Creatine for Exercise/Sports Performance

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Creatine is one of the most studied and popular ergogenic aids for athletes and recreational weightlifters seeking to improve sport and exercise performance, augment exercise training adaptations, and mitigate recovery time. Studies consistently reveal that creatine supplementation exerts positive ergogenic effects on single and multiple bouts of short-duration, high-intensity exercise activities, in addition to potentiating exercise training adaptations.

supplementation ergogenic aid athletic performance weightlifting resistance exercise training muscular power recovery muscular adaptation muscle damage

1. Introduction

In the area of sports performance and exercise, both athletes and recreational non-athletes are continuously seeking competitive advantages to improve their health and optimize physical performance. Although various activities and considerations interact to achieve this end, many people turn to various exercise and nutritional strategies to augment performance (i.e., enhanced muscular strength, power, and force) [1][2]. One of the most commonly used and scientifically supported ergogenic aids is creatine monohydrate (commonly referred to as creatine) [1][3][4][5]. Creatine is an amino acid found in relatively high concentrations in skeletal muscle. Since 1992, when the first reports emerged that exogenous creatine monohydrate supplementation increases intramuscular phosphocreatine (PCr) stores [6], and shortly afterwards, when these increases were inextricably linked to augmented exercise performance [7][8], the ability of creatine to function as an ergogenic aid has attracted great interest. Still today, creatine is one of the most popular nutritional ergogenic aids for athletes and recreational performers [1][3][4]. In addition to its popularity in the consumer realm, creatine's ability to enhance or augment some types of exercise performance has arguably been one of the most researched topics in the sport nutrition literature for the past 25 years [1][3][7][9][10][11]. In this regard, creatine has yielded predominantly positive effects regarding exercise performance measures with no ergolytic effects and minimal to no side effects in populations ranging from adolescents to the elderly [3][9]. The reported ergogenic benefits of creatine monohydrate include enhanced force output, augmented power output, increased strength, increased anaerobic threshold, increased work capacity, enhanced recovery, and enhanced training adaptations [1][3][4][9][12][13].

Although a complete discussion is beyond the scope of this review, several supplementation strategies have been explored to increase intramuscular creatine stores. A loading phase was initially proposed by Harris et al. in 1992 [6] and has subsequently been used in a large number of scientific investigations. This approach requires consuming four separate doses of 5 g/day for five consecutive days and consistently leads to a 20%–40% increase in creatine content [3]. Later, Hultman et al. [14] determined that smaller 'maintenance' doses (2–5 g per dose, 1 ×/day, or 0.03 g/kg/dose) could be used to maintain elevated creatine stores in the muscle. It is now commonly accepted that a loading phase may not be needed, but this approach remains the most rapid means to increase intramuscular PCr levels and, thereby, performance [14][15]. Notably, Law and colleagues [16] compared the efficacy of creatine loading on performance measures using a 2- and 5-day regimen (4 × 5 g/day) in 20 physically active men. They reported significant improvements in maximal leg strength and average anaerobic power following a 5-day creatine loading regimen compared to the placebo group; however, no significance in performance was found following 2 days of loading. Additionally, Sale et al. [17] found that the total ingestion of 20 g of creatine at 1 g per 30 min intervals for 5 days yielded lower urinary excretion of creatine than the typical loading regimen of 4 × 5 g/day over a 5-day period, leading the authors to conclude that this likely resulted in higher intramuscular levels. In this respect, it is without question that increasing intramuscular creatine stores through any number of supplemental approaches can increase intramuscular PCr levels and that these increases are directly linked to various ergogenic outcomes [3][9]. In this respect, Table 1 (adapted from: [3]) outlines the potential ergogenic benefits of creatine supplementation, whereas Table 2 provides examples of sports or sporting events that may be enhanced by creatine supplementation (also adapted from [3]). In addition to these tables, results from previous selected original investigations and review papers surrounding the ergogenic potential of creatine supplementation are summarized throughout this paper in tables. Finally, the interested reader is directed to other reviews that have outlined the impact of creatine supplementation on exercise performance [3][9][10][12][13][18].

Table 1. Potential ergogenic benefits of creatine supplementation.

• Increased single and repetitive sprint performance
• Increased work performed during sets of maximal effort muscle contractions
• Increased muscle mass and strength adaptations during training
• Enhanced glycogen synthesis
• Increased anaerobic threshold
• Possible enhancement of aerobic capacity via greater shuttling of ATP from mitochondria
• Increased work capacity

• Enhanced recovery
• Greater training tolerance

Adopted from Kreider et al. 2017 [3].

Table 2. Examples of sports and activities in which performance may be enhanced by creatine supplementation.

Increased PCr
• Track sprints: 60–200 m
• Swim sprints: 50 m
• Pursuit cycling
Increased PCr Resynthesis
• Basketball
• Field hockey
• America Football
• Ice hockey
• Lacrosse
• Volleyball
Reduced Muscle Acidosis

- Downhill skiing
- Water Sports (e.g., Rowing, Canoeing, Kayaking, Stand-Up Paddling)
- Swim events: 100, 200 m
- Track events: 400, 800 m
- Combat Sports (e.g., MMA, Wrestling, Boxing, etc.)

Oxidative Metabolism

- Basketball
- Soccer
- Team handball
- Tennis
- Volleyball
- Interval Training in Endurance Athletes

Increased Body Mass/Muscle Mass

- American Football
- Bodybuilding

- Combat Sports (e.g., MMA, Wrestling, Boxing, etc.)
- Powerlifting
- Rugby
- Track/Field events (Shot put; Javelin; Discus; Hammer Throw)
- Olympic Weightlifting

Adopted from Kreider et al. 2017 [3].

2. Exercise and Sports Performance

Creatine's ability to increase various parameters of acute exercise performance is well documented [3][9][10]. A review by Kreider in 2003 summarized the literature and concluded that approximately 70% of these studies had reported an improvement in some aspect of exercise performance [9]. The magnitude of the increase in performance is dependent on a large number of variables, which can include the dosing regimen, training status of the athlete, and any one of a number of acute exercise variables (intensity of exercise, duration of effort, etc.). An overview of this literature reveals that performance increases of 10%–15% are typically observed [9][12]. More specifically, 5%–15% improvements in maximal power and strength, anaerobic capacity, and work performance during repetitive sprint performance are commonly reported, whereas improvements in single-effort sprint performance have been indicated to range from 1%–5% improvements. Alternatively, several consistent reports indicate that supplementation with creatine may have an ergolytic or performance-decreasing response. In this respect, a large number of studies have commonly reported an increase in body mass of 1–2 kg during the first week of loading [3], which may or may not have ergolytic implications, depending on the type of athlete and the phase of training. Finally, research involving various types of endurance activity in conjunction with creatine supplementation has received some attention as well.

3. Recovery

Increases in intramuscular levels of creatine phosphate secondary to creatine supplementation increase the supply of a robust, energetic substrate that can be used to resynthesize ATP. In this capacity, creatine supplementation can help increase and maintain the delivery of ATP to working muscles, allowing for an increased ability to perform work, resulting in the widespread display of ergogenic outcomes commonly reported in the literature [3][9][19][20][21]. Aside from overt improvements in the performance of single bouts of maximal efforts, creatine is able to augment

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4. Antonio, J.; Candow, D.G.; Forbes, S.C.; Gualano, B.; Jagim, A.R.; Kreider, R.B.; Rawson, E.S.; Smith-Ryan, A.E.; VanDusseldorp, T.A.; Willoughby, D.S.; et al. Common questions and misconceptions about creatine supplementation: What does the scientific evidence really show? J. Int. Soc. Sports Nutr. 2021, 18, 1–17.

5. Fazio, C.; Elder, C.L.; Harris, M.M. Efficacy of alternative forms of creatine supplementation on improving performance and body composition in healthy subjects: A systematic review. J. Strength Cond. Res. 2021.

6. Harris, R.C.; Söderlund, K.; Hultman, E. Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. Clin. Sci. 1992, 83, 367–374.

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8. Greenhaff, P.L.; Casey, A.; Short, A.H.; Harris, R.; Soderlund, K.; Hultman, E. Influence of Oral Creatine Supplementation of Muscle Torque during Repeated Bouts of Maximal Voluntary Exercise in Man. Clin. Sci. 1993, 84, 565–571.

9. Kreider, R.B. Effects of creatine supplementation on performance and training adaptations. Mol. Cell. Biochem. 2003, 244, 89–94.

performance across multiple sets of performance and subsequently demonstrates a role in enhancing recovery. The term recovery is often contextual in nature and typically pertains to either physiological, subjective, or performance-based parameters. In this respect, creatine appears to positively influence recovery in regard to physical performance following bouts of intense activity, and has been shown to enhance recovery during bouts of intermittent activity, sustaining maximal performance across multiple bouts of exercise. In addition, creatine supplementation may also reduce the post-exercise inflammatory response, thereby attenuating markers of muscle damage and soreness in the hours and days following bouts of exercise-induced muscle damage. Finally, creatine may have efficacy as a therapeutic intervention following an injury or during periods of limb immobilization.

4. Other Considerations

Due to the popularity associated with creatine supplementation since the first published reports in the early 1990s, a number of other questions have been evaluated and considered regarding its efficacy. For example, the majority of the published literature on creatine has been completed using male athletes, leading to much less information being available on how creatine supplementation impacts females. Previous work has highlighted gender-specific differences in creatine production and turnover, which lays the foundation for gender considerations for creatine supplementation [4]. In regard to research involving exercise performance in females, Vandenberghe et al. [22] reported that creatine supplementation increases intramuscular PCr levels, muscle mass, and strength when compared to those females who took a placebo. Other research by Hamilton [23] showed improvements in upper-body exercise capacity, and Tarnopolsky showed improvements in high-intensity exercise performance [24], whereas Kambis et al. [25] reported improvements in knee extension muscle performance. Similarly, excellent potential exists for creatine to support the health and function of older populations. Although nearly all of the original research on creatine used young, athletic populations, research in the past 10–15 years has highlighted creatine's ability to increase the ability to perform daily living activities, to delay fatigue, and to improve muscle mass in older populations [26][27][28][29][30][31][32][33][34].

Overwhelmingly, the majority of research that has examined the potential of creatine to impact exercise performance has been conducted using the monohydrate version. Although several other forms of creatine have been proposed and marketed as alternatives, none have been shown to offer benefits above and beyond those seen with monohydrate. In this respect, a number of studies have been completed comparing various alternative forms of creatine, and the interested reader is directed to the following papers: [3][4][5][35][36][37][38][39][40]. In this respect, one must also realize that several studies have sought to examine the impact of combining creatine with other ingredients, such as beta-alanine [41][42], beta-hydroxy-beta-methylbutyrate (HMB) [43][44][45][46][47][48][49], glutamine [50], sodium bicarbonate [51], carbohydrates [20][52][53][54][55], and protein [20][56][53] to examine the potential for any synergistic outcomes. Furthermore, the interested reader is encouraged to read the critical review on this topic by Jäger et al. [36].

The level of creatine uptake is a key consideration, as it relates to the potential for health and performance outcomes. In this respect, one of the key considerations that has been identified in the literature is the presence of 'responders' and 'nonresponders'. This concept was discussed in a 1999 review by Demant and Rhodes, in which

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they summarized the available literature and highlighted the fact that creatine supplementation regimens could lead to marked increases in intramuscular PCr levels, whereas the same regimen may result in limited to no changes in other people following a similar supplementation regimen [57]. To illustrate this point, Kilduff et al. [58] identified subjects in their study as responders and nonresponders based on the magnitude of change seen in intramuscular PCr. When examined together, peak force was not changed due to supplementation, but when evaluated separately, the responders significantly increased their peak force production after creatine supplementation. Later, Syrotuik et al. [59] completed an analysis aiming to build a physiological profile of responders and nonresponders. In terms of creatine uptake, a commonly discussed factor that may dictate the extent to which intramuscular PCr levels change in response to creatine supplementation is the level of vegetarianism observed by the individual. In this respect, it is well known that meat-containing foods and products contain the highest amounts of creatine, and thus people who refrain from eating meats tend to consume the lowest amounts of creatine in their diet. Several papers are available that have examined the impact of creatine supplementation on people who follow various types of vegetarianism, with initial reports showing that vegetarians do, indeed, have lower levels of intramuscular PCr [60][61]. Shomrat and colleagues [62] were some of the first to examine this question and concluded that creatine supplementation equally impacted the ability of vegetarian and non-vegetarian individuals to generate peak power after an identical regimen of supplementation. Furthermore, additional studies by Watt [63] and Lukaszuk [64] highlighted the fact that creatine supplementation in vegetarian people can impact intramuscular and plasma levels of creatine in a similar fashion. Furthering this aim, reviews by Venderley and Kaviani concluded that creatine supplementation could be an effective strategy for vegetarian individuals to increase their intramuscular levels of PCr, a key factor that may impact an individual's ability to perform high-intensity exercise [60][61]. Finally, interested readers are encouraged to review the following articles by Antonio [4], as well as the International Society of Sports Nutrition's position on creatine [1].

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