Creatine Supplementation on Soccer Athletic Performance: A Systematic Review and Meta-Analysis

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Abstract: Creatine is one of the most used ergogenic aids by athletes. However, researches in soccer players has shown controversial results given that have been studied on general performance, without taking into account the metabolic energy system used. The main aim of this investigation was to perform a systematic review and meta-analysis to conclude the efficacy of creatine supplementation to increase performance on skills related to soccer depending on metabolism used (aerobic, alactic anaerobic and lactic anaerobic metabolism). A structured search was carried out following the PRISMA guidelines in the Medline/PubMed and Web Of Science, Cochrane Library and Scopus databases until January 2019. The search included studies with a double-blind and randomized experimental design in which the creatine supplementation was compared to an identical placebo situation. There were no filters applied to the soccer players’ level, gender or age. A final meta-analysis was performed using the random effects model and pooled standardized mean differences (G Hedges). Nine studies published were included in the meta-analysis. This revealed that the creatine supplementation did not presented beneficial effects on aerobic performance tests (standardized mean difference; 95% confidence intervals = -0.05; -0.37 – 0.28; p=0.78) and on alactic anaerobic metabolism performance tests (strength, single jump, single sprint and agility test) (0.21; -0.03 – 0.45; p=0.08). However, creatine supplementation showed beneficial effects on lactic anaerobic performance tests (1.23; 0.55 – 1.91; p=0.001). Concretely, creatine demonstrated a large and significant effect on Wingate test performance (2.26; 1.40 – 3.11; p=0.001). In conclusion, creatine supplementation with a high dose of 20-30 g/day divided 3-4 times per day ingested for 6-7 days or with a low dose of 3 mg/kg/day for 14 days or more presents positive effects on improving the physical performance tests related to lactic anaerobic metabolism, especially anaerobic power in soccer players.

Keywords: sport nutrition; nutritional supplements; recovery, team sports; physical performance; ergogenic aids
1. Introduction

Creatine (Cr) is one of the most used ergogenic nutritional aids by athletes. Studies have shown that the effective loading dose for Cr supplementation with 0.3 g/kg/d for 5 to 7 days, followed by a maintenance dose of 0.03 g/kg/d most commonly for 4 to 6 weeks [1] increases intramuscular phosphocreatine (PCr) concentrations by favoring lactic anaerobic metabolism [2], which may help explain the observed improvements in the performance of high intensity exercises that lead to greater training adaptations [3,4]. Likewise, Cr supplementation has been shown to favor the recovery of muscle glycogen, which can help those athletes who perform a prolonged sub-maximum effort (65-75% peak VO2max) [5] or repeated high intensity exercises [6,7], in relation with aerobic and lactic anaerobic metabolism, respectively. Due to this circumstance, there are many sports modalities that its practice involves the combination of high intensity actions, in isolation or repeatedly, with low intensity actions or rest periods [8]. Among them, in particular soccer is characterized by combining high-intensity activities such as: sprinting, running, accelerating, jumping, changing of direction with low intensity phases (stopping or walking) [9]. Besides, the average distance covered by the players during a soccer match is between 8 and 12 kilometers [10] where they perform between 50 to 250 high intensity actions [11] representing about the 1 to 12% of the total distance covered [12]. In this sense, during the high and maximum intensity phases, the energy that a player gets is obtained through anaerobic processes (both lactic and alactic), whereas during the general effort on a soccer match (90 minutes), it is obtained by aerobic ways [13]. Therefore, having substrates that provide the necessary energy in each moment seems to be an objective to obtain the maximum performance [14].

There have been numerous studies focusing on the effects of Cr supplementation on soccer performance with mixed results. Thus, while Biwer et al., [15] and Williams et al., [16] showed possible benefits on the aerobic performance, other authors do not show these benefits [17-19]. Similar case happens when it talks about tests that use alactic anaerobic metabolism. In this case, while there are several studies that observed potential positive effects the Cr supplementation in this metabolism [6,18,20], Ramirez-Campillo et al., [19] and Williams et al., [16] did not observe any benefits in the performance of individual actions, like in a single jump or in a sprint. However, all the studies that have focused on the effect of Cr supplementation in relation to lactic anaerobic metabolism, such as repeated sprints [17,19,21] or the Wingate test [6,7], showed possible beneficial effects, although the final effect is unknown given that some of these benefits are rather small [17,19,21].

Although Cr could improve soccer performance, the best of the authors’ knowledge, there is not a clear consensus on what type of soccer skills could be more effective. Moreover, it would be necessary to unify the data of the different studies in order to serve as support to soccer world and to be able to apply it over a season. To date, to our knowledge no previous meta-analysis has been published in that field. Therefore, it was proposed to carry out a systematic review with final meta-analysis of articles published in the scientific literature, whose main aim is to know the potential effects of Cr on soccer athletic performance depending on the metabolic energy system used (aerobic, lactic anaerobic and lactic anaerobic metabolism).

Thus, this systematic review with meta-analysis presents current information about the effects of Cr on soccer’s physical performance. In addition, it shows the effective doses and the ideal moment of its intake.

2. Methods
2.1. Searching strategies
The present article is a systematic review with a meta-analysis focusing on the effect of Cr or Cr monohydrate on soccer performance. It was carried out following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines that would help to improve the integrity of this review [22] and the PICOS model for the definition of the inclusion criteria [23]: P (Population): “soccer players”, I (Intervention): “creatine supplementation”, C (Comparators): “same conditions with placebo”, O (Outcome): “soccer-specific skills and relationships with aerobic, alactic anaerobic and lactic anaerobic performance”, and S (study design): “double-blind and randomized design”.

A structured search was conducted in the following databases: PubMed/MEDLINE, WOS (which includes other databases such as BCI, BIOSIS, CCC, DIIDW, INSPEC, KJD, MEDLINE, RSCI, SCIELO), Cochrane Library and Scopus. It was completed until 30-January-2019, while no year restriction was applied to the search strategy. Search terms included a mix of Medical Subject Headings (MeSH) and free-text words for key concepts related to Cr and soccer performance. Concretely, it used following search equation: ("football"[All Fields] OR "soccer"[All Fields]) AND "creatine supplementation"[All Fields] AND ("physical performance"[All Fields] OR "physical endurance"[All Fields] OR "physical"[All Fields] OR "endurance"[All Fields] OR "performance"[All Fields] OR aerobic[All Fields] OR anaerobic[All Fields]). It has obtained relevant articles in the field of applying the snowball strategy. All titles and abstracts from the search were cross-referenced to identify duplicates and any potential missing studies. Titles and abstracts were screened for a subsequent full-text review. The search for published studies was independently performed by two different authors (JMA and JCG) and disagreements were resolved through discussion between them.

2.2. Inclusion and exclusion criteria

There were no filters applied to the soccer players’ level, gender, race or age to increase the power of the analysis. However, for the articles obtained in the database search, the following inclusion criteria were applied to select the final studies: 1) in which there was an experimental condition that included the ingestion of Cr-or E-containing product before and/or during exercise which was compared to an identical experimental condition with the ingestion of a placebo; 2) testing the effects of Cr on soccer-specific tests and/or real or simulated matches; 3) with a blinded and randomized design; 4) with clear information regarding the administration of Cr (relative dose of Cr per kg of body mass and/or absolute dose of Cr with information about body mass; timing of Cr intake before the onset of performance measurements, etc.; 4) on soccer players with previous training background in this sport; 5) published in any language. On the other hand, following exclusion criteria were applied to the experimental protocols of the investigation: 1) articles that were not conducted with soccer players; 2) articles that were performed for clinical purposes or therapeutic use; 3) absence of a true placebo condition; 4) carried out in participants with a previous condition or injury.
year of publication), study design, Cr supplementation (dose and timing), sample size, characteristics of the participants (level and gender), and final outcomes of the interventions were extracted independently by two authors using a spreadsheet. Subsequently, disagreements were resolved through discussion until a consensus was achieved.

Experiments were clustered by the type of test used to assess team sport performance and groups of experiments were created which assessed the effect of Cr on aerobic performance (Yo-Yo test), alactic anaerobic measures (strength, jump, sprint, and agility course), lactic anaerobic measures (repeated sprint ability, and Wingate test). Six studies...
included measurements in two or more types of performance outcomes (e.g. aerobic and anaerobic), or even two types of tests for the same performance outcome. In these cases, each test or type of performance outcomes were treated as a single and independent set of data for the meta-analysis and included in the appropriate performance outcome.

Mean (M), standard deviation (SD) and sample size data were extracted by one author from tables of all included papers (DMJ). Whenever necessary, we made contact with the authors to get the data. When it was impossible, mean and SD were extrapolated from the figures. Any disagreement was resolved by consensus (JMA and DMJ), or third-party adjudication (JCG).

2.4. Quality assessment of the experiments

Methodological quality and risk of bias were assessed by two authors independently (JMA and DMJ), and disagreements were resolved by third part evaluation (JCG), in accordance with the Cochrane Collaboration Guidelines [24]. The items on the list were divided into different domains: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other type of bias. They were characterized as ‘low’ if criteria for a low risk of bias were met (plausible bias unlikely to seriously alter the results) or ‘high’ if criteria for a high risk of bias were met (plausible bias that seriously weakens confidence in the results). If the risk of bias was unknown, it was considered ‘unclear’ (plausible bias that raises some doubt about the results). Full details are given in Table 1 and Figure 1.

**Table 1.** Risk of bias graph: review authors’ judgements about each risk of bias item presented as percentages across all included studies. ● indicate low risk of bias; ○ indicate unknown risk of bias; ! indicate high risk of bias.

<table>
<thead>
<tr>
<th>Study</th>
<th>Random sequence generation (selection bias)</th>
<th>Allocation concealment (selection bias)</th>
<th>Blinding of participants and personnel (performance bias)</th>
<th>Blinding of outcome assessment (detection bias)</th>
<th>Incomplete outcome data (attrition bias)</th>
<th>Selective reporting (reporting bias)</th>
<th>Other bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mujika et al. 2000</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Bembr et al. 2001</td>
<td>●</td>
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<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Cox et al. 2002</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Biwer et al. 2003</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ostojic et al. 2004</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Claudino et al. 2014</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Williams et al. 2014</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ramírez-Camplillo et al. 2015</td>
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<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Yáñez-Silva et al. 2017</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>?</td>
<td>?</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
2.5. Statistical analysis

Descriptive data of the participants’ characteristics are reported as M±SD. Descriptive analyses and figures of risk of bias were performed using a spreadsheet (Microsoft Excel 2016 USA), whereas meta-analytic statistics were made with Review Manager (RevMan) [Computer program, Version 5.3, (Copenhagen: The Nordic Cochrane Centre. The Cochrane Collaboration, 2014)]. The standardized mean difference (SMD), the number of participants and the standard error of the SMD for each research was used to quantify changes in the performance variables when comparing the ingestion of Cr versus a placebo. SMD for each study group were calculated using the Hedges’ g [25]. SMD were weighted by the inverse of variance to calculate an overall effect and its 95% confidence interval (CI). The net treatment effect was obtained by subtracting the SMD of the control group from the SMD of the experimental group. Variance was calculated from the pooled SD of change scores in both groups. Considering that the effect of Cr on performance may differ according to doses and other moderators relating to participants, we decided to use a random effects model with the DerSimonian and Laird method [26]. The Cohen criteria were used to interpret the magnitude of SMD: <0.2, trivial; 0.2 to 0.5, small; 0.5 to 0.8, moderate; and >0.8, large [27].

To avoid problems using Q statistic to assess systematic differences (heterogeneity), it calculated the I² statistic, which indicates the percentage of observed total variation across studies that is due to real heterogeneity rather than chance [24]. I² interpretation is intuitive and lies between 0% and 100%. An I² value between 25% and 50% represents a small amount of inconsistency, where as an I² value between 50% and 75% represents a medium amount of heterogeneity and an I² value > 75% represents a large amount of heterogeneity [28]. A restrictive categorization of values for I² would not be appropriate for all circumstances, although it would tentatively accept adjectives of low, moderate, and high to I² values of 25%, 50%, and 75%

[28-30].

3. Results

3.1. Main Search
The literature search identified a total of 101 articles related to the selected descriptors, but only 9 articles met all the inclusion criteria (see Figure 2). From these 101 articles, 19 papers were removed because they were duplicated. From the remaining 82 articles screened, 11 papers were removed because they were narrative or systematic reviews and another 19 did not match the search descriptions. From the 52 full-text articles assessed for eligibility, another 43 papers were removed because they were unrelated to the effects of creatine on soccer physical performance. The topics and number of studies that were excluded were: 1 of them about gene polymorphisms, 7 other articles were combined Cr with other supplements such as: beta-alanine and beta-hydroxy-beta-methylbutyrate (HMB), 20 articles were on the effects of Cr on (different sports: soccer and rugby), 1 was related to muscle damage, 1 analyzed biochemical markers, 10 studied clinical markers and 3 about the self-reported prevalence of Cr consumption. Thus, the current systematic review and meta-analysis includes 9 studies.

**Figure 2.** Selection of studies.

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3.2. Creatine Supplementation
The general data of the experiments included in this systematic review are depicted in table 2. The total sample consisted of 168 soccer players (118 males, 50 females) with an age of 20.3 ± 2.0 years (from 15 to 30 years, as an average for the experiment sample). In this context, the sample in all included studies consisted of players who competed in professional or elite (n=2) to semi-professional or amateur teams (n=7), who had well established training habits, and whose age group varied from U-17 (n=2) to senior team categories (n=7). In 2 out of 9 studies Cr was administered based on an individual’s body mass, while an absolute dose was provided for all participants in 7 studies. In this way, the doses used in each study included values of 30 g/day (3x10 g) in one study, 20 g/day (4 x 5 g) in 6 studies, 0.3 g/kg, four times/ in one day and 0.03 g/day in other one. In 5 of the included studies, the time of ingestion of Cr was along with a meal (breakfast, lunch, dinner) or separated by 3-4 hours, while the others (n=4) did not mention the time of ingestion. Besides, there are 3 studies out 9 that use a loading dose of 20 g / day (divided into 4 doses) for a week and then a dose of 5 g / day for a period of 1 day, 5 weeks and 6 weeks, respectively. On the other hand, there are 4 studies whose duration is 6 days, 2 of 7 days, 1 of 14 days, 1 of 6 weeks and 1 of 7 weeks.

Commented [MK17]: I would like to see the BMI and its changes during the course of studies as it might help with interpreting the results.
Table 2. Summary of studies included in the systematic review.

<table>
<thead>
<tr>
<th>AUTHOR/S-YEAR</th>
<th>POPULATION</th>
<th>INTERVENTION</th>
<th>OUTCOMES ANALYZED</th>
<th>MAIN CONCLUSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mujika et al. 2000</td>
<td>17 male highly trained players (20.3 ± 1.4 years)</td>
<td>5 g, 4 times/day during 6 days</td>
<td>• Countermovement jump</td>
<td>• ↔</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Repeat sprint ability</td>
<td>• ↑</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Intermittent endurance Test</td>
<td>• ↔</td>
</tr>
<tr>
<td>Bemben et al. 2001</td>
<td>25 male university players (19.3±0.5 years)</td>
<td>5 g, 4 times/day (separated by 3–4 h) during 5 days</td>
<td>• Neuromuscular strength tests</td>
<td>• ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Anaerobic power test</td>
<td>• ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Isokinetic Test</td>
<td>• ↔</td>
</tr>
<tr>
<td>Cox et al. 2002</td>
<td>12 female elite players (22.1±5.4 years)</td>
<td>5 gr. 4 times a day during 6 days</td>
<td>• Sprint test</td>
<td>• ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Agility racing test</td>
<td>• ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Agility kick drill test</td>
<td>• ↔</td>
</tr>
<tr>
<td>Biwer et al. 2003</td>
<td>15 (7 males and 8 females) university players</td>
<td>0.3 g/kg, 4 times/ day (after breakfast, lunch, and dinner and before bedtime) during 6 days</td>
<td>• Sub-maximal running test</td>
<td>• ↔</td>
</tr>
<tr>
<td>Ostojic et al. 2004</td>
<td>20 male youth players (16.6±1.9 years)</td>
<td>10 g, 3 times/ day during 7 days</td>
<td>• Dribbling test</td>
<td>• ↑</td>
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<td></td>
<td></td>
<td></td>
<td>• Spring test</td>
<td>• ↑</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• Endurance Test</td>
<td>• ↔</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Countermovement jump</td>
<td>• ↑</td>
</tr>
<tr>
<td>Claudino et al. 2014</td>
<td>14 male professional players (18.3 ± 0.9 years)</td>
<td>5 g, 4 times/day (breakfast, lunch, dinner and before bedtime) during 7 days</td>
<td>• Countermovement jump</td>
<td>• ↑</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• 5 g/day during 6 weeks</td>
<td></td>
</tr>
<tr>
<td>Williams et al</td>
<td>16 male amateur players</td>
<td>5 gr 4 times/day (~4 hours between doses)</td>
<td>• Aerobic (circuit time),</td>
<td>• ↔</td>
</tr>
</tbody>
</table>

Commented [MK18]: Age is not mentioned here. Please add.
<table>
<thead>
<tr>
<th>Year</th>
<th>Participants</th>
<th>Intervention</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>(26.0 ± 4.5 years)</td>
<td>during 7 days</td>
<td>Speed (12- and 20-m sprint) • Explosive-power (vertical jump)</td>
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</tr>
<tr>
<td>Ramirez et al. 2015</td>
<td>30 female amateur players (22.9 ± 2.5 years)</td>
<td>5 gr 4 times/day (at break-fast, lunch, dinner and before bedtime) during 7 days • 5 gr/day (at lunch) during 5 weeks</td>
<td>Jump test • Repeated Sprint test • Resistance • Speed performance in direction change</td>
</tr>
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</tr>
<tr>
<td>Yañez-Siva et al. 2017</td>
<td>19 male youth players (17.0 ± 0.5 years)</td>
<td>0.03g/day (at midday meal) during 14 days</td>
<td>Maximal Power test • Average output power test • Fatigue Index Test • Total work test</td>
</tr>
</tbody>
</table>

↑: statistically significant increase; ↔ change with no statistical significance; ↓: statistically significant decrease.
3.3. Effect on Aerobic performance meta-analysis

Figure 3 represents the overall effect of Cr supplementation on aerobic performance, and indicates that Cr did not produce any significant effect on aerobic performance (SMD [95%CI]; effect size interpretation; F) -0.05 [-0.37 – 0.28]; trivial; 0%; p=0.78).

**Figure 3.** Forest plot representing a comparison among the effects of creatine supplementation on aerobic performance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>SMD Mean Difference</th>
<th>Effect Size</th>
<th>Total Weight</th>
<th>SMD Mean Difference 95% CI</th>
<th>SMD Mean Difference 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cr</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><em>P</em></td>
<td>0.64</td>
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</tbody>
</table>

3.4. Effect on Alactic anaerobic performance meta-analysis

In the same line, the pre-exercise Cr ingestion produced small but not significant increased the physical performance in the tests which are mainly related to alactic anaerobic performance (0.21 [-0.03 – 0.45]; small; 43%; p=0.08) (figure 4). The results indicated that Cr is associated with moderate but not significant improvements in strength performance (IRM, peak torque) (0.50 [-1.15 – 1.14]; moderate; 72%; p=0.13) and with trivial and not significant improvements in a single jump performance (0.14 [-0.12 – 0.39]; trivial; 0%; p=0.28), single sprint velocity (0.06 [-0.70 – 0.81]; trivial; 62%; p=0.88), and the time required to complete agility tests (-0.11 [-0.83 – 0.61]; trivial; 0%; p=0.77).
Figure 4. Forest plot representing a comparison between the effects of creatine supplementation on alactic anaerobic performance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Rest Mean Difference</th>
<th>Experimental Mean Difference</th>
<th>Control Mean Difference</th>
<th>Weight</th>
<th>Heterogeneity Test (F)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.1 Rest/Performance</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Garib et al. 2001</td>
<td>0.94125</td>
<td>0.4115</td>
<td>9</td>
<td>0.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garib et al. 2002</td>
<td>0.04391</td>
<td>0.03698</td>
<td>9</td>
<td>0.066</td>
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</tr>
<tr>
<td>Garib et al. 2003</td>
<td>0.03053</td>
<td>0.01965</td>
<td>9</td>
<td>0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garib et al. 2004</td>
<td>-0.01572</td>
<td>0.06869</td>
<td>9</td>
<td>0.035</td>
<td></td>
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</tr>
<tr>
<td>Garib et al. 2005</td>
<td>0.04952</td>
<td>0.4115</td>
<td>9</td>
<td>0.069</td>
<td></td>
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</tr>
<tr>
<td>Garib et al. 2006</td>
<td>1.1712</td>
<td>0.4963</td>
<td>9</td>
<td>0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garib et al. 2007</td>
<td>-0.0217</td>
<td>0.4963</td>
<td>9</td>
<td>0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garib et al. 2008</td>
<td>-0.21175</td>
<td>0.4963</td>
<td>9</td>
<td>0.031</td>
<td></td>
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<tr>
<td>Garib et al. 2009</td>
<td>2.7764</td>
<td>0.54462</td>
<td>9</td>
<td>0.031</td>
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<tr>
<td>SUM (95%)</td>
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</tbody>
</table>

3.5. Effect on Lactic anaerobic performance meta-analysis

However, a potential ergogenic large and significant effect of Cr was found in those tests which are mainly related to lactic anaerobic performance (1.23 [0.55 – 1.91]; large; 81%; p=0.001) (Figure 5). Although Cr demonstrated a large and significant effect on Wingate test performance [2.62 [1.40–3.11]; large; 72%; p=0.001], on RSA (repeated sprint ability) performance showed small but not significant effect (0.26 [-0.13 – 0.65]; trivial; 0% p=0.20).

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Figure 5. Forest plot representing a comparison between the effects of creatine supplementation on lactic anaerobic performance.

<table>
<thead>
<tr>
<th>Study or Subgroup</th>
<th>Effect Size</th>
<th>Control Mean</th>
<th>Control SD</th>
<th>Experimental Mean</th>
<th>Experimental SD</th>
<th>Weight</th>
<th>Effect Size</th>
<th>95% CI</th>
<th>Funnel Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ma et al. 2000</td>
<td>0.3525</td>
<td>4.867</td>
<td>0.496</td>
<td>4.873</td>
<td>0.499</td>
<td>10</td>
<td>0.447</td>
<td>0.262, 0.632</td>
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<tr>
<td>Ma et al. 2000</td>
<td>0.3525</td>
<td>4.867</td>
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<tr>
<td>Li et al. 2000</td>
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<td>4.867</td>
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<td>4.873</td>
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<td>Li et al. 2000</td>
<td>0.3525</td>
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</tr>
<tr>
<td>Rainham-Campbell</td>
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<td>4.867</td>
<td>0.496</td>
<td>4.873</td>
<td>0.499</td>
<td>10</td>
<td>0.447</td>
<td>0.262, 0.632</td>
<td>~2</td>
</tr>
</tbody>
</table>

4. Discussion

The main purpose of this systematic review with meta-analysis was to summarize the effects of Cr supplementation on physical performance tests related to aerobic and both lactate anaerobic metabolism in soccer players.

The main results indicate that Cr supplementation with 20-30 g/day for 1-7 weeks led to large and significant improvements on lactic anaerobic performance. On the other hand, the supplementation of Cr showed trivial/small, but no significant effect on tests related to aerobic and lactic anaerobic metabolisms. Thus, this meta-analysis suggests that Cr supplementation could be an ergogenic aid for soccer players.

The best method of increasing muscle Cr stores appears to be a Cr supplementation with a loading phase of 0.3 g/kg/day (~20-30g/day) for at least 3 days, followed by 3-5 g/day to maintain elevated Cr stores. Cr supplementation with 0.03 g/kg/day (~2-3 g/day) will increase muscle Cr stores over a 3-4 weeks period [31]. These protocols are important since Cr levels in the human body can be elevated for up to 30 days [31,32]. Therefore, the studies that were included in this review and meta-analysis complied with the protocols aimed at increasing the muscle Cr stores.

The physiological demands of soccer have changed dramatically over time [33]. Currently, soccer players cover greater distances, perform more explosive actions and compete at higher intensities than ever [34,35]. The sport science has played an integral key role in these advances [36].

Among them, in particular nutrition has played a key point in the search and the use of supplements that allow players to perform better at higher intensities [8]. In this sense, Cr is one of the most studied supplements in athletes, given that produces the ability to resynthesize the ATP that is used while exercising and consequently, the ability to maintain maximal exercise increases [31]. Thus, the supplementation with Cr could lead to greater adaptations of training due to a higher quality and volume of work done, as well as a better muscle recovery [37]. In terms of potential medical applications, Cr is intimately involved in several metabolic pathways [38]. For this reason, Cr could be perfectly recommended for the improvement of the soccer physical performance because in its practice are involved the different metabolic pathways [39].

4.1. Effect on aerobic performance

Soccer requires a great aerobic capacity based on the duration of a match [30, minutes] [40]. In addition, a relationship between aerobic power and competitive classification, the level of...
equipment and the distance covered during the match has been demonstrated [41,42]. For this reason, looking for ways to improve this capacity throughout the season is essential to maintaining a high level of performance. In this sense, oral supplementation with Cr during 7-days could improve aerobic performance in elite athletes [43] since it has been shown that after the supplementation with Cr there is an increase in the content of PCr at rest in muscle fibers type I [44]. In addition to a reduction in the use of muscle PCr, a lower accumulation of Pi, as well as, the decrease in muscle pH during exercise with low intensity after loading Cr, (which would indicate a delay of fatigue during prolonged periods of resistance work) [45]. However, these results are controversial, since in most studies the Cr supplementation did not improve the ability to perform a long-term submaximal exercise [46,47], nor did it modify the maximum absorption of oxygen, the circulatory, metabolic and ventilatory response to a progressive exercise test [48,49]. In this line, Mujika et al., [17, Ostojic [18] and Biwer et al., [15] did not observe changes in aerobic capacity in both (male and female soccer players) and in young soccer players after supplementation with 20 and 30 g / day of Cr for 6-7 days. Besides, Ramirez et al. did not see improvements on aerobic performance after 6-week supplementation with Cr on female amateur players [19]. Therefore, although aerobic metabolism plays a major role in soccer, given that provides the 90% of the energy cost during soccer match play [50], the results obtained in this meta-analysis indicate that the supplementation of Cr in soccer players has no benefit improving aerobic performance. Highly trained aerobic metabolism is dependent on intramuscular triglycerides and not on PCR or muscle glycogen [51], for that reason the Cr supplementation could not enhance aerobic performance [52].

4.2. Effect on alactic anaerobic performance

The anaerobic power and the explosive force are also essential components of soccer performance since it allows players to execute the constant muscular adjustments necessary for the performance of different actions, as well as allowing actions such as jumps, shots, short sprints or agility actions [53]. In this sense, the power of the lower extremities as a product of neuromuscular stimulus has been associated with the speed performance on soccer players [54]. Thus, several studies have examined the potential associations between the ability to sprint and several measures of strength and power in different exercises related to soccer performance [54,55]. Thus, it seems reasonable to expect soccer players to benefit from Cr supplementation because most of their activity in the field involves powerful and explosive anaerobic movements that require the immediate release of energy provided by ATP and the rapid re-synthesis of ATP from ADP and Cr [18].

In that way, results obtained in this meta-analysis indicate that the intake of Cr prior to exercise was associated with a small but not significant increase on physical performance in those tests that are mainly related to alactic anaerobic performance. Concretely, results showed moderate but not significant effects on different strength exercises (IRM and peak torque) performed by 25 college football players after 6 days of supplementation with 20 g / day of Cr [6]. However, only trivial and non-significant improvements were seen on the single jump performance, single sprint speed or in the time required to complete the agility tests. Although this type of activity requires ATP, its resynthesis is not decisive to jump or sprint because they are more dependent on neuromuscular performance [56]. In addition, the short duration of the Cr supplementation protocols used (5 g, 4 times) in this meta-analysis could also have influenced these results.

4.3. Effect on lactic anaerobic performance

It is currently recognized that the most decisive actions during soccer practice are related to anaerobic metabolism [57]. In this sense, the anaerobic power, together with the specific skills of the sport, seem to be the determinants for a high performance [58]. Although there are different tests to assess the anaerobic power and, therefore, the performance of the anaerobic metabolism of a player, the most important test used in the field of the physiology of soccer exercise is the gold standard anaerobic Wingate [59,60]. For that reason, The Wingate test has been used to validate field tests in

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this sport [61,62] because it has been positively correlated with better performance during soccer matches [63]. In addition, it has been used to monitor the effectiveness of different training programs [64,65]. Therefore, seeking better adaptations in lactic anaerobic metabolism seems to favor the performance of soccer players. In this sense, Cr seems to be a good ergogenic aid to produce improvements on tests performance in which anaerobic lactic metabolism predominates, as it has been demonstrated in this meta-analysis. Specifically, both Yafiee-Silva et al., [7] and Bemben et al., [6] showed that short-term Cr supplementation (6-7 days) improved the maximum and average anaerobic power, as well as the total work measured by the Wingate test in both young and university players. The positive effect of Cr supplementation on activities related to lactic anaerobic metabolism may be due to the benefits that Cr has on the muscle glycogen store [3].

4.4. Strengths, limitations and future lines of research

The main limitation of this meta-analysis is the scarcity of studies carried out in relation to Cr supplementation in soccer players (n=9), which has forced us to carry out the analyzes by mixing data of both sexes, different competitive levels and different research protocols. In this line, it should be indicated that neither the dose nor the duration of Cr supplementation protocol have been taken into account. In fact, implies that studies were mixed in which Cr supplementation was short-term (5-7 days) with long-term protocols (6-7 weeks) which may have influenced these results. Protocols used in some studies [16,21] may also influence results obtained in this meta-analysis, because some physical performance tests were joined together as a field test simulating match play (not isolated), which probably could affect the metabolic pathway of the participants during exercise, and consequently, the performance obtained in each single test. However, one important strength is that the proportion of the total variation that is attributable to the heterogeneity observed in many of the physical tests analyzed has been zero ($I^2=0\%$).

Future research lines would imply the use of the general protocol of Cr supplementation in different skills related to soccer performance that involve different metabolisms in both men and female soccer players, as well as in different levels of competition.

5. Conclusions

The results of this systematic review with meta-analysis have shown that Cr supplementation improved the performance of physical tests related to lactic anaerobic metabolism, especially anaerobic power, in soccer players. The effective dose of Cr supplementation to obtain positive effects describes with a high dose of 20-30 g / day divided 3-4 times a day ingested for 6-7 days or with a low dose of 3 mg / kg / day for 14 days or more.

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References


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