Published in : Science a Sports (2017), vol.32, 61-72. http://dx.doi.Org/10.1016/j.scispo.2016.11.001
Status : Postprint (Author's version)

INTEREST OF CREATINE SUPPLEMENTATION IN SOCCER
INTERET D'UN COMPLEMENT ALIMENTAIRE EN CREATINE DANS LE FOOTBALL

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SUMMARY

Objectives. This review article aimed to summarize the current state of understanding on creatine supplementation for soccer players. In other words, it investigated the beneficial (and potentially negative) effects of this supplementation on sport-specific skills and performance in soccer players. Furthermore, this article accordingly discussed the safest and most recommended protocols for the consumption of creatine by these athletes.

News. Studies have shown that creatine supplementation can have positive effects on sprint and vertical jump performances in soccer players. This supplementation may also enhance soccer players' muscle strength and adaptation to a high-intensity training regimen. Besides, creatine may be able to enhance muscle glycogen (as well as phosphocreatine) storage, reduce oxidative stress, and improve muscular repair and hypertrophy. Interestingly, creatine supplementation does not seem to affect aerobic performance.

Prospects and projects. Soccer players could take creatine during pre-season training (3 to 5g/day) in order to help them endure a high-intensity training regimen and enhance their muscular strength and adaptation resulting from strength and/or resistance training. A lower dosage (less than 3g/day) might also be sufficient and beneficial during the season in case of fatigue, in order to sustain adequate levels of phosphocreatine and glycogen in the muscles. Occasional intakes (about 3g) before games and/or extenuating practices could also give a physical and mental boost to the players.

Conclusion. Most of the studies measured the effects of creatine on skills or physical performances in isolation from the true athletic demands of soccer match play. In conclusion, there is still a need for more research in order to determine whether creatine supplementation is ergogenic regarding the (aerobic) capacity to repeat (very) high-intensity actions, more particularly during competitive soccer.

KEYWORDS

Creatine ; Supplementation ; Exercise ; Performance ; Soccer

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RESUME

Objectifs. Cet article avait pour ambition de faire l'état des connaissances actuelles relatives à l'utilisation d'un complément alimentaire (c.-à-d. la créatine) chez des joueurs de football. En d'autres termes, l'objectif était de passer en revue les effets bénéfiques (et potentiellement délétères) de ce complément alimentaire sur les performances physiques et les habiletés techniques des joueurs de football. Cet article propose finalement une démarche propre et précise à suivre pour un joueur de football vis-à-vis de la consommation de créatine.

Actualités. Les études ont montré qu'un complément alimentaire en créatine peut avoir des effets bénéfiques sur des performances en sprint et de détente verticale chez des joueurs de football. Ce complément pourrait aussi améliorer la force et les adaptations musculaires de ces joueurs suite à une période d'entraînements à haute intensité. De plus, il se peut que la créatine soit capable d'augmenter les réserves de glycogène (outre celles de phosphocréatine), de réduire le stress oxydatif et d'améliorer la reconstruction et l'hypertrophie musculaires. Il est intéressant de noter que la créatine ne semble pas affecter les performances aérobies.

Perspectives et projets. Les joueurs de football pourraient prendre de la creatine (3 à 5 g/jour) pendant la période de préparation d'avant-saison afin de les aider à endurer cette période d'entraînements à haute intensité mais aussi d'améliorer leur force ainsi que les adaptations musculaires résultant d'un entraînement de force et/ou de résistance musculaire. Une plus faible dose (moins de 3 g/jour) pourrait aussi être suffisante et bénéfique dans le cours de la saison en cas de fatigue mais aussi afin de maintenir des niveaux adéquats de phosphocréatine et de glycogène dans les muscles. Des prises occasionnelles (environ 3g) avant les matchs et/ou des entraînements très contraignants pourraient aussi donner un coup de fouet physique voire mental aux joueurs.

Conclusion. La plupart des études ont mesuré les effets de la créatine sur les performances physiques et les habiletés techniques isolément des réelles exigences athlétiques d'un match de football. Davantage de recherches sont nécessaires afin de pouvoir déterminer si ce complément alimentaire est ergogénique concernant la capacité (ou plutôt la puissance aérobie) à répéter des actions à (très) haute intensité, et plus particulièrement durant (voire tout au long d') un match de football.

MOTS CLÉS

Créatine ; Complément alimentaire ; Performance ; Football

1. Introduction

Creatine is an organic acid that is found in the human body, mostly in the muscles.

This chemical can be endogenously produced by the liver and the kidneys from the amino acids glycine and arginine. It can also be ingested from exogenous sources such as foods (fish and meat) and dietary supplements (made in a laboratory). Creatine helps to supply energy to all cells in the body and more particularly to the muscles when exercising at a (very) high-intensity [1].

The form of creatine that has been most extensively studied and commonly used in dietary supplements is creatine monohydrate (CM), which is 88% pure creatine bound with water (counting for the remaining 12%). Studies have consistently indicated that CM supplementation increases muscle creatine and phosphocreatine concentrations, enhances anaerobic exercise capacity, and increases training volume leading to greater gains in strength, power and muscle mass [2-7].

Additionally, the available evidence suggests that CM consumption is safe as long as it is consumed by following recommended protocols [3,7-10]. Anecdotal reports from athletes have appeared on muscle cramps and gastrointestinal complaints during creatine supplementation, but the incidence is limited and not necessarily linked to creatine itself. Despite several unproved allegations, liver (enzymes, urea) and kidneys (glomerular filtration urea and albumin excretion rates) show no change in functionality in healthy subjects supplemented with creatine, even during several months [8,10-13]. In a retrospective study, Schilling et al. [9] examined the effects of long lasting (up to 4 years) creatine monohydrate supplementation on health markers and did not notice any harmful effects (including muscle cramps or injuries) after long-term creatine consumption. Moreover, Dos Santos Pereira et al. [14] demonstrated that creatine do not have any carcinogenic effects on heterocyclic amine production in human subjects.

Notwithstanding the robust literature supporting the benefits of creatine in enhancing sports performance, only a few studies have been carried out on soccer-specifically [15-22]. A review article is thus particularly relevant in order to investigate the beneficial (and potentially negative) effects of this supplementation on sport-specific skills and performance in soccer players. Furthermore, this article accordingly discusses the safest and most recommended protocols for the consumption of creatine by these athletes.

2. Methods

A computerized search was carried out in the libraries of the University of Liège (Belgium) and the Long Island University (New York, USA). The databases used were PubMed and SPORTDiscus. No limit was used for the different searches. With the PubMed database, the following search terms were used to find the most recent studies and research articles that, on the one hand, involved soccer players as subjects and, on the other hand, aimed to establish the possible ergogenic effect of creatine supplementation on soccer-specific skills and performances:

- creatine AND Soccer: 98 results, five met the criteria (Claudino et al. [20]; Williams et al. [21]; Ostojic [18]; Cox et al. [17]; Mujika et al. [16]);
- creatine AND Football: 125 results, one met the criteria (Claudino et al. [20]);
- creatine supplementation AND Soccer: 23 results, five met the criteria (Claudino et al. [20]; Williams et al. [21]; Ostojic [18]; Cox et al. [17]; Mujika et al. [16]);
- creatine supplementation AND Football: 37 results, one met the criteria (Claudino et al. [20]).

The search using SPORTDiscus combined the keywords "Creatine supplementation" and "Soccer". It yielded 30 articles, six of which met the criteria (Claudino et al. [20]; Williams et al. [21]; Ostojic [18]; Cox et al. [17]; Larson-Meyer et al. [15]; Mujika et al. [16]). The search combining "Creatine supplementation" and "Football" essentially found the same articles of the PubMed search using the same keywords.

Two additional articles (Mohebbi et al. [19] and Machado et al. [22]), which also met the criteria, were retrieved by reviewing reference lists of articles. Google Scholar reinforced the relevance and/or the exclusivity of those eight articles by attesting the number of citations for each of them: Mujika et al. [16] (cited by 174); Larson-Meyer et al. [15] (cited by 42); Cox et al. [17] (cited by 65); Ostojic [18] (cited by 63); Machado et al. [22] (cited by 4); Mohebbi et al. [19] (cited by 2); Claudino et al. [20] (cited by 2) and Williams et al. [21] (cited by 0).

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3. Physiological aspect and demands of soccer

During a 90-minute game, professional soccer players cover between 10 and 13 kilometres and less than 5% of this distance is done by sprinting (running faster than 24km/h), which means that soccer players sprint between 200 and 500 meters [23-34]. On average, 15 to 30 sprints (95% of which are shorter than 30 meters long) are performed during a game. The remaining distance is covered by walking (25-30%), jogging (15-20%), low-speed running (25-30%), moderate-speed running (5-10%), high-speed running (5-10%) and backwards running (less than 5%). Besides, it has been shown that a high-intensity action lasts 3 ± 2 seconds and occurs every 30 to 45 seconds during a soccer game, with considerable variability within and between players [35]. These high-intensity actions include sprints (> 24 km/h), high-speed running (between 21 and 24km/h), jumps, headings, tackles, passes, shots, dribbles and also forceful contractions to maintain balance and ball control against pressure. Soccer can thus be described as an intermittent prolonged-duration high-intensity exercise [36].

In terms of physiology, phosphocreatine and muscular glycogen are the two primary energy sources used by soccer players [26]. Indeed, phosphocreatine provides adenosine triphosphate (ATP) for short (0 to 10 seconds) high-intense actions, which are numerous (between 150 and 250 in total) and frequently decisive during a soccer game [27,30]. Within this context, it is very interesting to remind that creatine supplementation increases muscle phosphocreatine storage in muscles and promotes faster regeneration of adenosine trisphosphate (ATP) between high-intensity exercises [2,4,37,38]. As a matter of fact, it has been reported that this supplementation can increase the creatine concentration in muscles by approximately 20 to 50%, with increases in phosphocreatine accounting for 20 to 40% of the difference [3,21,39,40]. Concretely, a creatine supplement may help the player increase his/her phosphocreatine storage and thereby enable him/her to repeat several bursts of physical activity with relatively short recovery time, for practicing but also for competing. For example, it could help soccer players perform an extra set of sprints or plyometric exercises during several practices, which could increase their power and speed in greater extent. In the course of game, a soccer player may also be able to perform an extra sprint, a longer sprint or other high-intensity actions (such as headings, tackles, shots and dribbles) that would enable him/her to have an advantage over his/her opponent.

Regarding the glycogen, a substantial amount is used for all the low- and moderate-intensity actions performed during a game, mostly aerobically. High-intensity actions are on average not long enough to trigger the anaerobic glycolysis, which explains why the lactate production remains relatively moderate and rarely exceeds 10mmol/L during a soccer game [26]. However, a few intense efforts may occur close to each other. The recovery time is then not long enough and anaerobic glycolysis can be launched. Therefore, the use of glycogen is even greater. Moreover, muscular glycogen content often ascertains the time-to-fatigue and performance in exercise longer than 60 minutes, such as soccer games and practices. Curiously, creatine supplementation may also enhance muscle glycogen storage [2,4,7,41]. Hickner et al. [41] for instance noted in 2010 that a creatine group presented higher (approximately 20% extra) resting muscle glycogen content after a 28-day creatine supplementation (3 g/day) when compared to a placebo group. Besides, the muscle glycogen concentration at the end of a two-hour ride was significantly higher (approximately 40% extra) in the creatine group than the placebo group ($P < 0.05$). This could be explained by a greater insulin spike and/or enhanced glucose transporter type 4 (GLUT4) expression. Creatine supplementation may eventually enhance insulin-induced glycogen synthesis and/or training-induced glycogen accumulation in muscles [2,4,7,41].

As a result, creatine provides an extra amount of energy (phosphocreatine and glycogen) for an athlete performing any sort of (intermittent) high-intensity exercise. In other words, competitions or training programs involving repeated bouts of high-intensity and/or causing muscle glycogen depletion could be enhanced by creatine loading [2,4]. From this angle, creatine supplementation appears relatively ergogenic for soccer players.

Another physiological aspect of soccer that creatine may affect is the oxidative stress induced by exercise. Indeed, the production of reactive oxygen species, which can affect muscle fatigue and protein turnover, increases as the intensity of the exercise increases [42]. Soccer players are thus likely to experience increased oxidative stress when performing near to maximal capacity for extended periods of time. Interestingly, creatine supplementation may neutralize free radicals and other reactive oxygen species [43] but also attenuate oxidative DNA damage and lipid peroxidation induced by a single resistance exercise protocol [44]. As a result, creatine supplementation could be used as a strategy to attenuate the potentially detrimental effects of the oxidative stress likely endured by soccer players.

Creatine supplementation may also be beneficial for a soccer players regarding muscle repair and hypertrophy. On the one hand, lower serum myostatin levels (caused by creatine supplementation) may augment the effects of resistance training on muscle mass and strength [45]. This action of creatine in conjunction with resistance training can be very interesting for a soccer player while weight training and/or repeating high-intensity exercises. Indeed, the training and muscle adaptations may be more important and then help soccer players become stronger and more powerful. On the other hand, creatine supplementation during resistance training may increase intramuscular IGF-1 concentration to a greater extent than resistance training single-handedly [46]. This could be translated into better muscle repair and, therefore, prevent soccer players from muscles injuries.

In addition, it appears that creatine supplementation could have beneficial effects on muscle cramps, dehydration and thermoregulatory responses [47]. Indeed, creatine may increase total body water (more specifically intramuscular water and not subcutaneous) without altering fluid distribution between intracellular and extracellular fluid [48]. This osmotic effect of creatine may furthermore be beneficial by attenuating the core temperature rise, the risk of dehydration and, as a result, the risk of muscle cramps [4]. The only concern regarding this aspect could be the body weight gain, especially for soccer players and/or other athletes who must be quick, fast and agile. This weight gain is usually in the range of 0.7 to 1.7 kg following a loading phase (20-25 g/day for 5 to 7 days) and can go up to approximately 4 to 5 kg if a maintenance phase (5 g/day) and a total body resistance training are performed for three to four weeks afterwards [47,48]. In this case, not only intramuscular water retention but also protein synthesis (hypertrophy) may explain such an important weight gain [48]. This potential adverse effect may be attenuated by a one-month washout period. Indeed, the cessation of creatine supplementation for one month can bring muscle creatine concentration back to the pre-supplementation value, which could therefore negate the water weight gain [40,49].

Besides, creatine may have a negative impact on the active range of motion (ROM) of several joints such as ankles and knees [4,50]. On the one hand, creatine supplementation may increase the intracellular water content in muscles, which can result in muscle stiffness and resistance to stretch. On the other hand, the increased volume of the muscle cells may affect the neural outflow of muscle spindles, which can negatively affect the ROM of any joints [4]. However, the studies showing these negative effects measured the reduced active ROM immediately after the loading phase. These effects may not be seen after several weeks of maintenance phase [50].

All this being said, it is important to note that some individuals may respond more (or less) to supplementation than others because they have lower endogenous muscle creatine content and/or greater population of type II fibers. Consequently, those "high-responders" possess higher potential to increase their phosphocreatine storage and thereby improve their performance and/or their capacity to train more in response to creatine supplementation.

In contrast, "low-responders" have normal to high endogenous muscle creatine levels, which keep them from experiencing any substantial increases of phosphocreatine storage and/or any improvements of performance with creatine supplementation [4,7,18,51]. The above-mentioned beneficial and adverse effects should therefore be evaluated and/or measured individually in each soccer players taking creatine supplementation.

4. SOCCER-SPECIFIC SKILLS AND PERFORMANCE

Mujika et al. [16] designed in 2000 an investigation in order to determine whether acute creatine supplementation could improve performance and recovery in highly-trained soccer players performing intermittent high-intensity exercises specific to competitive soccer. The soccer-specific testing protocol was divided into four exercises performed one after another: a countermovement jump test (CMJT), a repeated sprint test (RST), an intermittent endurance test (IET) and a "recovery" CMJT. Seventeen highly-trained male soccer players performed this entire session twice, 7 days apart. After the first session, they were randomly assigned to either a creatine monohydrate supplementation group or a placebo group. The groups were matched for physical characteristics, playing positions and level of performance on the first session. The creatine group ingested four 5-g doses of creatine per day for six days, whereas the placebo group ingested maltodextrin. Results showed that the creatine group's average 5-meter time during the RST was significantly faster after supplementation (0.95 ± 0.03 vs. 0.97 ± 0.02 s, $P<0.05$) and the creatine group's average 15-meter time during the RST was almost significantly faster after supplementation (2.29 ± 0.08 vs. 2.32 ± 0.07s, $P = 0.07$). These improvements were not observed (did not reach the statistical significance) in the placebo group but it is important to note that the placebo group's average 5-meter and 15-meter times after supplementation (placebo) were almost similar to the creatine group's average times (0.96 ± 0.03 vs. 0.95 ± 0.03 and 2.29 ± 0.05 vs. 2.29 ± 0.08, respectively). Nevertheless, the authors stated, "the observed improvement could represent a substantial performance advantage in competitive soccer because each player usually performs between 60 and 90 sprints per game and travels an average distance of 15 to 25 meters in each of those sprints." The 0.02 second improvement for the 5 meters and the 0.03 second improvement for the 15 meters in the creatine group correspond to 10.3 and 19.3 cm, respectively, which could probably help soccer players outrun an opponent and/or attain possession of the ball. Another relevant finding of this study concerns the recovery CMJT: the creatine group's performance remained statistically unchanged after supplementation when compared to the first CMJT of the protocol. In contrast, the placebo group showed a tendency toward worsened performance ($P = 0.07$ for the average of the three jumps). According to Mujika et al., this indicates a facilitated phosphocreatine recovery between the first and the last tasks of the protocol, which could have a positive influence on competitive soccer. Indeed, it may facilitate the aerial possession of the ball during the last minutes of a game and, therefore, determines the final score as this type of action can be decisive in competitive soccer match play [16,27,30].

In 2002, Cox et al. [17] undertook a study investigating the effects of creatine supplementation on the performance of elite female soccer players by using the same dosage and protocol as the previous study (four 5-g doses of creatine per day for six days for the creatine group and the same dosage of a glucose polymer for the placebo group). Twelve professional female soccer players performed a standardized testing protocol twice, seven days apart. The protocol was designed to mimic the physical demands of a soccer game and consisted of five 11-minute exercise-testing blocks separated by 1 minute of rest. Each block was composed of eleven 20-meter maximal sprints, two agility runs and one precision ball-kicking drill, interspersed by several 20-meter recovery walks, jogs and/or runs. The overall sprint performance (mean of 55 sprints) did not significantly change in both groups although the average time for the creatine group decreased from 3.75 ± 0.19 to 3.69 ± 0.18s (P = ns). However, it is important to note that nine of the 55 sprints reached a significant enhancement (sprints 11, 13, 14, 16, 21, 23, 25, 32 and 39, *P*<0.05). Similar results were observed for the agility runs: the overall performance (mean of 10 runs) did not significantly change in any group although the creatine group significantly achieved faster post-supplementation times in three agility runs (*P*< 0.05). In addition, the creatine group's average time for these 10 agility runs decreased from 11.2 ± 0.6 to 10.9 ± 0.4s (*P*=ns). Regarding the accuracy of shooting, no significant difference was noted when comparing pre-versus post-supplementation values within each group. Nevertheless, the observed mean improvement of 0.06 s across 20-meter sprints and 0.3 s in the agility runs (in the creatine group) could translate into distances of approximately 30 and 70 cm, respectively. These improvements are meaningful for the outcome of a game as they could enable soccer players to outrun an opponent and/or gain possession of the ball [17].

The effects of creatine supplementation on skill and sprint performances in young soccer player were investigated in 2012 by Mohebbi et al. [19]. Seventeen young male soccer players were randomly assigned to either creatine (5g/day for 6 days) or a placebo (same dosage of a glucose polymer). Before and after supplementation, each subject performed a RST, a dribble test and the same accuracy-shooting test than Cox et al. Creatine supplementation significantly improved the performance for the RST (*P* = 0.001). Indeed, the creatine group's sum of times was equal to 18.89±0.7s pre-test and 17.79 ± 0.5s post-test. This 1.1-second improvement (for 6 x15 m) means that each subject was on average approximately 0.18 seconds faster for each sprint. The results of this study also indicated a significant improvement for the dribble test in the creatine group after supplementation when compared to the dribble test performed before supplementation (6.75 ± 0.5s vs. 7.37 ± 1.09s, *P* = O.049, respectively). This dribble test worsened in the placebo group as the average best time increased from 7.06 ± 0.8 s to 7.38 ± 0.4. According to Mohebbi et al., this improvement was probably due to higher phosphocreatine storage and therefore higher production of ATP, which could explain the increase in the subjects' speed of motion [19]. Regarding the shooting accuracy, it enhanced in both groups but this improvement was not significant (*P* = 0.4 and *P* = 0.373 for creatine and placebo groups, respectively). This greater ability to kick the ball accurately after supplementation was likely due to learning in the post-test. The investigators concluded, "Short-term consumption of creatine supplementation is effective in improvement of performance, speed and skill of young soccer players" [19].

In 2004, Ostojic [18] examined the effects of acute creatine supplementation on soccer-specific performance in twenty young male soccer players as well. Subjects were randomly allocated to either a creatine or a placebo group. The subjects in the creatine group (*n* = 10) were asked to consume three 10-g doses of creatine mono-hydrate per day for seven days, while the subjects in the placebo group (*n* = 10) ingested an equal number of doses containing cellulose. Before and after the supplementation, each subject performed several soccer-specific skill and fitness tests: a dribble test, a sprint-power test, a vertical jump test and an endurance shuttle-run test. Dribble test times, sprint-power test times and vertical jump height significantly improved in the creatine group (*P* < 0.05) after the supplementation. Dribble test times decreased from 13.0 ± 1.5 to 10.2 ± 1.8 seconds, sprint-power times improved from 2.7±0.4 to 2.2 ±0.5 seconds and the vertical jump height increased from 49.2 ± 5.9 to 55.1 ± 6.3 cm (from pre- to post-supplementation, respectively). Furthermore, these performances were significantly superior in the creatine group post-supplementation when compared to the placebo group (*P*< 0.05), for which no changes were observed from pre- to post-supplementation. Besides, the endurance shuttle-run performance did not change within and between trials for any groups (*P*>0.05). These results suggest that 30g/day of creatine monohydrate for seven days favorably affects dribble, sprint and vertical jump performances in young soccer players, while endurance ability is not affected [18].

In 2008, Machado et al. [22] assessed the effect of a 5-day creatine supplementation on the metabolism of nitrogen compounds (possible inducers of fatigue during exercise) and physical performance in professional soccer players. The daily concentration of this supplementation was

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Status : Postprint (Author's version)

equal to 0.6g/kg of body weight per day containing 50% of creatine and 50% of dextrose for the experimental group, and 100% dextrose for the control group. This means that the creatine supplementation for the experimental group was in the range of 20.5 and 25.5g/day. It is important to note that the players undertook this protocol during the first week of pre-season, which included daily sessions of soccer training. Furthermore, it means that this investigation was preceded by a long rest period for the participants. Immediately after the five-day supplementation, the subjects underwent a graded exercise test until exhaustion on a treadmill. Blood samples were collected before the supplementation but also right before, 10 minutes after and 20 minutes after the exercise test, in order to measure ammonia, uric acid and urea levels. Ammonia and uric acid levels did not differ significantly between groups at any times ($P>0.05$). However, the authors found that the urea concentration increased by 60% in the control group between the first blood collection (before supplementation) and the pre-test measurement (after supplementation), while it remained stable in the experimental group. After the graded exercise test, the concentrations did not vary in any groups and thus remained elevated in the control group. The investigators postulated that creatine supplementation may have induced an increase in muscle protein synthesis, which would have reduced nitrogen excretion in the form of urea. Besides, they reported that training after a long rest period might lead to uremia in soccer players because of a higher protein breakdown and consequent amino acid oxidation. Concerning the graded exercise-testing, both groups achieved a time to exhaustion equal to 19 ±1 minutes [22]. This finding is not surprising as a higher phosphocreatine concentration in the muscles is not likely useful for a continuous and gradual running (endurance) exercise, which is in accordance with Ostojic [18] and Hickner et al. [41] who found a neutral (neither detrimental nor beneficial) effect of creatine supplementation on aerobic performance.

Larson-Meyer et al. [15] investigated the effects of creatine supplementation on muscle strength and body composition (including body mass, lean mass and fat mass) in female collegiate soccer players. This investigation was quite different than the studies previously discussed because it occurred off-season and lasted 13 weeks including a two-week break regarding supplementation and training. Also, the creatine supplementation was longer and organized in several phases. Indeed, the creatine group initially consumed two 7.5-g doses of creatine (incorporated in a sport drink) per day for 5 days (loading phase) while the placebo group ingested the same sport drink (but without creatine). Then, the creatine group started a 12-week maintenance phase by consuming 5 g of creatine per day (also incorporated in a sport drink) for five days a week while the placebo group ingested the sport drink (still without creatine). However, it is important to note that this maintenance phase consisted of two 5-week periods, which were separated by 2 weeks of rest with no practice and no supplementation. The amount of creatine ingested by the participants in the creatine group was eventually much higher than the studies made by Mujika et al. [16], Cox et al. [17], Ostojic [18], Machado et al. [22] and Mohebbi et al. [19]. At baseline and at the end of the protocol, each subject performed the following tests: 1 repetition maximum (1RM) bench press, a 1RM full squat and a vertical jump. The 1RM measurements (bench press and full squat) were also performed after the first 5-week period of the maintenance phase. During the 13 weeks, the collegiate soccer players performed three soccer practices weekly (including 20 minutes of sprint drills twice a week) and two or three strength training sessions. The creatine group showed a significant ($P = 0.05$) greater improvement in 1 RM bench press between baseline and the fifth week, when compared with the placebo group. Performance increased from 45.5 ± 9.9 to 49.1 ± 8.9kg and 46.1 ± 3.4 to 52.9 ± 4.7kg for the placebo and the creatine groups, respectively. In other words, the creatine supplementation was associated with an increase in 1RM bench press that was almost two times greater during the first five weeks (15 vs. 8%). With the physical contact involved in soccer, a stronger upper body may help a soccer player "push" (without making a fault) or keep an opponent away from the ball and, therefore, maintain or gain its possession under pressure. Regarding the 1RM full squat, a significant greater improvement was found between the fifth week and the end of

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Status : Postprint (Author's version)

the protocol for the creatine group, when compared to the placebo group (2.8 and 0.8% increase in the creatine and placebo groups, respectively). Full squat exercises are great for a soccer player in order to jump higher and become faster. Indeed, it has been shown that there is a strong correlation between maximal strength squats and jumping height (r = 0.78) and 10-meter sprint performance (r = 0.98) in high level soccer players [52]. The 1RM full squat improvement observed in the creatine group is therefore very relevant from a soccer player's point of view. Larson-Meyer et al. therefore suggested that off-season supplementation in female collegiate soccer players may enhance their adaptation to a high-intensity training regimen and (thereby) muscle strength [15].

In 2014, Claudino et al. [20] observed that creatine supplementation could prevent the progressive training-induced decrement in lower-limb performance in professional soccer players during pre-season. A counter-movement jump (CMJ) performance, which consisted of 8 jumps with 1-minute recovery between each attempt, was assessed before and after seven weeks of resistance and soccer-specific training (2 and 4 sessions/week, respectively) combined to a concurrent creatine monohydrate (creatine group) or dextrose (placebo group) supplementation (20g/day for one week followed by 5g/day for 6 weeks). Before and after this 7-week intervention, no significant differences were observed between groups for body mass and jumping performance. Nevertheless, jumping performance decrease (-0.7%) in the placebo group and increase (+2.4%) in the creatine group. According to the magnitude-based inference analysis, creatine supplementation may lead to a *very likely trivial effect* (96%) in jumping performance in professional soccer players during pre-season [20].

Also in 2014, Williams et al. [21] aimed to determine the effects of creatine supplementation on a 90-minute soccer-specific performance test, i.e. the Ball-sport Endurance And Speed Test (BEAST). This test consists of a 380.4-m circuit that includes sprinting at maximal speed (8.4% of the total distance covered), backward jogging (8.4%), walking (9.7%), jogging/decelerations (24.5%) and forward running at 75% of maximal speed (39%). This circuit is continuously repeated for 45 minutes (first half), followed by a 10-minute recovery period (halftime), and then repeated for 45 minutes once more (second half). After each lap, the subject must undertake an accuracy-shooting drill first (six rolled balls shot at an indoor soccer goal) and a vertical jump test then (on a jump mat). With the BEAST, it is ultimately possible to measure aerobic (circuit time), speed (12- and 20-m sprint) and explosive power (vertical jump) abilities. Also, this test claims to be a valid and reliable soccer-specific protocol that replicates most physical demands (in terms of movement patterns, volume and intensity) of a competitive soccer match play [53]. Sixteen male amateur soccer players participated in this investigation and were required to perform the BEAST before and after the supplementation, which corresponded to 20g/day of creatine monohydrate (creatine group) or corn flour (placebo group) for 7 days. No significant differences were observed between groups before and after the supplementation for mean circuit time, 12- and 20-m sprint times, vertical jump height and body mass. Furthermore, the performance measures of the first half decreased during the second half for both creatine (-1.2 to -2.3%) and placebo (-1.0 to -2.2%) groups. This suggests that creatine supplementation did not have any performance-enhancing effects or abilities to offset fatigue while performing an intermittent prolonged-duration high-intensity work. The researchers also reported that, when assessed for the whole 90-minute BEAST protocol, all effects of creatine were negative, which means that the chances of a detrimental effect were greater than the chances of a beneficial effect [21]. Nevertheless, it is important to note that on the one hand there was no evidence of weight gain after supplementation and, on the other hand, the post-supplementation urinary creatine concentration was ten times higher in the creatine group than the placebo group. This could imply that the creatine group already had elevated muscle creatine stores at baseline. Therefore, creatine supplementation might have had little impact on increasing muscle creatine concentration, and ultimately, body mass and performance (Table 1).

Published in : Science & Sports (2017), vol.32, 61-72. http://dx.doi.Org/10.1016/j.scispo.2016.11.001
Status : Postprint (Author's version)

Table 1 Creatine supplementation and soccer-specific skills and performance.

Study	Year	Dosage + protocol	Population	Findings
Mujika et al.	2000	Gr1 : CR monohydrate 4 x 5 g/d for 6 d Gr2: Maltodextrin 4 x 5 g/d for 6 d + NO extra and/or specific training	17 highly-trained male soccer players (age: 20.3 ± 1.4 years, body mass: 74.8±5.5kg, and height: 179.9±5.5cm) CR = 8 and PL = 9	→5-meter and 15-meter sprints respectively 0.02 and 0.03 s faster in CR after supplementation →CMJT performance did not decrease in CR after supplementation while it did in PL
Cox et al.	2002	Gr1 : CR monohydrate 4 x 5 g/d for 6 d Gr2: Glucose Polymer 4 x 5 g/d for 6 d + NO extra and/or specific training	12 professional female soccer players (age: 22.1 ±5.4 years, body mass: 62.6 ±6.4 kg, and height: 166.0±7.2cm) CR = 6 and PL = 6	→9 out of 55 20-meter sprints were significantly (*P*<0.05) faster (+ mean improvement of 0.06s for the 55 sprints) in CR after supplementation →No SIGNIFICANT improvements for agility runs and shooting accuracy in any groups BUT mean improvement of 0.3 s in agility runs in CR after supplementation
Mohebbi et al.	2012	Gr1 : CR monohydrate 4 x 5 g/d for 6 d Gr2: Glucose Polymer 4 x 5 g/d for 6 d + NO extra and/or specific training	17 moderately-trained young male soccer players (age: 17.2 ± 1.4 years, body mass: 61.7 ± 1.4 kg, and height: 169.6±6.2cm) CR = 8 and PL = 9	→ Mean improvement of 1.1 s for the total time of 6 x 15-meter sprints (≈0.18s faster for each sprint) in CR after supplementation →Significant improvement in a dribble test (≈0.62 s, *P*<0.05) in CR after supplementation while this performance worsened in PL
Ostojic	2004	Gr1 : CR monohydrate 3 x 10 g/d for 7 d Gr2 : Cellulose 3 x 10 g/d for 7 d + NO extra and/or specific training	20 moderately-trained young male soccer players (age: 16.6 ± 1.9 years, body mass: 63.6±5.6kg, and height: 175.2±9.1cm) CR = 10 and PL =10	→Dribble test times, sprint-power tests and vertical jump height significantly improved (*P*<0.05) in CR after supplementation AND were significantly superior in CR when compared to PL after supplementation →The endurance shuttle-run test did not change within and between trials in any groups
Machado et al.	2008	Gr1 : 0.6g/Kg of body weight with 50% CR monohydrate and 50% Dextrose for 5 d Gr2 : 0.6g/Kg of body weight with 100% Dextrose for 5d + NO extra and/or specific training	31 professional male soccer players CR = 17 (age: 25 ± 3 years, body mass: 73.0 ±1.8 kg) PL = 14 (age: 27 ±1 years, body mass: 73.9±5.4kg)	→Urea concentration increased by 60% in PL after the 5-day supplementation while it remained the same in CR AND this concentration did not vary in any groups after the graded exercise test, thus remained elevated in PL →Similar performance in the graded exercise test for both groups
Larson-Meyer	2000	Gr1: CR monohydrate 2 × 7.5 g/d for 5 d	14 collegiate female soccer players	→Increase in Lean Mass approximately 0.65 kg

et al.		(Each dose - 7.5 g - mixed with 60 mL of PowerAde and 480 mL of water) + Maintenance 5 g/day - 5d/week - for 12 Weeks (including 2-week break) Gr2: 60 mL of PowerAde and 480 mL of water twice/day for 1 week and once/day for 12 weeks (including 2-week break) + Soccer-specific and STRENGTH training (during 13 weeks in total including a 2-week break in the middle of the study)	CR = 7 (age: 19.3 ± 1.4 years, body mass: 61.9 ± 5.3 kg and height: 164.9 ± 2.4 cm) PL = 7 (age: 19.0 ± 1.5 years, body mass: 63.6 ± 9.0 kg and height: 166.3 ± 3.4 cm)	greater in CR after 13 weeks (BUT not statistically significant) →1 RM Bench Press significantly improved in CR between baseline and 5th week (*P*< 0.05) when compared to PL (almost twice greater: 15 vs. 8%, respectively) →1 RM Full Squat significantly improved in CR between 5th week and 13th week (*P*<0.05) when compared to PL (2.8vs 0.8%, respectively) + 1 RM Full Squat also increased between baseline and 5th week (20 vs. 13% in CR and PL, respectively) BUT this improvement was not significantly different between groups
Claudino et al.	2014	Gr1: CR monohydrate 4 × 5 g/d for 7 d + Maintenance 5 g/day for six weeks Gr2: dextrose 4 × 5 g/d for 7 d + Maintenance 5 g/day for six weeks + Soccer-specific RESISTANCE training (during 7 weeks in total)	14 professional male soccer players (age: 18.3 ±0.9 years, body mass: 69.9 ±8.8 kg, and height: 175.0± 10.0cm) CR = 7and PL = 7	→ Increase in body mass for both groups (CR = +0.8% and PL = 2.2%) but no significant differences for time × group interaction →Jumping performance decrease in PL after supplementation (-0.7%) while it increased in CR (+2.4%) but it did not reach statistical significance for time × group interaction +The proportion of subjects with a reduction in jumping performance was significantly greater in PL than CR (5 and 1, respectively; *P* = 0.05) after supplementation
Williams et al.	2014	Gr1: CR monohydrate 4 × 5 g/d for 7 d (Each dose - 5 g - mixed with 8 g of flavored glucose powder and interspersed by 4 hours) Gr2: corn flour 4 × 5 g/d for 7 d (Each dose 5 g - mixed with 8 g of flavored glucose powder and interspersed by 4 hours) + NO extra and/or specific training	16 amateur male soccer players CR = 8 (age: 25.4±4.5 years, body mass: 79.3 ±10.5 kg and height: 179.3±4.6cm) PL = 8 (age: 26.7 ±4.6 years, body mass: 80.8 ± 8.6 kg and height: 178.9±5.1cm)	→ Decrease in performance measures during the second half of the BEAST when compared to the first half for both CR (-1.2 to -2.3%) and PL (-1.0 to -2.2%) groups →No significant differences between groups for mean circuit time, 12- and 20-m sprints, vertical jump performance and body mass (before and after supplementation) →Negative tendency for 12-m sprint (-0.53 ±0.69s) and 20-m sprint (-0.39±0.59s)

CR: Creatine or Experimental Group; PL: Placebo or Control Group; CMJT: Countermovement Jump Test; 1RM: 1 Repetition Maximum.

5. RECOMMENDED CREATINE PROTOCOLS FOR SOCCER PLAYERS

A typical creatine supplementation protocol consists of a "rapid loading" phase (20g/dayor0.3g/kg/day - split into four daily intakes) followed by a "maintenance" phase (3 to 5 g/day or 0.05 to 0.075 g/kg/day) for the rest of the supplementation [4,7]. The loading phase is usually five to seven days long while the duration of the entire supplementation can vary from one week to several months. In other words, the supplementation can be limited to the (rapid) loading phase as most of the studies related to soccer-specific skills and performance have done [16-19,21,22]. Other protocols can also be undertaken such as a "slow loading" phase consisting of 3 to 5 g/day (or 0.05 to 0.075 g/kg/day) for four weeks. This (slow) loading phase can be followed by a "maintenance" phase as well (but not necessarily) in order to sustain elevated levels of creatine and phosphocreatine in the muscles [1,4]. Furthermore, Sale et al. [54] reported that a protocol consisting of 20 g of creatine monohydrate per day taken in 1-g doses (evenly ingested at 30-minute intervals) for five days resulted in reduced urinary creatine excretion and an estimated increase of 13% in whole body retention of creatine when compared with a typical loading supplementation. Thus, the ingestion of several doses of small amounts of creatine monohydrate spread throughout the day may be more beneficial in order to increase phosphocreatine storage and, therefore, lead to higher capacity to train and compete [54].

Unfortunately, the "rapid loading" may be detrimental for a soccer player during the season because of a possible decrease in range of motion, which could negatively impact players' abilities to handle the ball as well as pose an increased risk for injuries. Furthermore, this protocol may cause a substantial weight gain, which could hinder skilled and agile players from moving nimbly (with or without the ball) on the field. However, a "rapid loading" was used in most of the studies investigating soccer-specific skills and performance, which did not report any side effects or injuries. Moreover, some soccer-specific skills (such as dribbling and shooting) were either improved or maintained. This option may therefore be considered but only if both of the following conditions are met: the season is not about to start and the only purpose of the creatine supplementation is to undertake soccer-specific weight training and/or slightly increase lean body mass. These conditions should be respected in order to ensure players' skills, fitness and health.

Additionally, most of soccer players could take creatine off-season by following a "slow loading" protocol consisting of 3 to 5 g of creatine a day for several weeks. Indeed, this dosage may help them endure a high-intensity training regimen and therefore enhance their muscular strength and adaptation. In addition, a lower dosage (less than 3g/day) during the season might be sufficient and beneficial in case of fatigue, in order to sustain adequate levels of creatine, phosphocreatine and/or glycogen in the muscles, or also to improve the muscles' repair. The very last recommenced protocol would be occasional intakes (about 3 g) before the game(s) and/or extenuating practice(s) in order to give a physical and mental boost to the players.

Finally, the addition of carbohydrates, proteins and/or caffeine appears to be beneficial. On the one hand, the ingestion of carbohydrates and proteins in combination with creatine may create a greater insulin spike and, therefore, augment creatine uptake and glycogen storage in muscles [4,41,55]. On the other hand, the addition of caffeine may emphasize the primary ergogenic effect of creatine supplementation, which is an extra amount of energy, by delaying the onset of neuromuscular fatigue and, therefore, improve the ability to practice longer and/or perform at a higher level [49,56,57]. The addition of D-pinitol might also be considered as this supplement may negate the possible weight gain (possibly detrimental for soccer players) with creatine supplementation without affecting its advantageous benefits [58].

Published in : Science & Sports (2017), vol.32, 61-72. http://dx.doi.Org/10.1016/j.scispo.2016.11.001
Status : Postprint (Author's version)

Conclusions

To recapitulate, it is commonly accepted that creatine supplementation can enhance anaerobic exercise capacity and increase training volume, leading to greater gains in strength, power and muscle mass [2-7]. This should be the principle, and possibly only, reason for which an athlete uses this supplementation. It is also interesting to note that creatine may be one of the most popular and widely used nutritional supplements by athletes over the last few decades. In addition to soccer players, other team-sport athletes (i.e. rugby union, American football, handball, lacrosse, ice-hockey, baseball, volleyball and basketball players) have been supplemented with creatine in order to augment their training capacity (increase in load and/or performance) and thereby improve their performance [39,59-67]. Other athletes performing (intermittent) high-intensity exercises (i.e. wrestlers, swimmers or tennis players) could also benefit from creatine supplementation and may therefore consider it as a strategy for performance enhancement [66,67].

However, it should be kept in mind that creatine usage must be interrupted in athletes who do not respond to supplementation (likely "low-responder") or who report side effects. Even if there are no obvious health risks associated with creatine supplementation, it may be best to err on the side of caution when supplementing on a chronic basis. Creatine ingestion is still a burden to be eliminated by the kidney. A pre-supplementation investigation of kidney function may therefore be considered for individuals with pre-existing renal disease or with a potential risk of renal dysfunction (diabetes, hypertension) but appears unnecessary for normal healthy subjects [8]. Regular checkups of blood levels of liver enzymes, urea, and creatinine could also be interesting in case of chronic supplementation.

Regarding soccer-specific skills and physiological demands, creatine supplementation seems safe and somewhat ergogenic. Studies have specifically shown its positive effects on dribble, sprint and vertical jump performances in soccer players. Supplementation may also enhance soccer players' muscle strength and adaptation to high-intensity training regimens. Soccer players therefore may likely be "(high)-responders" to creatine supplementation. A (rapid and/or slow) loading phase may thus be of interest off-season and/or during pre-season. Light to moderate dose(s) of creatine (3 to 5 g - once or several times per week) during the season might also be beneficial in cases of fatigue, to sustain adequate levels of creatine, phospho-creatine and/or glycogen in the muscles, to improve the repair of muscles, or to give a physical (and mental) boost to soccer players. The addition of carbohydrates, proteins and/or caffeine may increase some of these advantageous effects [41,55-57].

Nevertheless, most reviewed studies measured the effects of creatine on soccer skills or physical performance in isolation from the real-life athletic demands of in-match soccer play. Williams et al. [21] were the only ones to closely simulate the intensity and duration of a full game by combining several soccer-specific tasks and physical challenges. Interestingly though, they did not report any positive effects and brought into question the potential of creatine as an effective ergogenic aid for soccer players in competition.

There is still a clear need for more research to determine whether creatine supplementation is truly ergogenic regarding the (aerobic) capacity to repeat high-intensity movement, specifically during competitive soccer. However, if supplementation enables a soccer or other team-sport athlete to practice more for a longer duration and/or with more intensity, it will most likely help him to improve athletically and be an overall better player on the field.

Disclosure of interest

The authors declare that they have no competing interest.

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