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Section III – Sports Training

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Maximum Oxygen Uptake of Male Soccer Players According to their Competitive Level, Playing Position and Age Group: Implication from a Network Meta-Analysis

by

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The aim of the present meta-analysis was to compare the maximum oxygen uptake (VO2max) characteristics of male soccer players relative to their competitive level, playing position and age group and the interaction between them. The meta-analysis was based on 16 studies, employing 2385 soccer players aged 10–39 years. Higher-level soccer players showed greater (ES = 0.58 [95% CI 0.08-1.08], SE = 0.25, var = 0.06, z = 2.29, p = 0.022) VO2max performance with respect to their lower level counterparts. Furthermore, lower VO2max values in goalkeepers than defenders (ES = 1.31 (SE 0.46) [95% CI 0.41-2.21], var = 0.21, z = 2.84, p = 0.004) and midfielders (ES = 1.37 (SE 0.41) [95% CI 0.58 to 2.17], var = 0.16, z = 3.40, p = 0.001) were found. Thus, VO2max increased significantly with age (all, p < 0.01): Under 10 versus Under 11 years, Under 11 versus Under 12 years, Under 12 versus Under 13 years, Under 13 versus Under 14 years, Under 14 versus Under 15 years and Under 16-18 versus Under 20-23 years. VO2max performance is the most powerful discriminator between higher and lower-level soccer players. These findings indicate also the need for sports scientists and conditioning professionals to take the VO2max performance of soccer players into account when designing individualized position specific training programs.

Key words: *aerobic performance, age, position, soccer.*

Introduction

Soccer is one of the most popular team sports practiced around the world. During the season, elite male soccer players practice on a daily basis, often twice a day, play one or two matches per week, and take part in international tournaments such as World Championships and the Olympic Games (Slimani and Nikolaidis, 2017; Slimani et al., 2018; Stølen et al., 2005). This heavy schedule of practices and games requires well developed physical, mental and physiological characteristics (Slimani et al., 2016).

Cardiovascular fitness is one of the most important aspects of physical fitness in soccer (Da Silva et al., 2008; Nikolaidis, 2011; Stølen et al., 2005). In this context, well-developed aerobic fitness helps soccer players to maintain repetitive high-intensity actions within a soccer match, to accelerate the recovery process, and to maintain their physical condition at an optimum level during the entire game and season (Stølen et al., 2005).

In the extant scholarly literature, previous reviews dealing with physiological attributes and correlates of soccer players have been published

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(Da Silva et al., 2008; Stølen et al., 2005). However, these reviews detailed only physiological demands of Brazilian soccer players and without providing detailed information about the difference between competitive levels, playing positions and age categories. Since the last review (Stølen et al., 2005), more than 10 studies investigating the physiological profile, particularly aerobic performance, of soccer players according to many factors, have been published, underscoring the importance of this topic. Thus, the authors of this paper take the opportunity to re-evaluate the evidence to date. It is well known that understanding the specific requirements of soccer players of different competitive levels, playing positions and age categories can provide insightful information regarding what is truly needed for competitive success in that sport and prepare them for higher playing levels later in their career (Nikolaidis et al., 2014, 2015).

Despite the existing studies investigating the aerobic performance relative to different competitive levels, playing positions and age groups, the interaction between the above mentioned factors (competitive levels × playing positions × age groups) remains inconclusive. Furthermore, no meta-analysis review has been conducted so far. Identification of positional differences between competitive levels and age groups can be achieved with the use of meta-analysis: a method that allows to overcome the problems of small sample size and low statistical power. Meta-analysis is a quantitative approach in which individual study findings addressing a common problem are statistically integrated and analyzed (Hedges and Olkin, 1985). Since meta-analysis can effectively increase the overall sample size, it also can provide a more precise estimate of the age and playing position that requires a high level of aerobic performance. Thus, the purpose of this meta-analysis was to establish the physiological profile, particularly maximum oxygen uptake (VO_{2max}), of male soccer players according to their competitive level, playing position and age group, and to examine the interaction between them.

Methods

A meta-analysis was conducted to verify whether VO_{2max} measures distinguished between soccer players of different competitive levels, playing positions and age groups. Relevant studies were combined and analyzed to provide an overview of the available research on this topic. Conclusions were based on the included studies with suggestions for practical applications for strength and conditioning professionals as well as future investigations.

Search Strategy

The present meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines (Moher et al., 2009). The reviewed articles were selected following an extensive search process of the English language literature, including major databases such as PubMed/MEDLINE, Google Scholar, Web of Science and Scopus databases, with the dates ranging from January 1, 1995 to May 31, 2017. Search terms included: soccer, physical and physiological features, maximum oxygen uptake, VO_{2max}, age, playing positions, and experience level.

Inclusion and Exclusion Criteria

The inclusion criteria followed the ones of the Population/Intervention/Comparison/ Outcome(s) (PICO) framework:

(a) Population: Studies recruiting male soccer players at any age category and competitive level as participants.

(b) Intervention: Original investigations focusing on aerobic performance (VO_{2max}), as assessed using different methods (Laboratory tests: Treadmill test, Maximal Bruce Treadmill test, Cycloergometer; Field tests:20-m progressive run test, 20 m multistage shuttle run test, continuous progressive track run test, 1,000-m run/walk test) and at any period of the season (off-season (before the season), preseason (the beginning of the season, pre-season), competitive season (in-season, precompetitive period, the beginning of the competitive season, competitive season), and end of the season) of male soccer players.

(c) Comparison: VO_{2max} of male soccer players relative to their competitive level, playing position, and/or age group.

(d) Outcome(s): VO_{2max} value.

The exclusion criteria were as follows:

(a) Reviews, comments, opinions, and commentaries, interviews, letters to the editor, editorials, as well as gray literature (posters, conference

abstracts, book chapters, and books) were excluded; available reviews were scanned for increasing the chance of including potentially relevant articles.

(b) No comparison of VO_{2max}between soccer players of different competitive levels, playing positions, and/or age groups.

(c) Lacking quantitative information and details.

Screening Strategy

The studies were independently screened by two authors looking at study titles and abstracts for potential eligibility. Screening questions had been developed and pilot tested with a subset of records before implementation. Disagreement was assessed using κ statistics and resolved through discussion until consensus was reached.

Quality Appraisal

Two reviewers conducted methodological quality assessment on each included article using the modified Downs and Black scale (Downs and Black, 1998), which is appropriate for non-randomized control trials (NRCTs) and case–control study designs. Twenty seven items were used to determine the Methodological Quality Checklist of each study. Twenty-six 'yes'-or-'no' questions were scored totaling up to 26 possible points. In this review, the questions were categorized under 4 sections: Reporting (10 items), External validity (3 items), Study bias (7 items), and Confounding and selection bias (6 items).

Statistical Analyses

For the meta-analysis part, data were extracted from the included studies using a standardized documentation form. The variables extracted included the surname of the first author, year of publication, sample size, age, competitive level and playing position of players. Effect estimates were computed as standardized mean differences, with their 95% confidence interval (CIs). Meta-analyses were carried out using the commercial software Comprehensive Meta-Analysis (CMA v3.0). While the concept of multiplicity of statistical testing and, as such, the need for correcting and adjusting generated *p*-values for multiple comparisons have been widely recognized and addressed in primary research, these issues have been overlooked in research synthesis and meta-research. Some scholars think, indeed, that meta-analyses, relying upon effect sizes and not on *p*-values, and pooling together a relevant number of studies, are not plagued by the increased probability of falsely rejecting a true null hypothesis. Instead, "although research synthesis may combine findings from hundreds of studies and thousands of respondents, they are not immune to inflated type 1 error when many statistical tests are conducted without adequate control for the error rate" (Bender et al., 2008; Cook and Campbell, 1979). Currently, there is still no consensus regarding the best way to address this issue. In the current paper, we performed a univariate meta-regression (a multi-variate regression was not possible because of the number of included studies and moderators under scrutiny), to study the overall effect and after we performed standard direct pairwise comparisons, adjusting the *p*-value for multiple testing. Statistical heterogeneity was also assessed in our meta-analysis, using the I^2 statistic. If I^2 was >50%, this was regarded as substantial significant heterogeneity. Possible publication bias was visually inspected with a funnel plot, looking at asymmetry of the graph, as well as computing the Egger's regression test.

When available, standard direct/head-to-head pairwise comparisons were synthesized. Indirect comparisons were estimated via the formula of Bucher and colleagues (1997).

Results

Study Selection

The search strategies yielded a preliminary pool of 1521 possible papers. The full text of 35 articles was retrieved and assessed for eligibility against the inclusion criteria. After a careful review of their full text, 18 articles were excluded and the remaining 17 articles were eligible for inclusion in the review. Particularly, 4 papers assessed VO_{2max} of soccer players according to the competitive level. Eight articles focused on VO_{2max} of soccer players relative to their playing position. Nine studies focused on VO_{2max} of soccer players relative to age groups.

Subjects

The total number of participants included in this review was 2385. Sample size ranged between 27 and 296. The subject's age within the selected studies ranged from 10 to 39 years. Additionally, the training status of participants

varied from amateur to elite.

Methodological Quality

The methodological quality scores ranged from 8 to 15, with the average score being around 11.

Random-effect Model

Due to the statistically significant heterogeneity found, a random-effect model was applied in the current paper. VO_{2max} values stratified according to competitive levels, playing positions and age groups, I^2 resulted 93.05%, 96.70%, and 97.77%, respectively.

Competitive levels

Greater VO_{2max} values in higher-level soccer players than in lower-level players were observed (ES = 0.58 [95% CI 0.08-1.08], SE = 0.25, variance = 0.06, z = 2.29, p = 0.022; Figure 1). Statistically significant predictors were found to be the performed test (p = 0.0076) and the period of the season (p = 0.0056; with values higher at off-season and lower at the end of the season, p = 0.0051 and p = 0.0449, respectively). Age was not found to significantly impact VO_{2max} stratified according to competitive levels (p = 0.7792). No evidence of publication bias could be found, both performing the Egger's regression test and visually inspecting the funnel plot.

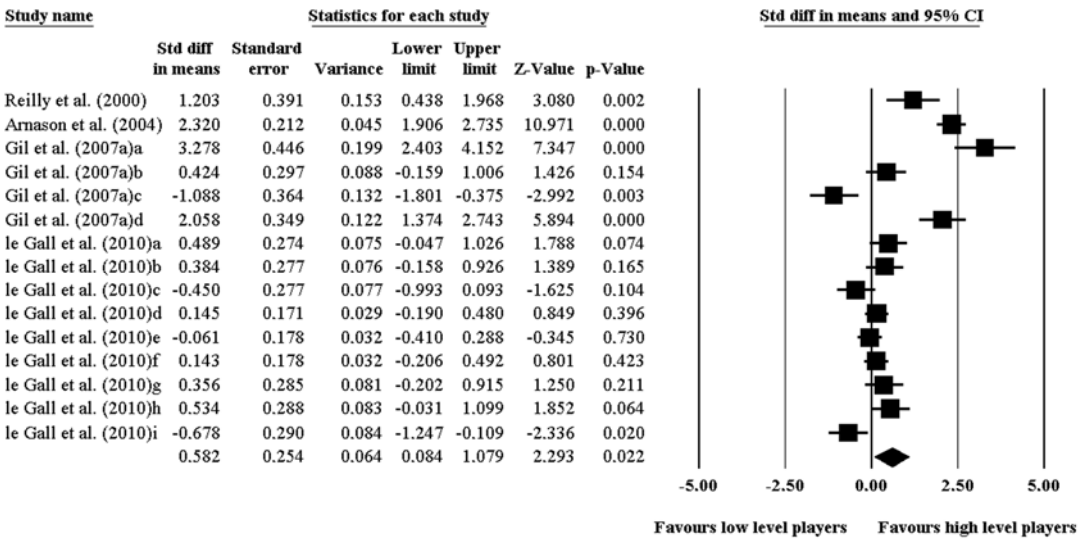

Figure 1

Forest plot of differences in VO_{2max} values stratified according to competitive levels (higher- versus lower-level).

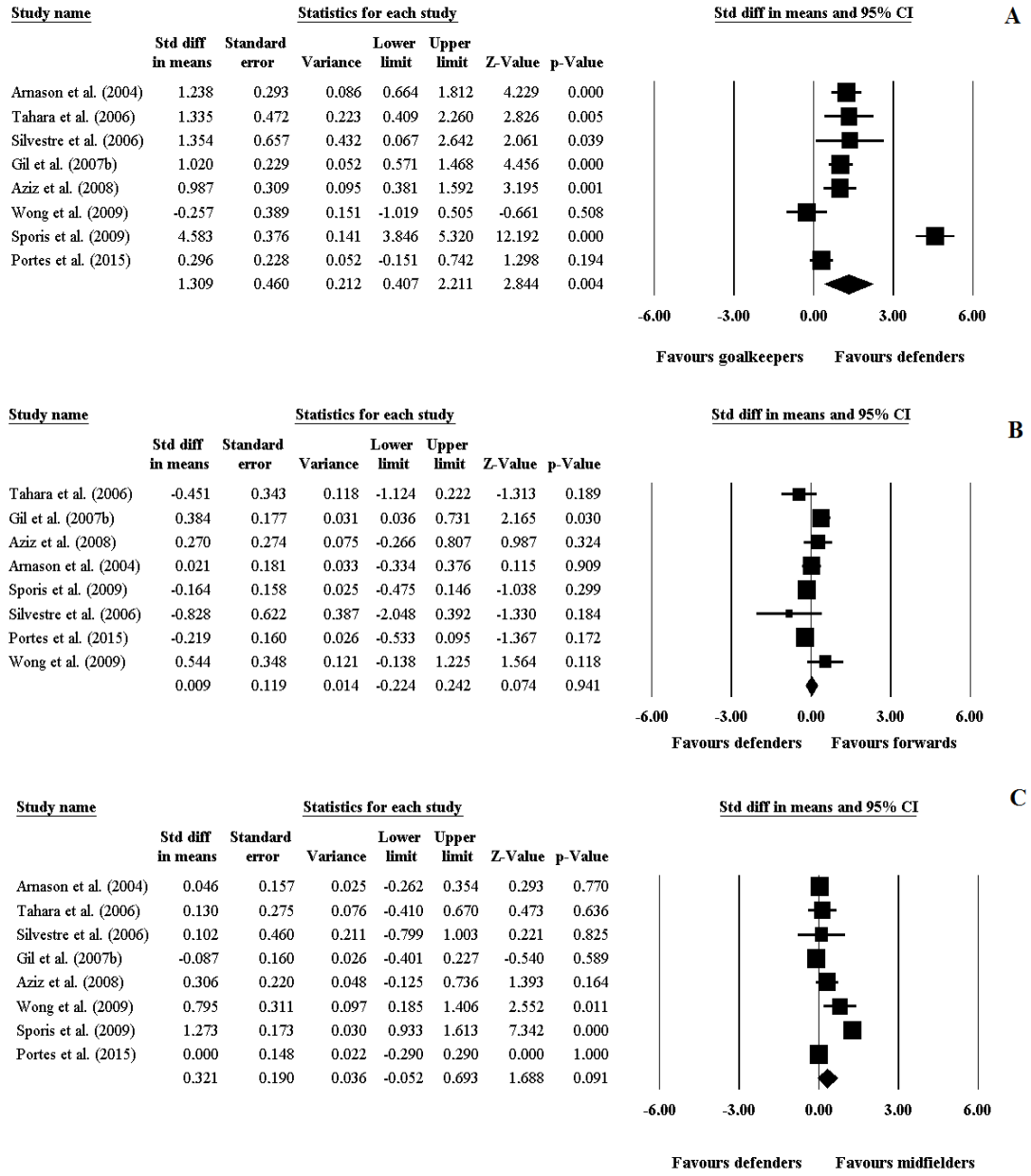

Figure 2a.

Forest plot of differences in VO_{2max} values stratified according to playing positions (defenders versus goalkeepers [A]; forwards versus defenders [B]; defenders versus midfielders [C]).

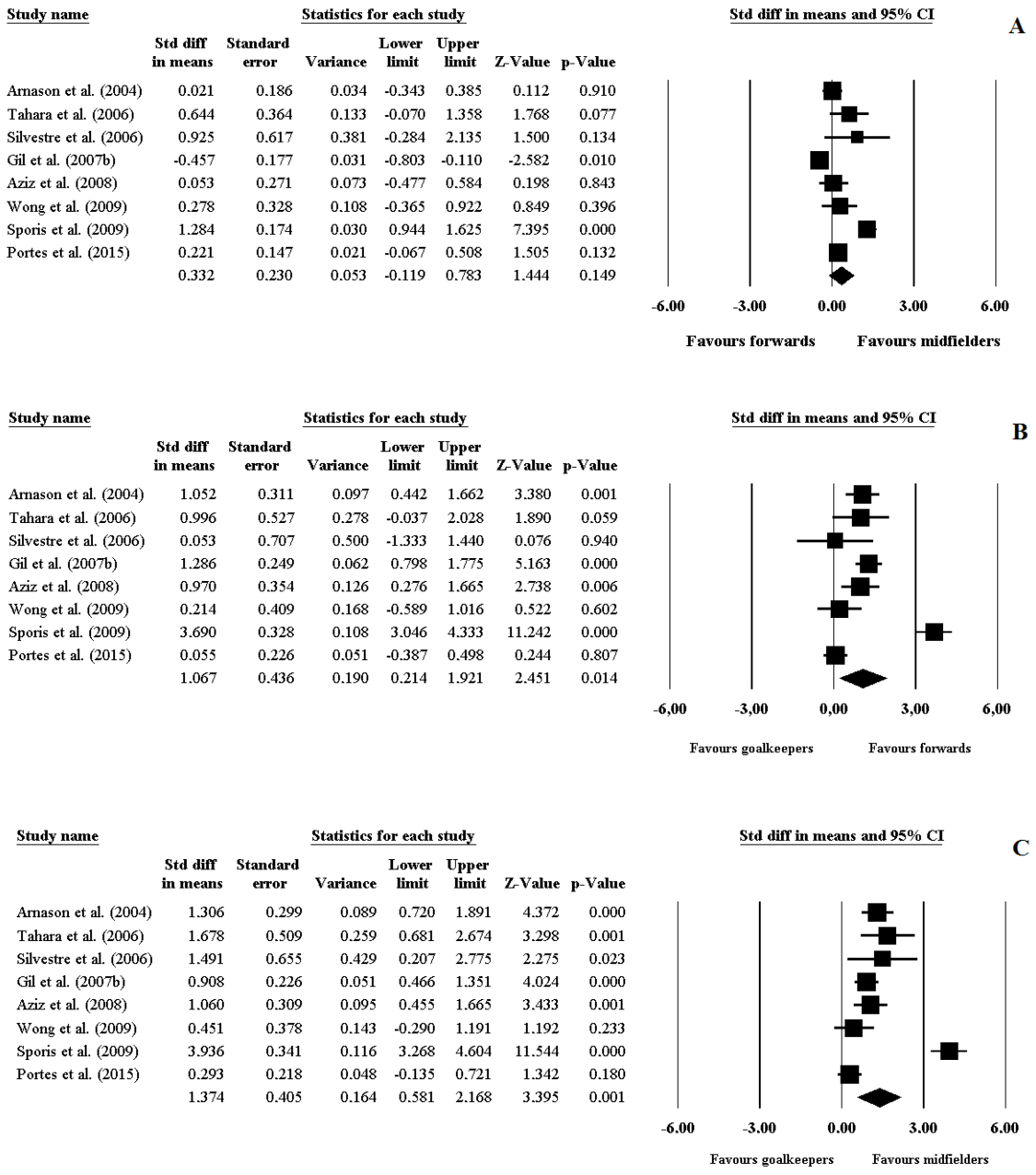

Figure 2b.

Forest plot of differences in VO_{2max} values stratified according to playing positions (midfielders versus forwards [A]; goalkeepers versus forwards [B]; goalkeepers versus midfielders [C]).

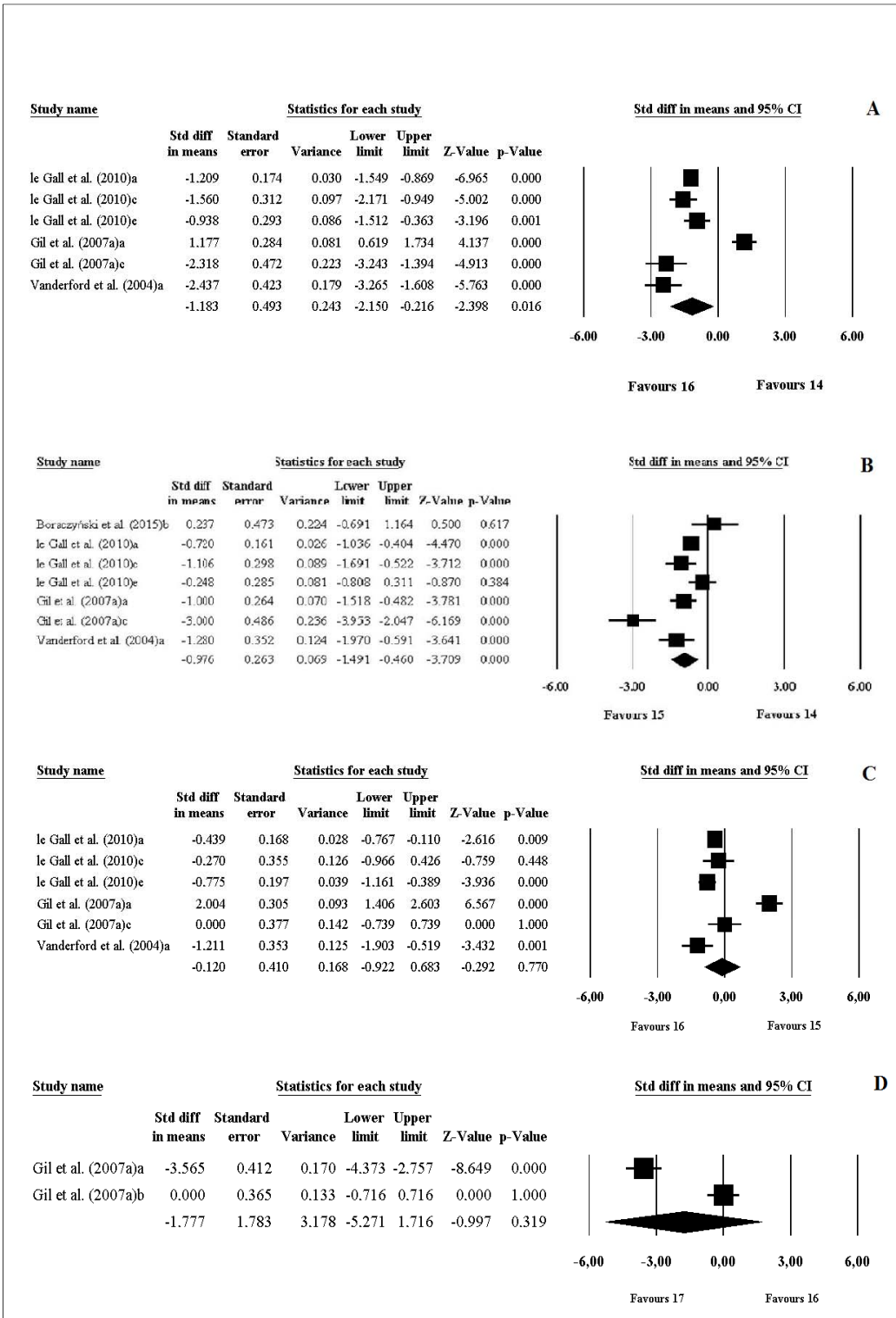

Figure 3.

Forest plot of differences in VO_{2max} values stratified according to age groups (Under 14 versus 16 years [A]; Under 14 versus 15 years [B]; Under 15 versus 16 years [C]; Under 16 versus 17 years [D]).

Playing positions

Overall, the competitive level (p = 0.0564) and period of season (p = 0.0537) did not significantly impact VO_{2max} values stratified according to playing positions, as well as the performed test (p = 0.5179) and age (p = 0.8792). No evidence of publication bias could be found. Focusing on pairwise comparisons, the difference in VO_{2max} values between midfielders *versus* forwards (ES = 0.33 (SE 0.23) [95% CI -0.12 to 0.78], var = 0.05, z = 1.44, p = 0.149), as well as the difference between midfielders *versus* defenders (ES = 0.32 (SE 0.19) [95% CI -0.05 to 0.69], var = 0.04, z = 1.69, p = 0.091) was not significant. Greater VO_{2max} values in midfielders than in goalkeepers (ES = 1.37 (SE 0.41) [95% CI 0.58 to 2.17], var = 0.16, z = 3.40, p = 0.001) were observed, whereas the difference between forwards *versus* defenders (ES = 0.01 (SE 0.12) [95% CI -0.22 to 0.24], var = 0.01, z = 0.07, p = 0.941) did not yield statistical significance. Finally, higher VO_{2max} values in forwards (ES = 1.07 (SE 0.44) [95% CI 0.21-1.92], var = 0.19, z = 2.45, p = 0.014) and in defenders (ES = 1.31 (SE 0.46) [95% CI 0.41-2.21], var = 0.21, z = 2.84, p = 0.004) than in goalkeepers was detected. Concerning pairwise comparisons, no evidence of publication bias was found apart from defenders *versus* goalkeepers (Figures 2a, 2b).

Age Groups

VO_{2max} increased significantly with age. At the meta-regression, period of the season (p = 0.0003; with higher values during the competitive season with respect to the pre-season, p = 0.0112, and to the end of the season, p = 0.0001), and the competitive level (p = 0.0002) were found to be statistically significant predictors of VO_{2max} values stratified according to age. No evidence of publication bias could be found, both visually inspecting the funnel plot and performing the Egger's regression test.

Concerning pairwise comparisons, higher VO_{2max} values in U14 than in U15 (ES = -0.98 (SE 0.26) [95% CI -1.49 to -0.46], var = 0.07, z = -3.71, p< 0.001), and in U14 than in U16 (ES = -1.18 (SE 0.49) [95% CI -2.15 to -0.22], var = 0.24, z = -2.40, p = 0.016) were found. The difference between U15 *versus* U16 group, instead, failed to achieve statistical significance (ES = -0.12 (SE 0.41) [95% CI -0.92 to 0.68], var = 0.17, z = -0.29, p = 0.770). Similarly, the difference between U16 *versus* U17 was not significant (ES = -1.78 (SE 1.78) [95% CI -5.27 to 1.72], var = 3.18, z = -1.00, p = 0.319). For further details, the reader is referred to Figure 3. Concerning pairwise comparisons, no evidence of publication bias was found.

Other pairwise comparisons were estimated *via* indirect comparisons according to the equation of Bucher and colleagues (1997). Age 14 *versus* age 17 yielded an ES of 0.59 [95% CI -3.03 to 4.22], whereas age 15 *versus* age 17 an ES of 1.66 [95% CI -1.93 to 5.25].

Discussion

The present meta-analysis shows that aerobic fitness was a discriminator of successful performance in soccer between higher- and lower-level players. It was also shown that the outfield players, except for forwards, exhibited the highest VO_{2max} values in the team. Thus, VO_{2max} increased significantly with age, particularly comparing the groups each year, between Under 10 and 15 years. Furthermore, the competitive level, positional and age differences varied by the period of the season.

Determining VO_{2max} of soccer players according to the competitive level, playing position, and age group is useful when assessing talent, in selection of players, the design of physical conditioning programs, predicting and monitoring physical match performance. Therefore, establishing reference variables in high performance players can assist in making important informed decisions, particularly for the strength and conditioning staff at soccer clubs to optimize the training program.

Competitive Level

Overall, VO_{2max} values were in the range of 48–62 ml/kg/min for male soccer players regardless of their competitive level. Particularly, VO_{2max} values reported range from 59.2 to 63.2 ml/kg/min, from 59.2 to 61.5, from 58.2 to 62.2 and from 57.8 to 61.7ml/kg/min for elite, international, profesional and amateur male soccer players, respectively, in different competitive levels and age groups.Furthermore, the present meta-analysis reported that VO_{2max}largely distinguished higher-from lower-level soccer players. Particularly, significantly greater VO_{2max} values were reported in three investigations, all of which stratified by the competition level. Specifically, Reilly et al. (2000) and Arnason et al. (2004) reported that VO_{2max} was significantly greater amongst elite soccer players when compared with sub-elite ones. In agreement

with the high VO_{2max} values in superior competitors, significantly greater VO_{2max} values were reported in selected soccer players when compared with non-selected counterparts (Gil et al., 2007a). In contrast, when comparing within competition levels, le Gall et al. (2010) reported that $VO_{2max}$was not a discriminator of successful performance in soccer at the age of 14, 15 and 16 years. Furthermore, the competitive level differences varied by the period of the season and the assessment method of VO_{2max}.

In conclusion, aerobic performance is an important variable for achieving high-level soccer performance and accurately discriminates between higher- and lower-level soccer players. For that reason, practitioners should plan specific training sessions soliciting the aerobic system in amateur soccer players, in order to simultaneously improve the recovery pattern and performances as in elite players, with respect to the period of the season and the performed test.

Playing Positions

Identifying each player's specialized position is especially important in order to optimize their physical development so that to prepare them for higher playing levels later in their career. Particularly, the current meta-analysis found significant differences in VO_{2max} between playing positions. More specifically, higher VO_{2max} values in outfield players, except for forwards, than in goalkeepers were reported. Overall VO_{2max} values reported in the scientific literature varied between 48.4 and 57.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for male goalkeepers, between 53.2 and 62.8 $ml \cdot kg^{-1} \cdot min^{-1}$ for defenders, between 54.7 and 63 $ml \cdot kg^{-1} \cdot min^{-1}$ for midfielders, and between 54.5 and 62.9 $ml \cdot kg^{-1} \cdot min^{-1}$ for forwards. A possible reason for this is that each playing position has different tactical requirements and that goalkeepers cover the least distance while midfielders run the greatest distances during soccer match-play (Mohr et al., 2003; Rampinini et al., 2007). VO_{2max} values of each playing position may also reflect training effects from the match-play in competition as well as in training, in addition to the organized conditioning performed by these players. In addition, the present meta-analyses showed that the competitive level, period of the season, performed test, and participants' age did not significantly impact VO_{2max} values stratified according to playing positions. A previous systematic review reported that non-professional forwards had higher mean VO_{2max} values compared with non-professional young midfielders and defenders, but when the players approached the professional level, positional differences also existed, with higher VO_{2max} values in elite young midfielders compared with elite attackers and defenders (Slimani and Nikolaidis, 2017). It seems that positional differences appear at all ages. Finally, practitioners should adopt an appropriate training plan considering playing positions of players that would adequately elicit heightened cardiorespiratory demands in outfield players, except for forwards, at all ages compared to goalkeepers.

Age Groups

It was shown that VO_{2max} increased with age, particularly between Under 10 and Under 14 years (Boraczyński et al., 2015; Canhadas et al., 2010), Under 14 and Under 15 years and between Under 14 and Under 16 years. Higher VO_{2max} values in senior than in junior soccer players were also observed (Aziz et al., 2008). This is explained in part by the differences of biological maturity status, body size and training volume between Under 10 and Under 15 years and between senior and junior soccer players (Mendez-Villanueva et al., 2010). One possible reason for heterogeneity between studies in young soccer players is that the variety of tests to exhaustion that have been used in male soccer studies to predict VO_{2max} may influence the comparison between the results of non-professional young athletes who presented greater heterogeneity in the mean values of VO_{2max}. Moreover, VO_{2max} measurements may be not reliable in patients as well as in unmotivated or exercise tests-naïve subjects, who may stop exercising before reaching VO_{2max} (Poole et al., 2017). On the other hand, for young elite or professional players, VO_{2max} means were more homogeneous and the comparisons between different ages showed a larger effect size, indicating a stronger effect. Thus, VO_{2max} exercise tests in young healthy athletes can be performed until exhaustion. For instance, while running or cycling, the incremental cardiopulmonary exercise test yields a highly reproducible VO_{2max} irrespective of the exercise test protocol, work rate, forcing function or pacing strategy (Poole et al., 2017). In addition, there were no significant differences between Under 15 and Under 16,

between Under 16 and Under 17, between youth (14 years) and senior (24 years) players (Chamari et al., 2005), between pubescent (13.4 years) and post-pubescent (17 years) players (Cunha et al., 2011) and between 18.6, 22.5, and 26.7 year old players (Botek et al., 2016). This phenomenon could be explained by the small difference in chronological and biological age between those groups. Finally, soccer players should be at different maturation levels, and those who are more mature are likely to present greater aerobic performance (Carling et al., 2009; Hirose et al., 2009; Lovell et al., 2015). These differences in VO_{2max} across ages indicate that high-intensity training may be administered in older soccer players' training programs, with respect to their competitive level and the period of the season.

Period of the Season

The competitive soccer season lasts from eight to nine months, with a mean of two matches a week and a high aerobic intensity demand estimated at about ~80% of VO_{2max} by game(Reilly et al., 2000). This intensity is similar to the anaerobic threshold values of professional players (Edwards et al., 2003), what makes it difficult to keep optimal physical fitness throughout the entire season. This statement is supported by present findings which indicated that the period of the season significantly impacted VO_{2max} values stratified according to competitive levels and age groups. Coaches and strength and conditioning specialists should determine the differences in VO_{2max} performance between competitive levels and age groups at the off-season and competitive season rather than at the end of the season and the pre-season.

Assessment Method Effect

Regarding the evaluation of VO_{2max}, studies demonstrated a special attention to field-test assessment , about 60% of all of them proposed continuous and intermittent shuttle running field-tests (Aziz et al., 2008; Boraczyński et al., 2015; Canhadas et al., 2010; Gil et al., 2007a, b; Le Gall et al., 2010; Portes et al., 2015; Reilly et al., 2000; Silvestre et al., 2006) for their ecological, criterion and synchronized validity and subsequently a very strong (r = 0.8-1.0) relationship with the direct assessment method for senior athletes (Bangsbo et al., 2008; Castagna et al., 2009; Leger and Lambert, 1982; Paliczka et al., 1987; Rampinini et al., 2007). Present meta-analyses highlighted that the type of a test significantly impacted VO_{2max} values stratified according to competitive levels and age groups. This result indicated an important confounding factor, since the measurement method could influence VO_{2max} results.

Limitation and Practical Implications

Present results could not provide insights into the interactions between the reported factors as our meta-analysis is based on a variety of studies using different combinations of factors (e.g., competitive levels, playing positions, age groups, period of the season, and performed tests). Previous studies did not consider these specific factors, most of investigations verified only the influence of one or two independent factors. In addition, previous studies had very heterogeneous sample sizes, what makes our meta-regression analysis essential, demonstrating the effect size and considering the samples.

The ability of the cardiorespiratory system to transport oxygen to the muscles refers to the central component of VO_{2max} – the most physiologically important and, therefore, the most frequent measured variable in the assessment of male soccer players. To insure valid and reliable VO_{2max}, present findings indicated practical concerns according to the competitive level, playing position and age groups. Results allow us to suggest that maturational and training effects on oxygen delivery (via pulmonary diffusion, cardiac output, and blood volume and flow) should be considered in training programs, as higher effect sizes of age and level comparisons were demonstrated in meta-regression analysis. Results showed that the outfield players, except for forwards, exhibited higher VO_{2max} values, while goalkeepers showed the lowest values of VO_{2max}. These findings seems to suggest that each player's position needs to consider specific muscle mass and the motion used for soccer' training programs, since the potential sites for VO_{2max} limitation in the peripheral component include mitochondrial enzyme (facilitating the ATP production) levels, muscle diffusion capacity and capillary density (Bassett and Howley 2000). Moreover, VO_{2max} variables can be used to design specific training programs for particular playing positions.

Conclusions

Despite the strengths given by its systematic approach, the current meta-analysis is

characterized by a number of shortcomings that should be properly recognized. High, statistically significant heterogeneity is the major limitation, calling for caution in interpreting the findings. Furthermore, evidence of publication biases was noticed. The lack of consistency or uniformity in testing protocols to assess VO_{2max}, variety in the fitness status of players, the stage of the season when they were tested, their motivation and environmental conditions make it difficult to compare between studies and only assumptions should be made when assessing these differences. In regard to the above-mentioned limitations, the present meta-analysis is essential to characterize and create a more detailed profile of soccer players' aerobic fitness in their different competitive levels, playing positions and age groups.

Among trained soccer players, the VO_{2max} test was able to discriminate between goalkeepers and outfielders, except for forwards, which suggests that aerobic performance is one of the most important indicators of talent in soccer. This finding emphasizes outfield-position specific fitness training. Superior aerobic performance was also associated with a higher level of competitiveness and/or adaptation to high-intensity training and this has implications for the teams' training strategies. Practitioners should adopt an appropriate training plan that would adequately stress the cardiorespiratory system in soccer players, with respect to their age, competitive level and period of the season.

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