Review

Effect of creatine supplementation on anaerobic capacity: a meta-analysis

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Summary

The purpose of the present meta-analysis was to integrate and summarize the results of different studies as well as to examine the moderating variables in the effect of creatine (Cr) supplementation on anaerobic capacity. Eighty-one studies on creatine supplementation were retrieved by searching several databases, and 17 that met the criteria were included. Random effects models using the standardized mean difference effect size (*ES*) were used to pool results. A total of 131 *ES* were coded, representing 1447 participants (nG_{Ex}=889; nG_{Pl}=559). A statistically significant moderate overall *ES* was found for the experimental group (G_{Ex}) (*ES*=0.34, p<0.001; CI: 0.24-0.44). Also, a statistically significant small overall *ES* was found for the placebo group (G_{Pl}) (ES=0.13, p>0.05; CI: 0.02-0.24). A statistically significant difference was found between both groups ($F_{(1, 129)}$=9.56, p<0.05, α=0.05). The heterogeneity analysis reported low heterogeneity (Q= 96.95; p= 0.083; α= 0.10), and low inconsistency (I^2=18.51%) in the experimental group. Nine moderator variables were analyzed, Pearson correlation analysis were used when variables were continuous and variability analysis (ANOVA) when variables were categorized. Only the variable which described how supplementation was offered was significant (load *ES*=0.37; load + maintenance *ES*=0.22; F($_{1-77}$)=6.22; p=0.015), suggesting a positive effect on load phase, but not on load plus maintenance. Not found significant differences in sex, skill level of the athlete, type of sport, doses, type of performance assessment. In conclusion, supplementation with creatine had a moderate effect on anaerobic capacity.

Key words:
Creatine. Anaerobic capacity. Meta-analysis. Supplementation.

Efecto de la suplementación con creatina en la capacidad anaeróbica: un meta-análisis

Resumen

El objetivo del presente meta-análisis fue integrar y resumir los resultados de distintos estudios, así como examinar las variables moderadoras en el efecto de la suplementación con creatina (Cr) sobre la capacidad anaeróbica. Para ello se localizaron 81 artículos completos de diversas bases de datos electrónicas, donde solo 17 cumplieron con los criterios de inclusión. Para calcular el Tamaño de Efecto (*TE*) se utilizó el modelo de efectos aleatorios. Se codificaron un total de 131 *TE*, que representan 1447 sujetos (nG_{Ex}= 889; nG_{Pl}= 559). El *TE global* del grupo experimental (G_{Ex}) fue moderado (*TE*=0,34, p<0,001; IC: 0,24-0,44), en tanto que el TE del grupo placebo (G_{Pl}) fue pequeño (*TE*=0,13, p>0,05; IC: 0,02-0,24); siendo significativamente diferentes entre sí ($F_{(1,129)}$=9,56, p<0,05, α=0,05). El análisis de heterogeneidad indicó que los TE de los artículos incluidos en el grupo experimental son homogéneos (Q= 96,95; p=0,083; α= 0,10), con una baja variabilidad (I^2=18,51%). Se utilizó la correlación de Pearson para determinar el efecto de las variables moderadoras continuas y el análisis de variabilidad, para variables categóricas. Se evaluaron nueve variables moderadoras, de las cuales únicamente la forma en la que se dio la suplementación fue significativa (carga *TE*=0,37; carga + mantenimiento *TE*=0,22; $F_{(1-77)}$= 6,22; p=0,015), sugiriendo que el efecto es positivo durante la fase de carga, no así cuando existe carga + mantenimiento. No hubo diferencias significativas en las variables moderadoras de sexo, nivel de entrenamiento, tipo de deporte, la dosis brindada, ni en la forma de medición del rendimiento físico. En conclusión, existe un efecto moderado de la suplementación con Cr en la capacidad anaeróbica.

Palabras clave:
Creatina. Capacidad anaeróbica. Meta-análisis. Suplementación.

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Introduction

Creatine (Cr) is a natural compound that is endogenously synthesized via glycine, arginine and methionine in the kidney, liver and pancreas. In the kidney, the transaminase enzyme creates ornithine and guanidinoacetate from arginine and glycine. Guanidinoacetate is transported to the liver, where it receives a methyl group of methionine leading to the formation of methyl-guanidoacetic acid (creatine) and adenosine homocysteine. Cr is released into the bloodstream and stored in the skeletal muscle both freely and in phosphorylated form. It plays a fundamental role in regulating adenosine triphosphate (ATP)[1].

When ATP is needed as a source of cellular energy, such as during intense, short-term muscle contraction, Cr reacts with phosphocreatine kinase and ATP to create phosphocreatine (PCr) and adenosine diphosphate (ADP). Through an inverse reaction, ADP and PCr react with the enzyme creatine kinase to regenerate ATP. Therefore, Cr indirectly acts to meet the muscular system's energy needs[1-4].

Fatigue occurring short-duration, maximum-intensity exercise has been associated with depletion of PCr. In this sense, much research has suggested that Cr supplementation improves physical performance. Firstly, by delaying the onset of fatigue by favouring the rate of PCr resynthesis during recovery in maximum-intensity exercises. Secondly, by generating improvements in maximum strength and sprint speed, among others[5-9].

Several meta-analyses on this topic have analysed the effect of Cr supplementation on several variables, some investigating whether Cr favours increased muscle strength and power in healthy adults, finding positive effects in weightlifting when supplementing with Cr in addition to strength training among such individuals[10]. However, such studies mention that there is little evidence to draw conclusions with respect to women or older adults.

Furthermore, Nissen and Sharp[11] performed a meta-analysis on the effect of supplementation with various dietary supplements (including Cr) on muscle mass and strength gains through resistance training, reviewing 18 articles and finding significant increases in both variables, with an effect size (ES) of 0.26 (CI: 0.65-1.02%) and 0.36 (CI: 0.28-0.43%) (p<0.001), respectively.

Similar to that meta-analysis, Branch[12] analysed the ES on body composition, duration and intensity of the task, type of exercise (simple, repeated, in laboratory, in the field, using upper or lower extremities), duration of supplementation and the subjects' gender. They found a significantly large ES in lean mass with short-term supplementation, especially in exercises with several repetitions less than 30 seconds long using the upper extremities. However, no effect was found in runners or swimmers, nor did they identify differences between men and women or between trained and untrained subjects.

Gutiérrez *et al.*[13] also performed a meta-analysis studying the effect of Cr supplementation on physical performance, body composition and biochemical variables. In that study, a large and significant effect was found for variables such as peak power, peak force and performing one repetition at maximum effort (1 RM) under both the conditions of supplementation and placebo; a greater effect was revealed in the experimental condition (Cr).

However, those research studies did not account for the effect of the type of Cr used, nor were effects identified with respect to the subjects' gender, the type of physical activity or sport performed, the number of days that supplementation was taken, or the total dose administered. In addition, information regarding Cr supplementation and anaerobic capacity as a specific variable of physical performance has yet to be summarised. For these reasons, this meta-analysis—unlike the existing ones—intends to identify and summarise the effect of Cr supplementation on anaerobic capacity. Following the methodology set forth by Borenstein *et al.*[14], the individual and overall effect size is calculated accounting for such moderating variables as those aforementioned aspects while also considering the reported findings of the different studies used.

Methodology

The present meta-analysis was carried out as per the PRISMA guidelines for reporting of systematic reviews and meta-analyses[15].

Study selection criteria

The inclusion criteria used in elaborating this meta-analysis were: 1) studies of healthy subjects with or without previous training, 2) studies presenting descriptive statistics, 3) studies presenting results of the effect of Cr supplementation on anaerobic capacity, 4) studies reporting the dose of Cr used , 5) studies not carried out with populations on special diets (e.g. vegetarians), 6) no conditions of modified temperature or dehydration, 7) full text in English, Spanish, French or Portuguese.

The quality criteria used were based on the internal validity of the study, including: 1) randomization of subjects, 2) intra-subject studies (pre-post test), 3) presence of an experimental group (Gex) and placebo or control group (GPl), 4) double-blind studies.

Data sources

The literature search was carried out using electronic databases, from 10 August to 1 December 2015. References included in previous meta-analyses, systematic reviews and some relevant articles were reviewed. In cases where we could not find the descriptive statistics of articles of interest or their full-text version, we requested such information from the respective author; only two articles were obtained in this way. In total, 84 complete articles were used, of which only 17 studies were meta-analysed.

Seven electronic databases were used: Sport Discus, Pub-Med, Science Direct, Springer Link, Medline, Proquest and Academic Search Complete.

The keywords used were: "effect of", "creatine", "supplementation", "performance" and their combinations in English and Spanish.

Selection of studies and data coding

The selection of studies and coding of their respective data of interest was carried out by one person. A second person reviewed the previous process and, in consensus with a third person, all identified inconsistencies were resolved. In doing so, a database previously developed in the Microsoft Excel 2013® program was used. The analysis of the moderating variables took into account: subject characteristics, measurement of physical performance, Cr supplementation characteristics and placebo characteristics. Table 1 details the aspects that were considered in coding these variables.

Methodological quality of the studies

We used a modified version of the scale developed by Jiménez *et al.*[16], which consists of five items used to evaluate criteria of internal validity in experimental studies, namely: 1) the randomization process is described and is adequate, 2) the study had a placebo or control group, 3) there were pre-test and post-test measurements and 4) the existence and management of experimental mortality was reported.

Studies with a score of four were considered to be of "excellent" quality, scores of three "good" quality, scores of two "regular" quality and scores of one "poor" quality.

Procedure for calculating individual effect sizes

The ES of Cr supplementation on anaerobic capacity was calculated as the change between the pre-test and the post-test measurement in the given variable. Calculating the ES of each study and the global ES was done by following the procedure suggested by Borenstein *et al.*[14] for the random-effects model. The analyses were performed using the Microsoft Excel® program, with confidence intervals of 95%.

Heterogeneity and bias

The heterogeneity of the included studies was assessed using Cochran's Q test, while inconsistency was assessed using the I^2 statistical test. Significance for the Q test was established at $p \leq 0.10$ due to its lack of statistical power. I2 values of less than 25% are considered to represent very low inconsistency; between 25 and 50%, low inconsistency; between 50 and 75%, moderate inconsistency; greater than 75%, highly inconsistent. A funnel plot and Egger's test were performed through the RStudio program to assess general bias as they indicate the possibility of not including all relevant studies in the meta-analysis. Publication bias was assessed through the effect of archived papers[17].

Table 1. Moderating variables.

Areas of interest	Coding scheme
Subject characteristics	Sample size, age, gender, condition (experimental, placebo or control), level of physical activity (trained, untrained), type of physical activity/ sport performed.
Physical performance measurement	Measurement type.
Cr supplement characteristics	Type, duration (days), total dose (g), supplementation phase (loading, maintenance, both).
Placebo characteristics	Type, duration (total days), total dose (g), supplementation phase (loading, maintenance, both).

Data analysis

With the obtained information, a Pearson correlation (r) was performed in the cases where the measurement scale of the variables was continuous, while a one-way analysis of variance for independent groups (ANOVA) was performed in cases where variables were categorical, with a significance level of 0.05. The global ESs were calculated using the Microsoft Excel 2013® program, while statistical analysis (correlations and ANOVA) was performed with the IBM-SPSS 20.0® program. In the case of the moderating variables, only those that presented an ES with *n* greater than three were analysed.

Results

Studies included

Of the 81 articles reviewed, only 17 met the inclusion criteria. While one article did not have a GPI, the necessary information on various types of Cr was available, owing to which it was used in this study[18]. A diagram depicting the selection of included studies is shown in Figure 1 and their characteristics are shown in Table 2.

In the case of a study that presented two experimental conditions and a control condition, this condition was not considered in the analysis as it was the only study with this characteristic[19]. The flowchart for the selection of studies is shown in Figure 1, while Table 3 presents a description of the main characteristics of the studies included in this meta-analysis.

Of the 17 articles, a total of 131 ES were obtained (80 ES from the experimental condition and 51 ES from the placebo condition), encompassing a total of 1,447 subjects, the distribution and characteristics of whom are presented in Table 2.

The quality of the included studies was considered "good" according to the scale used to evaluate their internal validity, as shown in Figure 2, where the distribution of articles according to quality level is depicted.

Individual effect size

As demonstrated in the forest plots in Figure 3, the distribution of individual ESs is mostly greater than zero, as well as the global ES of Cr supplementation in anaerobic capacity (95% confidence intervals).

Figure 1. Flowchart for selection of articles, based on Prisma 2009[20].

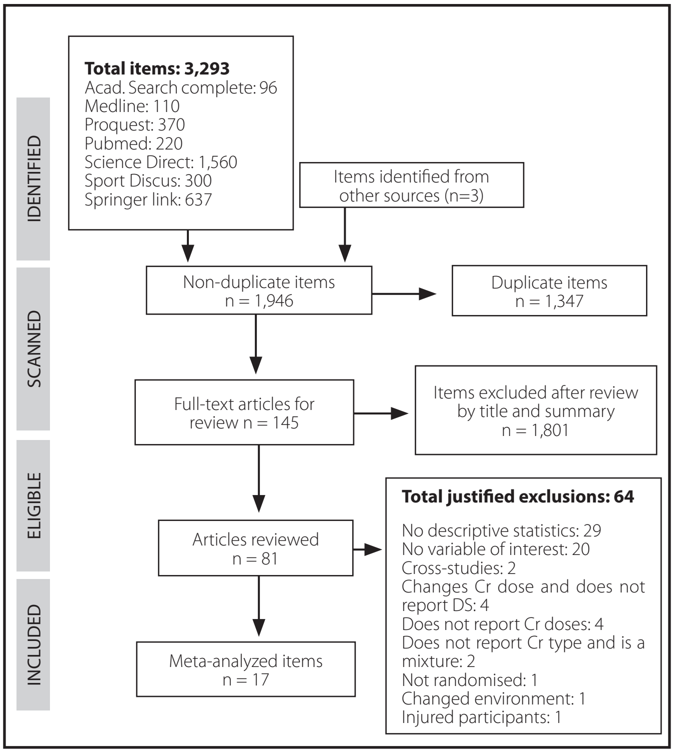


Figure 2. Distribution of the quality of analysed studies.

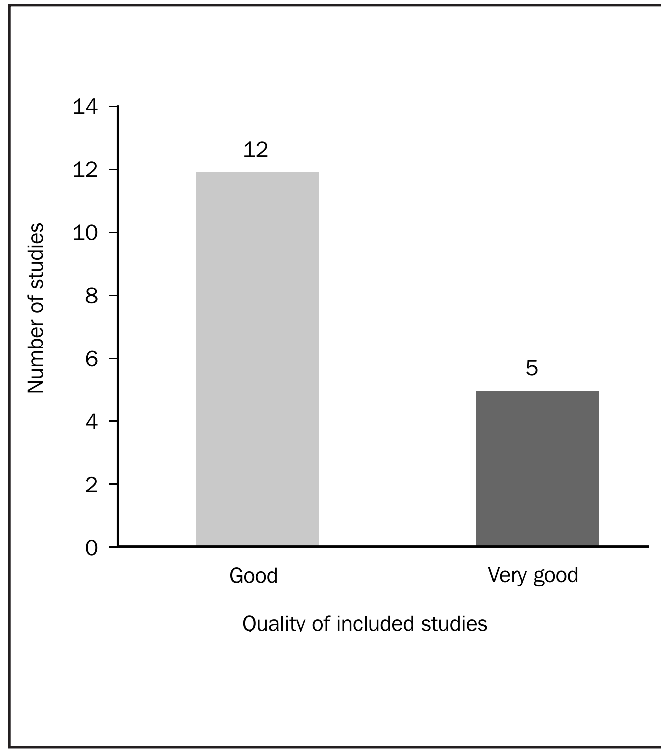
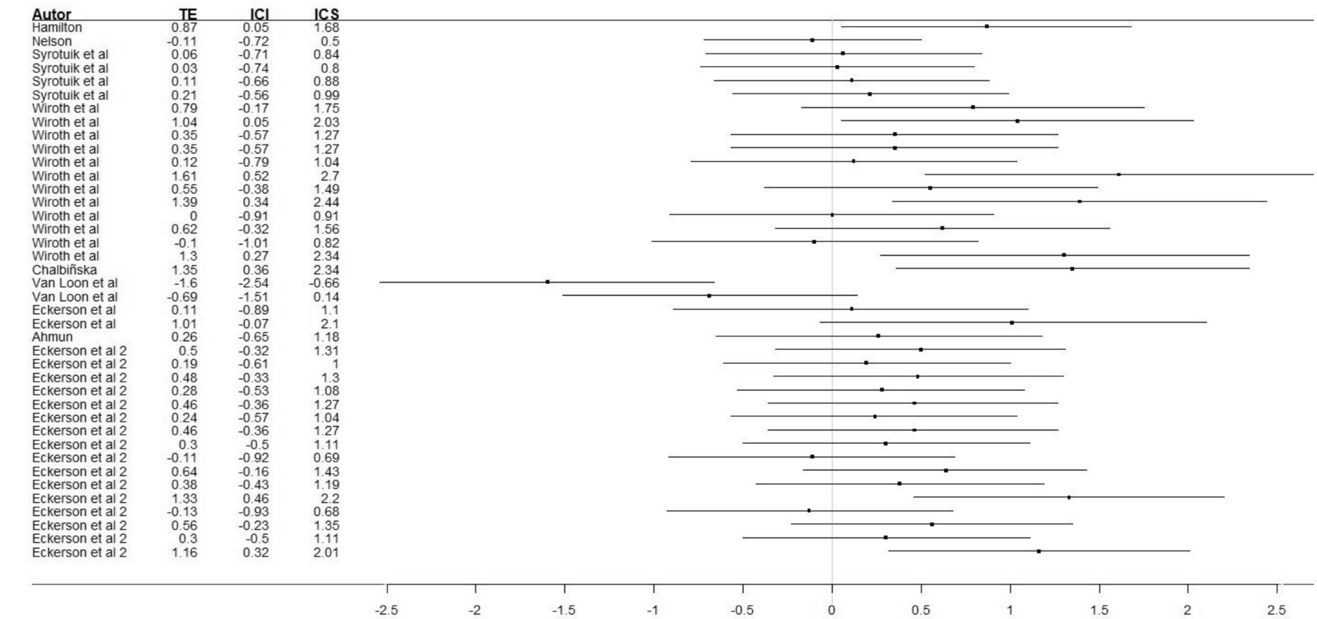


Table 2. Characteristics of meta-analysed studies.

Author	Year	N	Gender	Age	Training Level	PA / Sport	Total days	Total g	Supplem. Time	Cr Type
Hamilton[21]	2000	24	F	22.5	T	Throwing	7	175	Loading	CrM+sucrose
Nelson, *et al.*[22]	2000	36	B	NR	UT	Recreational	7	175	Loading	CrM+2,12 g sucrose
Syrotuik, *et al.*[23]	2001	22	B	23.0	T	Row	5	100	Loading	CrM
Wiroth, *et al.*[24]	2001	42	M	65.1	T	NR	5	225	Loading	CrM
Chalbińska[25]	2001	16	M	22.5-25.3	T	Row	5	100	Loading	CrM
Van Loon, *et al.*[26]	2003	20	M	21.3-20.6	UT	NR	42	174	L-M	CrM+15g GLu+10 g Mal
Eckerson, *et al.*1[27]	2004	10	F	22.0	T	NR	2	40	Loading	
							5	100	Loading	Cr+18 g dextrose
Ahmun[28]	2005	14	M	20.6	T	Rugby	5	100	Loading	CrM
Eckerson, *et al.* 2[29]	2005	61	F	21.0	T	NR	2	40	Loading	CrCit+dextrose
							2	40	Loading	CrCit+PNA+dextrose
							6	120	Loading	CrCit+dextrose
							6	120	Loading	CrCit+PNA+dextrose
Hoffman, *et al.* 1[30]	2005	20	M	21.7	T	NR	6	18	Loading	Cr+P+fructose+gel
Hoffman, *et al.* 2[31]	2006	22	M	NR	UT	Strength/power	70	735	L-M	CrM
Reardon, *et al.*[32]	2006	13	M	NR	T	NR	7	140		CrM+maltodextrin
O'Connor, *et al.*[19]	2007	22	M	24.5	T	Rugby	42	126		3gCr+3gHMB+6gCHO
Azizi[33]	2011	20	F	20.9	T	Swim	6	120	Loading	CrM
Jagim, *et al.*[18]	2012	35	M	25.5	T	Counter-resistance	7	140		CrM
							7	140		KA-H (eqCrM)
							7	10,5		KA-L (eqCrM)+5 g dext
Sterkowicz, *et al.*[34]	2012	10	M	20.4	T	Judo	42	210		CrMaleate
Deminice, *et al.*[35]	2013	25	M	17.1	T	Football	7	151		NR

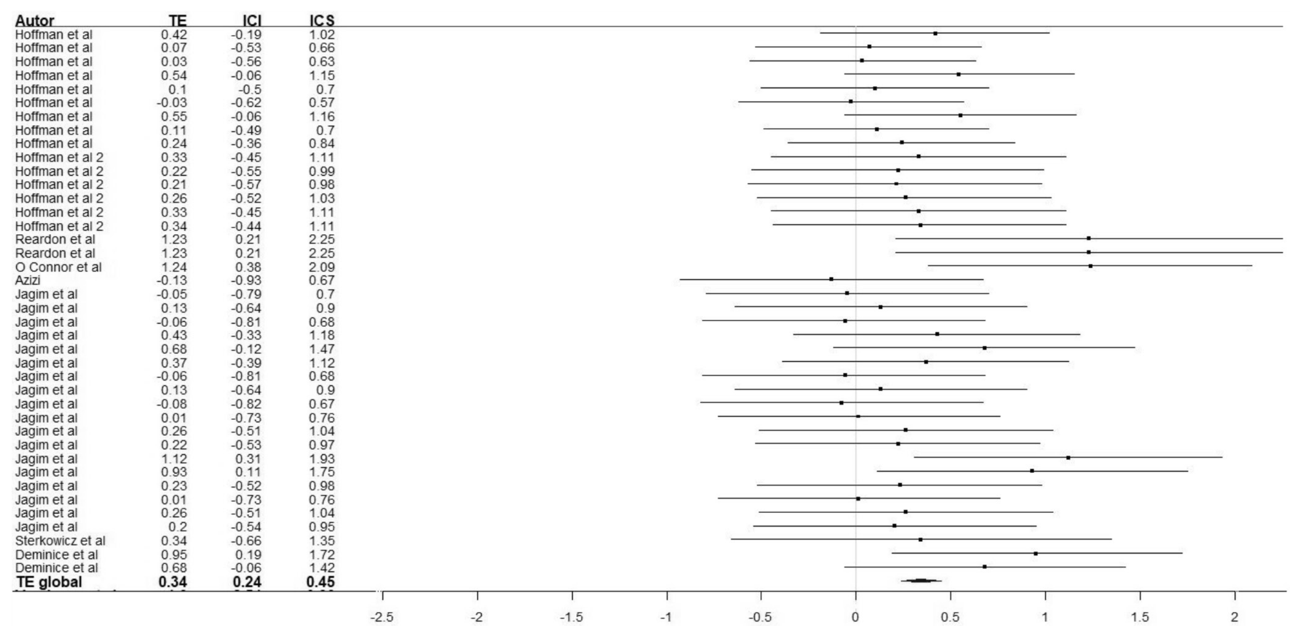
B: Both; F: Female; M: Male; T: Trained; UT: Untrained; CrM: Creatine Monohydrate; HMB: Hydroxymethylbutyrate; CrCitPNa: Creatine Citrate+Sodium Phosphate, PKA-H equivalent to CrM; KA-L: equivalent to CrM+dextrose.

Figure 3a. Forest plot depicting the distribution of individual ES of Cr supplementation and its effect on anaerobic capacity (n=80).



ES: Effect size: ICI: inferior confidence interval; ICS: superior confidence interval.

Figure 3b. Forest plot depicting the distribution of individual ES of Cr supplementation and its effect on anaerobic capacity (n=80)



ES: Effect size: ICI: inferior confidence interval; ICS: superior confidence interval.

Global effect size

The global ES of G_{Ex} was moderate (ES = 0.34, $p<0.001$; IC: 0.24-0.44), while ES in the placebo group G_{Pl} was small (ES= 0.13, $p>0.05$; IC: 0.02-0.24). This constitutes a significant difference among both groups ($F_{(1, 129)}= 9.56$, $p<0.05$, $\alpha= 0.05$), as can be observed in Table 4.

Analysis of heterogeneity and bias

As evidenced in Table 4, Cochran's Q test revealed significance in G_{Ex} ($p=0.083$; $\alpha= 0.10$) but not in G_{Pl} ($p=0.50$). This demonstrates that the ES of the articles included in the first group are homogeneous, presenting low variability ($I^2=18.51\%$).

Table 3. Characteristics of subjects included in individual effect sizes according to condition (experimental or placebo).

	Characteristic Placebo	Experimental Condition
n	889	558
Age (years)	26.48	30.35
Weight (kg)	77.72	77.42
Gender		
Men (nES)	53	40
Women (nES)	20	4
Mixed (nES)	7	7

Table 4. Significance of global effect sizes calculated per group (experimental and placebo).

	Experimental	Placebo
N studies	17	16
N ES	80	51
N (studies)	442	
ESg	0.34*	0.13
p	<0.001a	>0.05
IC	0.24 – 0.44	0.02 – 0.24
Q	96.95	49.22
p	0.083b	0.50
I^2	18.51	0
K_0	52	--

[a]α=0.05; [b]α= 0.10; Standard Deviation; CI: Confidence interval.

Moreover, according to the analysis of publication trends, 52 non-significant effect sizes are required to reduce the overall ES obtained in the G_{Ex} to a small one (Table 4).

An asymmetrical dispersion of the individual TeS can be appreciated in the funnel plot (Figure 4). This was confirmed by Egger's regression analysis as it is significant (*p*=0.027 with $\alpha \leq 0.05$), which indicates the presence of bias.

Moderating variables

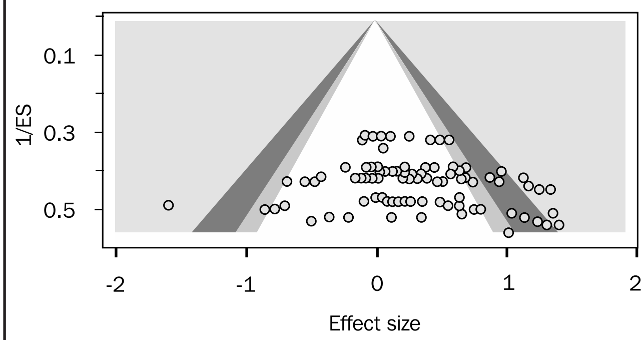
Moderating variables were analysed with the purpose of independently analysing the characteristics that could better explain the global ES.

To determine the effect of the moderating variables, correlation analysis (Pearson) or analysis of variance (ANOVA) were performed for continuous and categorical variables, respectively, using the SPSS statistical software® version 20.0.

Of the moderating variables analysed, only the form of supplementation was significant (*p*=0.01) (Table 5).

In the gender variable, despite the fact that there were no significant differences between them ($F_{(2-77)}$=0.22; *p*=0.81), the ES was moderate and

Figure 4. Funnel plot of ES of Cr supplementation on anaerobic capacity.



(t=2.23, gl=129, p=0.027 with $\alpha \leq 0.05$).

significant in studies where men and women were individually analysed (*p*<0.01 in both cases) and was not in those with a mixture of genders (*p*=0.25), showing, moreover, a greater trend in the group of women.

Also, the training level was not significant ($F_{(1-78)}$=0.13; *p*=0.71). However, the group of trained subjects showed a significant moderate effect size (ES=0.34; *p*<0.01); this was not so in untrained subjects, for whom the ES was non-significant (ES=0.30; *p*=0.45).

In addition, the type of sport or activity performed was analysed and no significant differences were obtained ($F_{(4-75)}$=0.27; *p*=0.89). However, like the previous cases, subjects who played force-power sports with a ball (football, rugby, football) and exercised recreationally obtained a significant moderate ES (*p*<0.05).

Regarding the way of measuring physical performance, there were no significant differences between the analysed methods ($F_{(1-78)}$=0.10; *p*=0.75); in both cases the ES was moderate (ergometers: ES= 0.32, others: ES= 0,60; *p*<0.05).

The ES among the types of Cr analysed was not significant ($F_{(7-72)}$= 1.73; *p*= 0.12). Table 5 shows that only two of the nine classified types of Cr (equivalent to 1.5 g Cr monohydrate (CrM) and other types) did not present a significant ES, while seven types (others: CrM, Cr phosphate + fructose + gel, 5g Cr Citrate (Cr Cit) + 18 g dextrose, 5 g Cr Cit + 4 g Na^+ and K^+ + 18 g dextrose, equivalent to 1.5 g CrM, 5g CrM + 10 g sucrose, 10.5 g CrM + 3.2 g β-alanine) did present a moderate ES (*p*<0.05).

Regarding the form of supplementation, only variables with an nTE>3 were analysed. Significant differences were found between the loading and loading + maintenance phases ($F_{(1-77)}$= 6.22; *p*= 0.015), with a higher ES when there was only a loading phase (ES=0.34; *p*<0.01) than those including the phase of loading + maintenance (ES=0.22; *p*=0.13) (Figure 5).

No relationship was found between ES and age (r= 0.18; *p*= 0.14), total days of supplementation (r= -0.22; *p*= 0.54), and the total dose of Cr (g) (r=-0.02; *p*= 0.84).

Table 5. Significance of effect sizes of Cr supplementation on anaerobic capacity, according to moderating variables

	nTE	TE	IC	*z*	F	*r*	p
Subject characteristics							
Age	71	0.33	0.23 – 0.43	6.58		0.18	0.14
Sex	80	0.34	0.24 – 0.44	6.79	0.22		0.81
Male	53	0.32*	0.19 – 0.44	5.07			
Female	20	0.42*	0.25 – 0.59	4.85			
Mixed	7	0.29	-0.08 – 0.66	1.52			
Level of training	80	0.34	0.24 – 0.44	6.79	0.13		0.71
Untrained	10	0.30	-0.26 – 0.87	1.06			
Trained	70	0.34*	0.25 – 0.43	7.25			
Type of sport/activity	80	0.31	-0.25 – 0.87	1.06	0.27		0.89
Individual	7	0.47	0.04 – 0.90	2.13			
Not performed	10	0.30	-0.26 – 0.87	1.06			
In team with ball	10	0.48*	0.26 – 0.69	4.37			
Recreational	14	0.28*	0.09 – 0.47	2.88			
Strength-Power	39	0.32*	0.20 – 0.44	5.28			
Physical performance							
Measurement type	80	0.34*	0.24 – 0.44	6.79	0.10		0.75
Ergometers	76	0.32*	0.22 – 0.42	6.38			
Others (RAST, dynamometer)	4	0.60*	0.12 – 1.07	2.47			
Supplementation characteristic							
Type of creatine	80	0.34*	0.24 – 0.44	6.79	1.73		0.12
Cr Monohydrate	19	0.22*	0.07 – 0.38	2.88			
Cr phosphate + fructose + gel	9	0.22*	0.07 – 0.36	2.98			
5 g Cr Cit + 18 g dextrose	8	0.28”	0.10 – 0.47	3.06			
5 g Cr Citr + 4 g Na^+ phosphate and K^+ +18 g dext	8	0.57*	0.28 – 0.86	3.80			
Equiv. 5 g Cr Monohydrate	6	0.38*	0.12 – 0.64	2.88			
Equiv 1.5 g Cr Monohydrate	6	0.22	-0.13 – 0.58	1.24			
5 g CrM + 10 g Sucrose	12	0.62*	0.31 – 0.93	3.94			
10.5 g CrM+3.2 g β-Alanine	3	0.29*	0.25 – 0.34	12.67			
Others	9	0.41	-0.25 – 1.07	1.20			
Total days of supplementation	80	0.34*	0.24 – 0.44	6.79		-0.22	0.54
Supplementation type	79	0.34*	0.24 – 0.44	6.73	6.22		0.01*
Loading	59	0.37*	0.36 – 0.47	6.84			
Loading + Maintenance	20	0.22	-0.01 – 0.45	1.88			
total g (total dose)	80	0.34*	0.24 – 0.44	6.79		-0.02	0.84

* Significance with α= 0.05.

(RAST: *Running Based Anaerobic Sprint Test;* Cr: Creatine; Cit: Citrate; dext: Dextrose; CrM: Creatine monohydrate; Glu: Glucose; Other types of Cr: CrM+2.12 g sucrose, CrM+1gmaltodextrine, 3gCr+3 gHidroxi-Methyl-Butyrate+6 g CHO, Cr+18 g dext, CrMaleate, CrM+15 g Glu+10 g Maleate, 10.5 g CrM+3.2g β-Alanine).

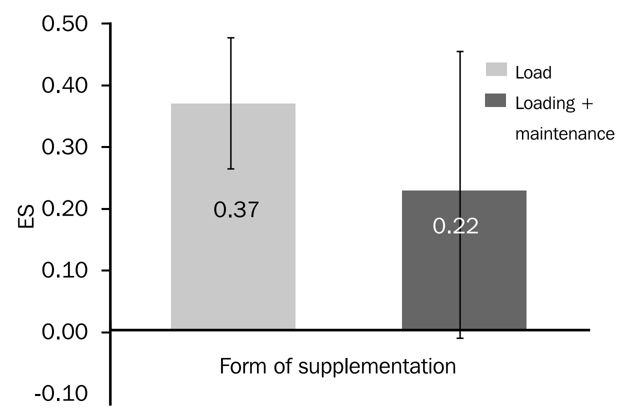
Discussion

This meta-analysis found a moderate-small global ES (ES=0.34) in anaerobic capacity following consumption of Cr according to Cohen's36 conventions, where an ES of 0.20 or less is small, around 0.50 is moderate and 0.80 or higher is large.

The overall ES was different between conditions (experimental > placebo) ($F_{(1, 129)}$= 9.56, p<0.05, α=0.05), with significance in the G_{Ex} but no significance in the G_{Pl}. This is contrary to the meta-analysis of Gutiérrez *et al.*[13], in which improvements were noted in both groups in variables such as peak power, total work, peak strength and 1RM.

The test for heterogeneity (Cochran's Q) proved to be non-significant, meaning that the individual ESs analysed are homogeneous. Thus, this analysis was performed for the purpose of observing any specific behaviour in the variables and to explain the global ES.

Figure 5. Difference in ES according to supplementation type.



Loading n= 59; loading + maintenance n = 20 F1-77= 6.22; p= 0.015.

Subject characteristics

This meta-analysis showed no gender-related differences (*p*=0.81), showing improvements in the ES of anaerobic capacity for both men and women (ES=0.32 and 0.42, respectively).

Similar to this study's findings, Ledford and Branch[37] conducted a double-blind study on nine physically active women who were given 20g/day x 5 days of CrM or a placebo (Polycose), measured at day 5, in addition, leaving a washout period of 95 ± 3 days (without treatment, making measurements). Those authors used the *Wingate Test* (WT) to measure peak power (PP) and work capacity (WC), finding no improvement (G_{Ex} PP: CrM: 540 ± 30, 484 ± 23, 435 ± 19 W *vs*. G_{Pl}: 522 ± 30, 481 ± 22, 403 ± 32 W; between treatments p=0.30; treatment-measurement: *p*=0.39; CT: CrM: 12.39 ± 0.67; 10.60 ± 0.50; 9.56 ± 0.59 kJ *vs*. GPl: 12,09 ± 0,32; 10,60 ± 0,54; 9.39 ± 0,67 kJ; between treatments *p*=0.76; treatment-measurement=0.66).

Eckerson *et al*.[29], in a cross-sectional double-blind study of 31 men and 30 women, aimed to determine the effect of supplementation with three treatments (creatine phosphate (CP), Creatine (Cr) and a Placebo (Pl= dextrose)) on working capacity (WC) through the critical power test, which was performed pre-treatment and two and six days after supplementation. That study found no differences in WC or significant interactions between measurements and treatments in women, while men significantly improved WC with significant interactions between measurements (23.8% after two days and 49.8% after six days of supplementation) *vs*. a placebo. When analysing WC between treatments without a group difference, an increase of 13-15% was found for the group with Cr *vs*. the placebo group. However, these results were not significant.

Physical performance

In this study, anaerobic capacity was measured with 76 ES via ergometers (including cycle ergometers, kayak ergometers, rowing ergometers, among others) and four using other methods (dynamometers and the Running-based *Anaerobic Sprint Test* [RAST]). No significant differences were found between the methods (*p*=0.75). However, significance was found in ES, as moderate ES was identified in both cases (ES=0.32 and 0.60, respectively).

In the meta-analysis performed by Dempsey *et al.* [10], which included three studies with a total of nine ES and an *n*= 149 subjects (*n*Cr= 75; *n*Pl= 74), no significant ES was identified in the anaerobic capacity measured by the peak power obtained with cycle ergometers. Similarly, no statistical significance was found when analysing three studies that measured peak torque using dynamometers.

Supplementation characteristics

In the present case, there were no significant differences in ES depending on the type of Cr consumed by the subjects; small to moderate ES were identified (ES=0.22 to 0.62). Similarly, Stout *et al*.[38] conducted a double-blind study over eight weeks with 24 college football players with three treatment conditions: 1) placebo (35 g carbohydrates [CHO]); 2) 5.25 g of creatine monohydrate (CrM) + 1g CHO; or 3) 5.25 g CM + 33 g CHO. These treatments were consumed four times a day for five days and then twice a day until the eight weeks were completed. They resulted in significant improvements in the bench press, vertical jumping and a 100-yard dash, identifying significant differences in the group that consumed CrM + CHO in the vertical jump and 100-yard dash, while the bench press showed significant improvement in all three treatments (*p*<0.01).

Furthermore, Rebello *et al*.[29], conducted a double-blind, placebo-control study on 18 swimmers (6 women and 12 men) distributed in two groups. One group received four daily doses of 5 g of Cr + 20 g of CHO, while the placebo group (Pl) received four doses of 20 g of CHO. In that study, among the findings on performance variables, it is indicated that a high intensity anaerobic resistance test was performed for 30-150 seconds; namely, a 100 m swim at maximum intensity. The results indicated higher lactate levels in Pl *vs*. Cr. While no differences were observed between the groups, some were noted between measurements in the Pl.

The form of supplementation (loading *vs*. loading + maintenance) did show a significant difference between ESs (ES=0.37 *vs*. 0.22, respectively).

Conclusion

Anaerobic capacity is improved by consuming Cr in any of its presentations, in both sexes and in both trained and untrained subjects.

The greatest effect of Cr on anaerobic capacity occurs during the loading phase *vs*. scenarios in which a loading and maintenance phase occurs (ES=0.37 *vs*. 0.22), while the total dose of this ergogenic aid did not show a significant ES (*p*=0.84).

Recommendations

It is recommended that journals request researchers to include descriptive statistics in their manuscripts to favour the inclusion of articles in meta-analyses.

More experimental studies should be performed with specific tests depending on the sport being performed and a detailed description of the test and treatment.

Finally, it is recommended to carry out more studies in women, clearly defining and describing the training, and to perform studies comparing loading or maintenance doses in a period of 28 days or more.

Conflicts of interest

The authors declare no conflict of interests.

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