players. However, control group data from a previous study by Helgerud *et al*[7] can be referred to. The control group performed additional technical training whilst the training group performed high intensity aerobic interval training (4×4 min intervals at 90–95% Hf_{max}) twice a week for 8 weeks. The Vo_{2max} of the training group improved by 11% over the 8 week intervention, but the Vo_{2max} of the control group was unchanged (58.4 (4.3) to 59.5 (4.4) ml kg^{-1} min^{-1}).

The C_R of the players in this study was not significantly changed after the training intervention. This is in contrast to the findings of Helgerud *et al*[7] who reported an improved C_R of 6.7% in junior players, but of only 3.7% when using treadmill training with elite players,[33] with the latter improvement explained by gains arising from concurrent maximal strength training. It should be noted that the training intervention of Helgerud *et al*[7] involved straight line running only, therefore an improved C_R may be expected for junior players with relatively low endurance values on the basis of more running practice. The aerobic endurance intervention in the present study was carried out dribbling a soccer ball around a specially designed track.[34] Dribbling a soccer ball around the track raises the oxygen demand when compared to running,[41] as does the frequent changes in direction and pace involved. Hoff *et al*[34] reported that a mean exercise intensity of 93.5% Hf_{max} when dribbling a soccer ball around the track corresponded to 91.7% Vo_{2max}. C_R was unchanged in the present study, but it can be postulated that soccer specific work economy may have improved somewhat, with relevant gains not detectable by conventional treadmill testing.[7]

Although C_R was unchanged after the intervention period, mean Hf for treadmill running at 9 km h^{-1} at 5.5% inclination decreased significantly from 162 (14) to 154 (14) beats min^{-1} ($p<0.001$). This decrease in Hf could be attributed to an increased Vo_{2max}. A reduction in sub-maximal Hf of approximately 10 beats min^{-1} is indicative of an increase in Vo_{2max} of approximately 3–5 ml kg^{-1} min^{-1}.[7 13 33]

Several authors have concluded that endurance training inhibits or interferes with strength[42–45] and therefore power performance.[46] 1RM half squat strength was measured pre- and post-intervention in the present study, but due to the players being limited by technique and apprehension as they were not familiar with this exercise movement, the recorded values for the pre-intervention assessment results were artificially low. During the final 4 weeks of the endurance training intervention period technical training for carrying out a safe half squat was performed twice a week using an unloaded Olympic bar. Therefore, only post-intervention squat strength scores for the players in this study are reported. RFD and 10 m sprint times in the present study were unaffected by the aerobic intervention program and the lifting technique program, although jumping height improved significantly over the 10 week period ($p<0.05$). Therefore, it appears that power related performance was not hindered by the aerobic interval training regime used in the present study. Similarly, Helgerud *et al*[7] showed substantial gains in Vo_{2max} from an 8 week endurance training intervention with no reduction in sprinting and jumping abilities.

High intensity aerobic 4 min intervals are an effective tool for increasing Vo_{2max} in soccer players, with the training effect of each session being approximately 0.5%. The results from this study and that of Helgerud *et al*[7 33] demonstrate that it is possible to elevate the Vo_{2max} of youth soccer players from typical values (for example, 58–64 ml kg^{-1} min^{-1}) to

What is already known on this topic

Improving Vo_{2max} in soccer players has previously been shown to significantly increase work rate during competitive soccer match play. It has previously been demonstrated that the Vo_{2max} of soccer players can be increased by performing high intensity aerobic interval training at 90–95% of Hf_{max} using conventional running.

What this study adds

This study has shown that high intensity aerobic interval training designed to increase Vo_{2max} can be performed effectively by dribbling a soccer ball around a specially designed track. Performing high intensity aerobic interval training in addition to conventional soccer training can elevate the Vo_{2max} of soccer players to levels approaching 70 ml kg^{-1} min^{-1}.

levels approaching or exceeding 70 ml kg^{-1} min^{-1} without hindering power related performance. For example, soccer players with a moderate initial Vo_{2max} of approximately 60 ml kg^{-1} min^{-1} can raise their Vo_{2max} to a level approaching 70 ml kg^{-1} min^{-1} by performing four sets of 4 min high intensity intervals at 90–95% Hf_{max} twice a week over a 10 week training period, in addition to regular soccer training.

In conclusion, high intensity aerobic interval training can be effectively performed by dribbling a soccer ball around a specially designed track. The addition of high intensity interval training at 90–95% Hf_{max} to the training regimes of professional youth soccer players can elevate Vo_{2max} levels from low to moderate values to that of elite Champions League soccer players, with no negative interference effects on strength, jumping ability, and sprint performance.

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