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ORIGINAL INVESTIGATION

Maximal Aerobic Power Characteristics of Male Professional Soccer Players, 1989–2012

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Purpose: The purpose of this investigation was to quantify maximal aerobic power (VO_{2max}) in soccer as a function of performance level, position, age, and time of season. In addition, the authors examined the evolution of VO_{2max} among professional players over a 23-y period. ***Methods:*** 1545 male soccer players (22 ± 4 y, 76 ± 8 kg, 181 ± 6 cm) were tested for VO_{2max} at the Norwegian Olympic Training Center between 1989 and 2012. ***Results:*** No differences in VO_{2max} were observed among national-team players, 1st- and 2nd-division players, and juniors. Midfielders had higher VO_{2max} than defenders, forwards, and goalkeepers ($P < .05$). Players <18 y of age had ~3% higher VO_{2max} than 23- to 26-y-old players ($P = .016$). The players had 1.6% and 2.1% lower VO_{2max} during off-season than preseason ($P = .046$) and in season ($P = .021$), respectively. Relative to body mass, VO_{2max} among the professional players in this study has not improved over time. Professional players tested during 2006–2012 actually had 3.2% lower VO_{2max} than those tested from 2000 to 2006 ($P = .001$). ***Conclusions:*** This study provides effect-magnitude estimates for the influence of performance level, player position, age, and season time on VO_{2max} in men's elite soccer. The findings from a robust data set indicate that VO_{2max} values ~62–64 mL · kg^{-1} · min^{-1} fulfill the demands for aerobic capacity in men's professional soccer and that VO_{2max} is not a clearly distinguishing variable separating players of different standards.

Keywords: relative VO_{2max}, aerobic capacity, soccer, physical performance

The importance of high maximal aerobic power (VO_{2max}) in modern soccer is heavily debated. Reported test results have varied widely with VO_{2max} values between 50 and 75 mL · kg^{-1} · min^{-1} among outfield athletes.[1] Some investigations indicate that lower-ranked teams have lower VO_{2max} than the best teams.[2,3] Reilly et al[4] claim that VO_{2max} is not a sensitive measure of performance capability in soccer and suggest that VO_{2max} >60 mL represents a threshold to possess the physiological attributes for success in men's elite soccer. In contrast, Stølen et al[1] claim that it would be reasonable to expect about 70 mL · kg^{-1} · min^{-1} for a 75-kg professional soccer player, a value similar to that in elite middle-distance athletes.[5] It is also unclear whether there are positional differences in VO_{2max} among male soccer athletes.[4,6,7] Stølen et al[1] claim that junior soccer players traditionally have lower VO_{2max} than seniors. Casajús[8] and Magal et al[9] noted a higher VO_{2max} at the end of the season, while Heller et al[10] and Metaxas et al[11] reported best VO_{2max} at the end of preseason or beginning of season. Stølen et al[1] claim that VO_{2max} among high-performance teams has been elevated over the last decade compared with values reported in the 1980s. Unfortunately, most of these statements are based on small samples and homogeneous athlete groups. Previously published studies do not adequately represent variation in performance level, playing position, age, or season time. No studies have examined development in VO_{2max} among elite soccer players over time.

The Norwegian Olympic training center has served as a standard testing facility for a large number of teams across a broad range of performance levels, including essentially all national-team players. A database of VO_{2max} results collected over 2 decades provided the potential for more rigorously testing the hypotheses presented in previous studies. Thus, the aim of this study was to quantify possible differences in VO_{2max} as a function of athlete playing standard, field position, age, and time of season. In addition, we evaluated the evolution of VO_{2max} in the Norwegian national squad over a 23-year period.

Materials and Methods

Subjects

Data from 1545 male soccer players (22 ± 4 y, 181 ± 6 cm, 76 ± 8 kg) were collected between 1989 and 2012 (Table 1). Of these, 700 players were tested once, 381 were tested twice, and 464 were tested 3 times or more. In total, 3751 VO_{2max} tests formed the basis for this investigation. All tests were performed between 11 AM and 8 PM at the Norwegian Olympic training center in Oslo. These were preexisting data from the quarterly, semiannual, or

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annual testing that these teams underwent for training-monitoring purposes. The Norwegian Olympic Committee and Norwegian Confederation of Sports approved the use of data for our research purposes, provided that the anonymity of individual test results would be protected. This study was approved by the ethics committee of the Faculty for Health and Sport, University of Agder.

Senior national-team athletes were defined as players who represented Norway in World Cup, Euro Cup, qualifying matches, or training matches. Since 1989, the Norwegian squad has been ranked among the top 10 several times in the official FIFA ranking (www.fifa.com/worldfootball/ranking). The international ranking at the time of this writing (June 2012) was 26. Junior national-team players in the database had represented Norway in the under-20 age group. The first-division athletes represented clubs from the highest division level in the Norwegian soccer league system. The second-division athletes in this study were playing in the second-highest division. The junior athletes in the database were playing in the highest division level in the Norwegian junior-league system. National-team and first- and second-division players were fulltime professional performers, while the third- to fifth-division and junior players were semiprofessionals or amateurs, with part- or full-time jobs or educational programs in addition to their sports career.

Apparatus

A 200 × 70-cm Woodway Sports Performance treadmill was used until June 2008, then replaced by an ELG Woodway treadmill (Woodway Gmbh, Weil am Rhein, Germany); both were calibrated for speed and inclination before all tests. For this athlete group, maximal treadmill testing was always performed at a constant treadmill inclination of 3° (5.25%). During the test, the subjects breathed into a Hans Rudolph 2-way breathing valve (2700 series, Hans Rudolph Inc, Kansas City, MO, USA) connected to metabolic-gas analyzers. Gas-exchange and ventilatory variables were continuously sampled in a mixing chamber and reported every 30 seconds. Oxygen uptake was measured using EOS Sprint (Jaeger-Toennis, Wurtzburg, Germany) from 1989 to June 2002, and an Oxycon Pro (Jaeger-Toennis, Wurtzburg, Germany) metabolic test system was used from June 2002 onward. An internal comparison of 194 tests for cross-country skiers demonstrated identical regression lines for the running-velocity–VO_2 relationship before and after the apparatus shift. The test equipment underwent a standard calibration procedure before each test.

Testing Procedures

Athletes were instructed to prepare themselves as they would for a regular competition, including no high-intensity training the 2 to 3 days before testing. They completed a standard 15- to 20-minute warm-up program before testing, consisting of 15 minutes low- to moderate-intensity jogging on a separate treadmill. The last part of the warm-up was performed on the test treadmill with several short intervals equivalent to or higher than the starting test velocity, which was selected to elicit an oxygen demand equaling 80% of VO_{2max}. The VO_2 testing procedure was a stepwise increase in running velocity until exhaustion occurred after 4 to 6 minutes. In general, the increase was 1 $km \cdot h^{-1} \cdot min^{-1}$. The last velocity step was held for at least 1 minute. The same 2 exercise physiologists supervised all testing during the entire period. During all tests, athletes were continuously updated with oxygen uptake, time, and running velocity to motivate for true voluntary exhaustion. VO_{2max} was defined as the highest average of 2 consecutive 30-second measurements. Test results with peak respiratory-exchange ratio below 1.05 at voluntary exhaustion were excluded.

Statistics

SPSS 18 was used for all analyses. VO_{2max} is expressed relative to body mass ($mL \cdot kg^{-1} \cdot min^{-1}$) for all analyzed categories. Means and 95% confidence intervals were calculated for each group or category. Data from a single athlete were only included in 1 category, except for the season-time analysis. That category was the athlete's affiliation on the day of his best result. Player positions were identified for athletes by their coaches or by self-report as goalkeepers, defense players, midfielders, or forwards. Athlete age was calculated from date of birth and testing date and categorized as <18, 18–20, 20–23, 23–26, 26–29, and >29 years. To quantify the development of VO_{2max} over time, the database was divided into 4 time epochs: 1989–1995, 1995–2000, 2000–2005, and 2005–2012. The playing-standard analysis included all players (n = 1545), while position, age, and time-epoch analyses were restricted to national-team and first- to second-division players (n = 716) at the time of testing. One-way ANOVA followed by Tukey post hoc test where necessary was used to identify differences among groups or categories. For the season-time analysis, 108 professional players (103 field players, 5 goalkeepers) who performed VO_{2max} testing during preseason (January 1 to March 31), in-season (April 1st-October 15th), and off-season (October 15 to December 31) of the same competitive season were identified, based on the Norwegian competitive season. General-linear-model repeated measures were used to identify possible differences among these categories. Effect size (Cohen *d*) was calculated to evaluate the meaningfulness of the difference between category means. Effect magnitude was interpreted categorically as small (*d* 0.2–0.6), moderate (*d* 0.6–1.2) or large (*d* 1.2–2.0) using the scale presented by Hopkins et al.[12]

Results

Figure 1 shows relative VO_{2max} values for all playing-standard categories. With the exception of third- to fifth-division players, mean VO_{2max} for all other categories was contained within a range of 62 to 64 mL · kg^{-1} · min^{-1}, and these groups did not differ significantly. Junior players and senior players did not differ significantly in VO_{2max}. Amateur players from third- to fifth-division teams demonstrated lower VO_{2max} than the higher-playing standard groups analyzed (mean difference = 2 mL · kg^{-1} · min^{-1}, 95% confidence interval [CI] = 0–4 mL · kg^{-1} · min^{-1}, P < .009 for all comparisons; small effect).

Figure 2 shows 95% CIs for relative VO_{2max} values by position for professional players in the current study. Midfielders had higher VO_{2max} than forwards (mean difference = 2 mL · kg^{-1} · min^{-1}, 95% CI = 1–3 mL · kg^{-1} · min^{-1}, P < .001; small effect), defenders (mean difference = 1 mL · kg^{-1} · min^{-1}, 95% CI = 0–2 mL · kg^{-1} · min^{-1}, P = .043; small effect), and goalkeepers (mean difference = 5 mL · kg^{-1} · min^{-1}, 95% CI = 3–7 mL · kg^{-1} · min^{-1}, P < .001; moderate effect).

Figure 3 shows relative VO_{2max} capacity across the age groups for the professional players. Players younger than 18 years had higher VO_{2max} than 23- to 26-year-old players (mean difference = 2 mL · kg^{-1} · min^{-1}, 95% CI = 0–4 mL · kg^{-1} · min^{-1}, P = .016; small effect).

Figure 4 shows relative VO_{2max} capacity for the professional players (n = 108) who performed maximal testing during preseason, in-season, and off-season of the same competitive season. Using this group to estimate the generalized impact of time of season on VO_{2max} showed no significant differences across the 3 seasonal phases. The averaged within-subject variation was 3.3% (±2 mL · kg^{-1} · min^{-1}) across the 3 testing time points.

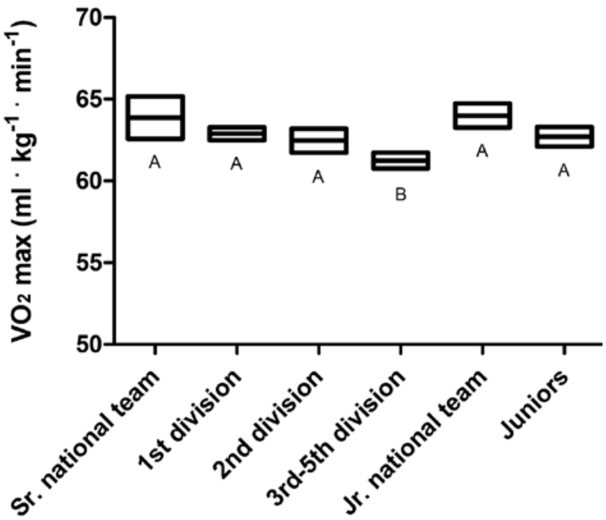

Figure 1 — 95% confidence intervals for relative maximal aerobic power (VO_{2max}) as a function of performance level. Differing letters indicate significant differences among groups.

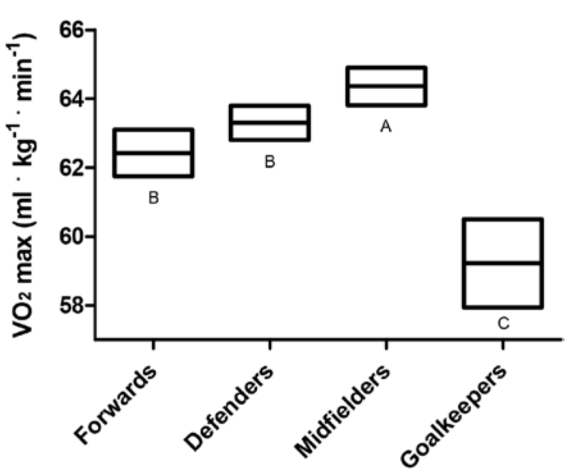

Figure 2 — 95% confidence intervals for relative maximal aerobic power (VO_{2max}) as a function of playing position. Differing letters indicate significant differences among groups.

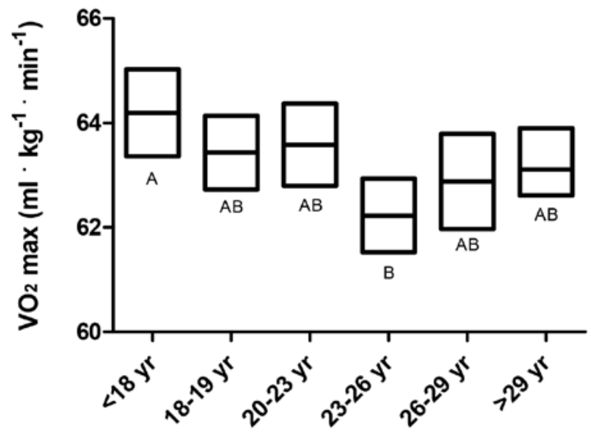

Figure 3 — 95% confidence intervals for relative maximal aerobic power (VO_{2max}) as a function of age. Differing letters indicate significant differences among groups.

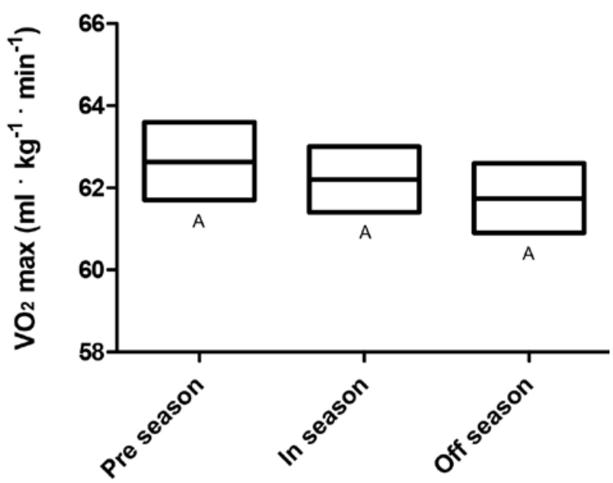

Figure 4 — 95% confidence intervals for relative maximal aerobic power (VO_{2max}) as a function of season time. Differing letters indicate significant differences among groups.

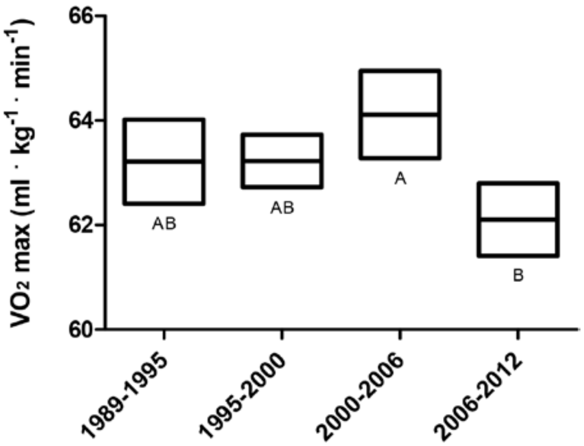

Figure 5 — 95% confidence intervals for relative maximal aerobic power (VO_{2max}) as a function of time epoch. Differing letters indicate significant differences among groups.

Figure 5 shows 95% CIs for relative VO_{2max} values by time epoch for the professional players. Players from time epoch 2000–2006 had higher relative VO_{2max} than 2006–2012 players (mean difference = 2 mL · kg^{-1} · min^{-1}, 95% CI = 0–4 mL · kg^{-1} · min^{-1}, P = .001; small effect).

Discussion

In the current study, data from a large sample of athletes demonstrate no differences in VO_{2max} among national-team players, first- and second-division players, and juniors. However, all these playing-standard categories had higher relative uptake than third- to fifth-division players. Midfielders had higher relative uptake than defenders and forwards, while goalkeepers had the poorest VO_{2max} values. Absolute VO_{2max} tended to be lower in junior athletes, associated with their lower body mass. The professional players had lower relative uptake during off-season compared with preseason and in season by a small margin. Relative to body mass, VO_{2max} among the professional players in this study has not changed over time.

Playing Standard

This study demonstrates that VO_{2max} does not distinguish soccer players from different standards of play ranging from national team to second division and juniors. All playing-standard groups had mean VO_{2max} values between 61 and 64 mL · kg^{-1} · min^{-1} (Figure 1), and only the third- to fifth-division players differed significantly from the other groups. In theory, body-mass differences across categories could have an impact on the VO_{2max} values.[13] However, the relationship remained consistent even when the VO_{2max} was expressed in relation to body mass raised to the power of 0.75, as all groups showed mean VO_{2max} values between 182 and 190 mL · kg^{-1} · min^{-1}. In this analysis, third- to fifth-division players and the junior group scored significantly lower values than the other categories. Stølen et al[1] concluded in their review that VO_{2max} values of ~70 mL · kg^{-1} · min^{-1} should be expected for 75-kg professional players. This is about 10% to 12% higher than the mean values in our study. Assuming comparable monitoring instruments and procedures, we do not believe that aerobic demands in soccer are similar to those of elite middle-distance runners.[5] Apor[2] reported that lower-division teams in Hungary had lower VO_{2max} than teams playing in higher divisions. However, those differences were not tested for significance. Wisløff et al[3] showed that the best first-division team at the time in Norway had superior VO_{2max} values compared with the team that finished last. However, that study was based on a small sample and did not adequately represent variation in performance level. Our findings support the claims of Reilly et al,[4] who suggested that VO_{2max} above 60 mL represents a threshold to possess the physiological attributes for success in men's elite soccer. Beyond this baseline, other physical qualities such as linear-sprinting speed,[13] agility,[14] or repeated-sprint ability[15] probably become more important. Most game analyses have shown that neither total distance covered nor high-intensity running is a performance-determining factor in men's elite soccer,[17–19] even though there are exceptions.[20]

Playing Position

Small to moderate differences in VO_{2max} according to playing position were observed in our investigation. Midfielders scored the highest mean VO_{2max} values, ahead of defenders, forwards, and then goalkeepers, in that order. The internal ranking by player position is in accordance with the findings of Reilly et al.[4] Bangsbo[7] showed that central defenders had the poorest VO_{2max} among outfield players, while fullbacks and midfielders scored the best VO_{2max} values. In contrast, Arnason et al[6] reported only minor positional differences in VO_{2max} among Icelandic outfield players. VO_{2max} must be seen in relationship to the physical demands of the different positions on the field. Wide midfielders and external defenders perform more high-intensity running than players in other positions.[18] Our playing-position categorization is somewhat limited, but we observed that midfielders, who typically cover the longest distances during games,[20–23] had somewhat higher VO_{2max}. Nevertheless, we are somewhat surprised that the mean group difference between midfielders and goalkeepers in the current study is only ~5 mL · kg^{-1} · min^{-1}, or less than 10%.

Age

We observed practically no differences in VO_{2max} across age groups, except for the ~2-mL · kg^{-1} · min^{-1} difference between <18 and 23- to 26-year-old players (Figure 3). When the VO_{2max} was expressed in relation to body mass raised to the power of 0.75, no significant group differences were noted as all age categories showed remarkably similar mean VO_{2max} values between 186 and 188 mL · $kg^{-0.75}$ · min^{-1}. There was a trend toward higher absolute VO_{2max} and body-mass index with increasing age for the professional soccer players in our study (Table 1). Stølen et al[1] summarized several studies and concluded that juniors traditionally have lower VO_{2max} than senior players, even though exceptions were pointed out. However, their conclusion was mainly based on studies with either small samples or very young players (<16 y) who would be expected to have lower training volume. The current study suggests that male professional soccer players achieve no improvement in VO_{2max} from junior age. This stagnation may be considered in the context of other priorities of physical capabilities among soccer coaches.

Season Time

It is surprising that our results showed no significant VO_{2max} differences across the 3 season-time categories (n = 108; Figure 4). A cross-sectional ANOVA analysis

Table 1 Sample Size, Age, Body Mass, Maximal Aerobic Power (VO_{2max}), and Velocity at VO_{2max} (vVO_{2max}) for Analyzed Categories, Mean ± SD

Category	n	Age (y)	Body-mass index	VO_{2max} (L)	vVO_{2max} (km/h)
Performance level					
national team	52	25.5 ± 3.6[a]	23.3 ± 1.5	5.02 ± 0.47	16.5 ± 1.0
1st division	546	23.6 ± 4.1	23.5 ± 1.5	4.90 ± 0.48	16.2 ± 0.9
2nd division	156	23.7 ± 3.7	23.3 ± 1.4	4.82 ± 0.44[g]	16.2 ± 1.0
3rd–5th division	439	22.7 ± 3.8	23.2 ± 1.9	4.64 ± 0.47[g]	15.5 ± 1.2[k]
junior national team	118	17.9 ± 1.2	22.3 ± 1.6[c]	4.68 ± 0.49[g]	16.0 ± 1.1
juniors	234	17.4 ± 1.3	22.1 ± 1.7[c]	4.43 ± 0.50	15.7 ± 1.0[k]
Playing position					
forward	167	23.1 ± 4.3	23.6 ± 1.7[d]	4.91 ± 0.52	16.2 ± 1.0
defender	237	23.1 ± 4.4	23.3 ± 1.4	4.96 ± 0.49	16.3 ± 0.9
midfielder	253	22.2 ± 4.1	22.9 ± 1.5[d]	4.76 ± 0.45[h]	16.4 ± 0.9
goalkeeper	59	23.1 ± 7.1	23.6 ± 2.2	4.89 ± 0.45	15.2 ± 1.1[l]
Age					
<18 yr	91	17.1 ± 0.5	22.5 ± 1.6[e]	4.68 ± 0.42[i]	16.1 ± 1.0
18–20 y	152	19.0 ± 0.6	22.7 ± 1.7	4.72 ± 0.53[i]	16.1 ± 1.0
20–23 y	147	21.4 ± 0.9	23.0 ± 1.5[e]	4.87 ± 0.46	16.3 ± 0.9
23–26 y	152	24.4 ± 0.8	23.7 ± 1.3[e]	4.97 ± 0.46	16.2 ± 1.0
26–29 y	104	27.3 ± 0.9	23.8 ± 1.3	5.00 ± 0.44	16.3 ± 0.9
>29 y	70	31.1 ± 1.7	24.2 ± 1.6	5.04 ± 0.51	16.1 ± 1.0
Season time					
preseason	375	22.6 ± 4.3	23.3 ± 1.6	4.89 ± 0.48	16.2 ± 0.9
in season	104	22.6 ± 4.4	23.0 ± 1.6	4.81 ± 0.46	16.4 ± 0.9[m]
off-season	172	23.3 ± 4.2	23.4 ± 1.8	4.88 ± 0.52	16.1 ± 1.0
Time epoch					
1989–1995	124	20.7 ± 3.6[b]	22.5 ± 1.5[f]	4.70 ± 0.42[j]	15.9 ± 1.2
1995–2000	277	23.0 ± 4.1	23.3 ± 1.6	4.89 ± 0.48	16.4 ± 0.9[n]
2000–2006	148	23.8 ± 4.4	23.4 ± 1.6	5.01 ± 0.50[j]	16.3 ± 0.9[n]
2006–2012	167	23.0 ± 4.5	23.6 ± 1.6	4.85 ± 0.50	16.1 ± 0.8

[a] National team players > other performance-level categories ($P < .05$). [b] Players from epoch 1989–1995 < other epoch groups ($P < .001$). [c] Junior national team and juniors < other performance-level groups ($P < .01$). [d] Midfielders < forwards ($P = .001$). [e] <18-y and 18- to 20-y players < 20–23 y < the other age groups ($P < .001$). [f] 1989–1995 players < the other epoch players. [g] National team, 1st and 2nd > 3rd–5th and junior national team (except 2nd vs junior national team) > juniors ($P < .001$). [h] Midfielders < forwards and defenders ($P < .05$). [i] <18-y and 18- to 20-y players < other age groups ($P < .05$) except 18–20 vs 20–23 y. [j] 1989–1995 < all other epochs ($P < .05$). 2000–2006 > 2006–2012 ($P < .05$). [k] 3rd–5th and juniors < other performance-level groups ($P < .001$). [l] Goalkeepers < other positions ($P < .001$). [m] In season > preseason and off-season ($P < .01$). [n] 1989–1995 < 1995–2006 > 2006–2012 ($P < .05$).

(n = 716; Table 1) showed essentially the same results. This indicates that the soccer players in our study have prioritized other physical qualities through the whole competitive season. Casajús[8] and Magal et al[9] reported higher VO_{2max} at the end of the season than early season, while Heller et al[10] and Metaxas et al[11] noted best VO_{2max} values at the end of preseason or beginning of the competitive season. The divergence of previous studies with respect to the impact of season phase on VO_{2max} may be explained by varying fitness programs and conditioning philosophies among soccer teams.

Trends Over Time

VO_{2max} among the Norwegian professional players in this study has not changed over time. In fact, players from 2006–2012 had ~2 mL · kg^{-1} · min^{-1} lower VO_{2max} than 2000–2006 players. No studies have so far monitored professional soccer players' VO_{2max} characteristics in a long-term perspective. Our data do not support the contention that VO_{2max} among male players has improved over time. However, we do not know if players from other nations have experienced the same trend. Stølen et al[1] suggested that VO_{2max} among high-performance teams has been elevated over the last decade compared with that reported in the 1980s. However, that claim was based on 3 or 4 studies from the 1980s with small sample sizes. Our time-epoch analysis was restricted to professional players, and our findings are not likely to be explained by a selection bias. Instead, we hypothesize that Norwegian teams have prioritized other physical qualities. This contention is supported by our finding of a moderate improvement in sprinting velocity over time for the same group of players.[13] All findings together strongly support the conclusion of Reilly et al,[4] who argued that a VO_{2max} of about ≥60 mL · kg^{-1} · min^{-1} represents a threshold to perform the intermittent work pattern of soccer, while other qualities are more predictive of individual and team success beyond this threshold.

Practical Applications

In the current study, no differences in VO_{2max} were observed among players from a broad range of playing standards. Only small differences in VO_{2max} (~2 mL · kg^{-1} · min^{-1}) among outfield players were identified. Furthermore, our investigation shows there were no differences in VO_{2max} between age groups. No VO_{2max} differences across the 3 season-time categories were observed. Finally, VO_{2max} among the professional players in this study has not changed over time. Our findings indicate that VO_{2max} varies little between playing standards in male professional soccer players. Soccer performance depends on a large physiological and technical skill set. The key skills must be maximized, while certain capabilities merely need to meet a minimum requirement. It is therefore important that coaches and conditioning experts balance their training methods and exercises to optimize these different skills in relation to their contribution to overall soccer performance.

Conclusions

This study provides effect-magnitude estimates for the influence of playing standard, player position, age, and season time on VO_{2max} in men's elite soccer. Our findings from a robust data set indicate that VO_{2max} values ~62 to 64 mL · kg^{-1} · min^{-1} fulfill the demands for VO_{2max} in men's professional soccer and that VO_{2max} is not a clearly distinguishing variable separating players of different standards.

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