ERGOGENIC AIDS THAT WORK

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Ergogenic, *adjective,* ər-gə-ˈje-nik

"enhancing physical performance"

Merriam-Webster

For purposes of this presentation, only those dietary supplements recognized by the International Olympic Committee (IOC) will be included. The IOC, being a regulating body, is a trusted resource in the evaluation of nutritional supplements for individuals and athletes.

Maughan RJ, Burke LM, Dvorak J, et. al. *Int J of Sport Nutr and Exerc Metab*. 2018;28(2):104-125

In review of the literature, a team of scientists working with International Olympic Committee (IOC) has identified a short list of supplements that do show benefits on athletic performance:

Caffeine
Creatine
Beta-Alanine
Nitrate
Sodium Bicarbonate

The IOC is a regulating body and a trusted resource in the evaluation of nutritional supplements for individuals and athletes.

Maughan RJ, Burke LM, Dvorak J, et. al. *Int J of Sport Nutr and Exerc Metab*. 2018;28(2):104-125

Overview

Ergogenic Aid

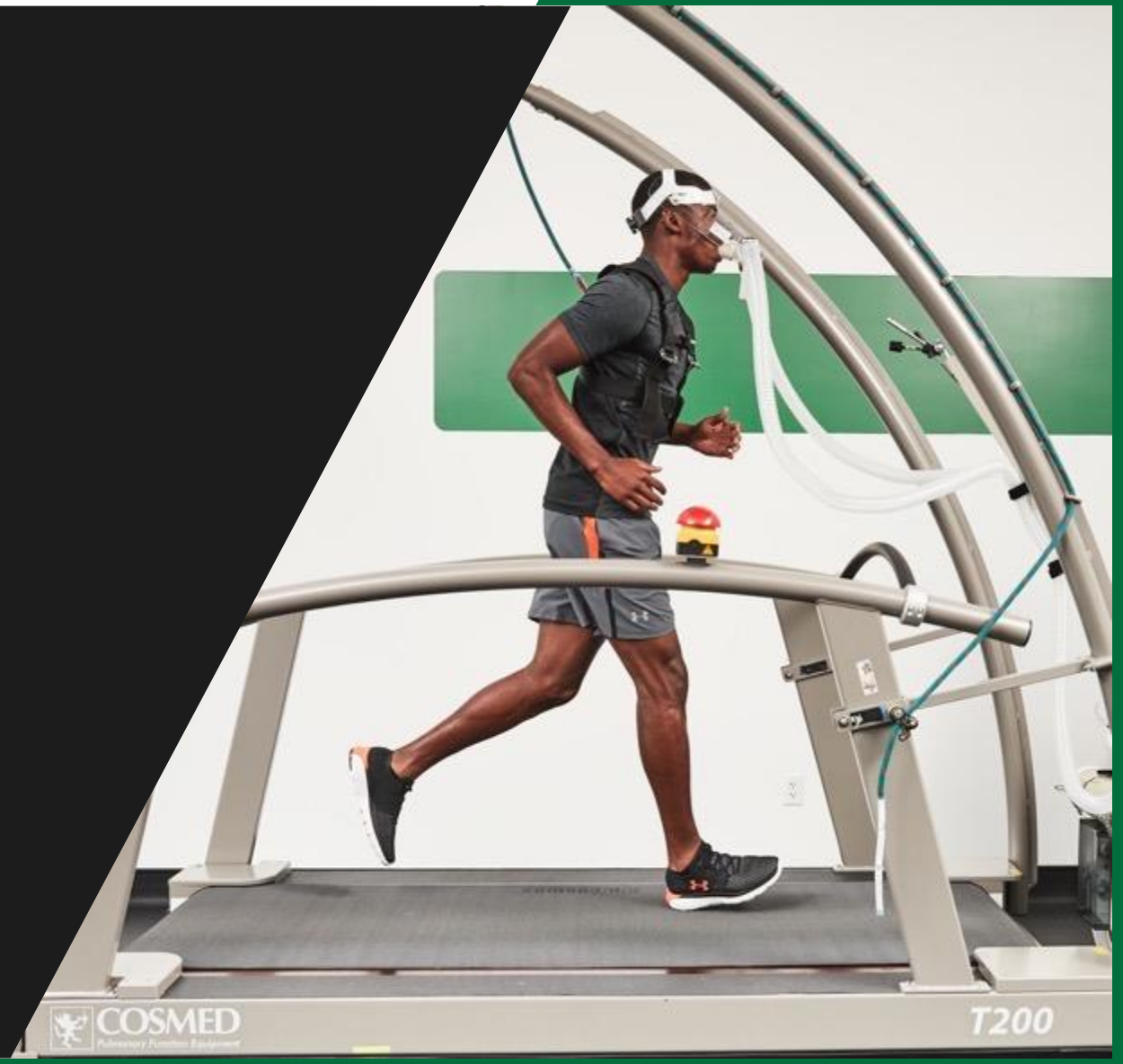
Mechanism of Action

Ergogenic Benefit

Recommended Use & Potential Side Effects

Caffeine
Creatine
Beta-Alanine
Nitrate
Sodium Bicarbonate

CAFFEINE



Caffeine

- Caffeine (1,3,7 – trimethylxanthine) is a natural alkaloid
- Present in the leaves, fruits, and seeds of a variety of plants such as coffee and tea
- Most well-studied "supplement"
- Most widely used

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Mechanism(s) of Action

- Metabolized by the liver (enzymatic action) which results in paraxanthine, theophylline, and theobromine
- Following ingestion, appears in blood stream within **15 to 45 minutes**, with peak levels appearing around **1 hour**
- Multiple mechanisms proposed due to ability to cross blood brain barrier as well as membranes of all tissues in the body
- Most likely (significant) even at low doses is the effect on the central or peripheral nervous system competing with adenosine at receptor sites

Ergogenic Benefit

- Enhanced endurance performance (time to exhaustion)
- Improved reaction time, concentration and self-perceived energy levels (even when sleep deprived)
- Enhanced glycogen resynthesis
- Improved performance in repeated high-intensity exercise bouts (i.e. team sports), but only in those already conditioned
- Though little to no effect on strength-based events (i.e. one-repetition maximum testing), velocity is enhanced and velocity loss attenuated over consecutive repetitions

Grgic J, Grgic I, Pickering C, et. al. *Br J of Sports Med*. 2020;54(11):681-688

Recommended Use & Potential Side Effects

Recommended Use

Low doses of ~200 mg or ~1.5 to 3 mg/kg body mass are effective and should be used initially

Dose of ~3 to 6 mg/kg body mass safe and effective

Higher doses (≥ 9 mg/kg body mass) provide no further benefit and is accompanied by significant side effects

Consumption should occur approximately 1 hour before event for effect

Consideration: International Olympic Committee and National Collegiate Athletic Association have limits on caffeine excreted in urine

Potential Side Effects

Insomnia

Headache

Nervousness/anxiety

Gastrointestinal problems

These are not common with the doses recommended, unless caffeine naive

Spriet LL. *Sports Med*. 2014;44(2):175-184
Goldstein ER, Ziegenfuss T, Kalman D, et. al. *J of the Int Soc of Sports Nutr*. *2010;7*(5)

Genetics & Caffeine

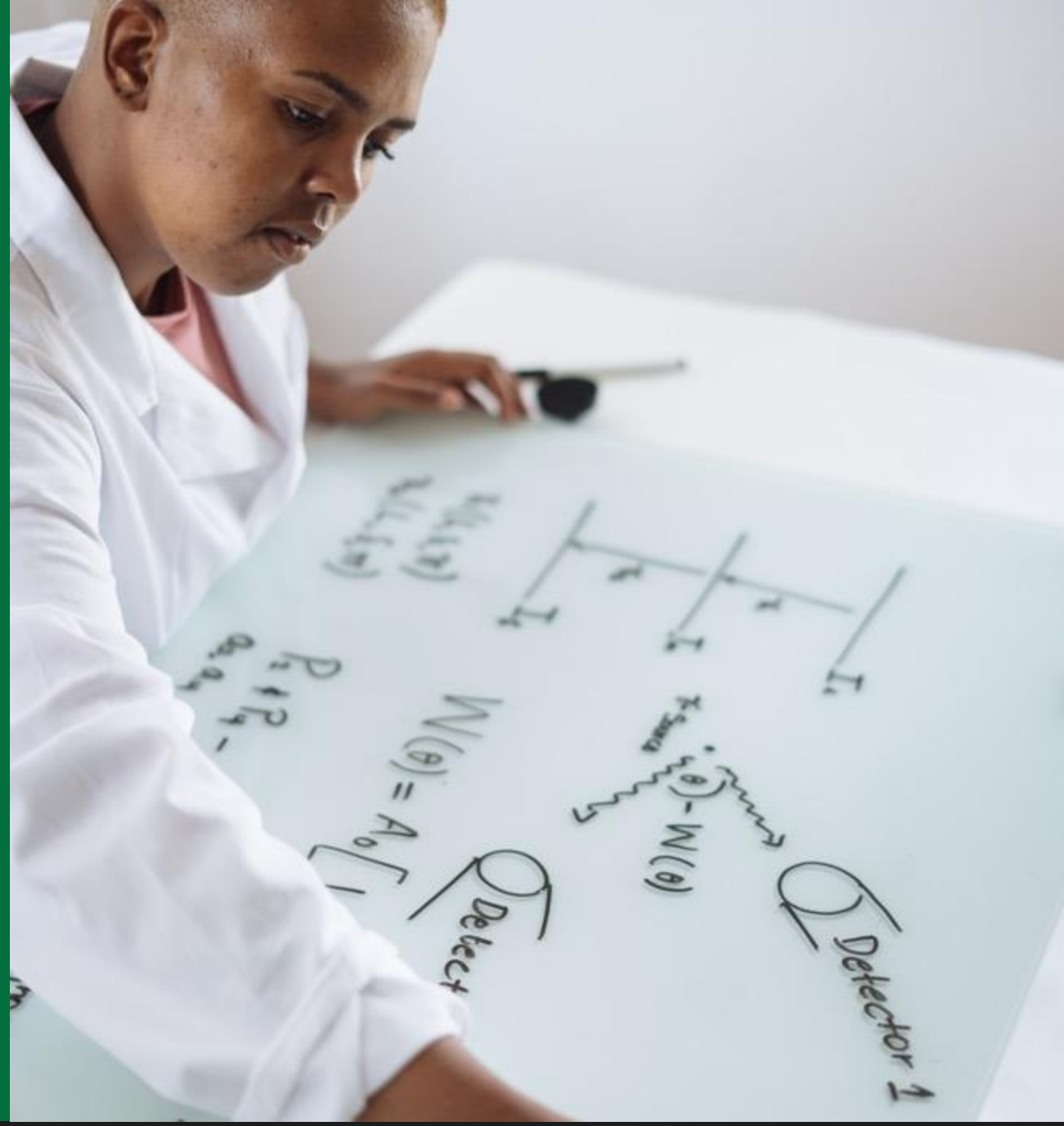
Responders vs. Non-Responders

Some individuals do not experience performance benefits associated with caffeine ingestion

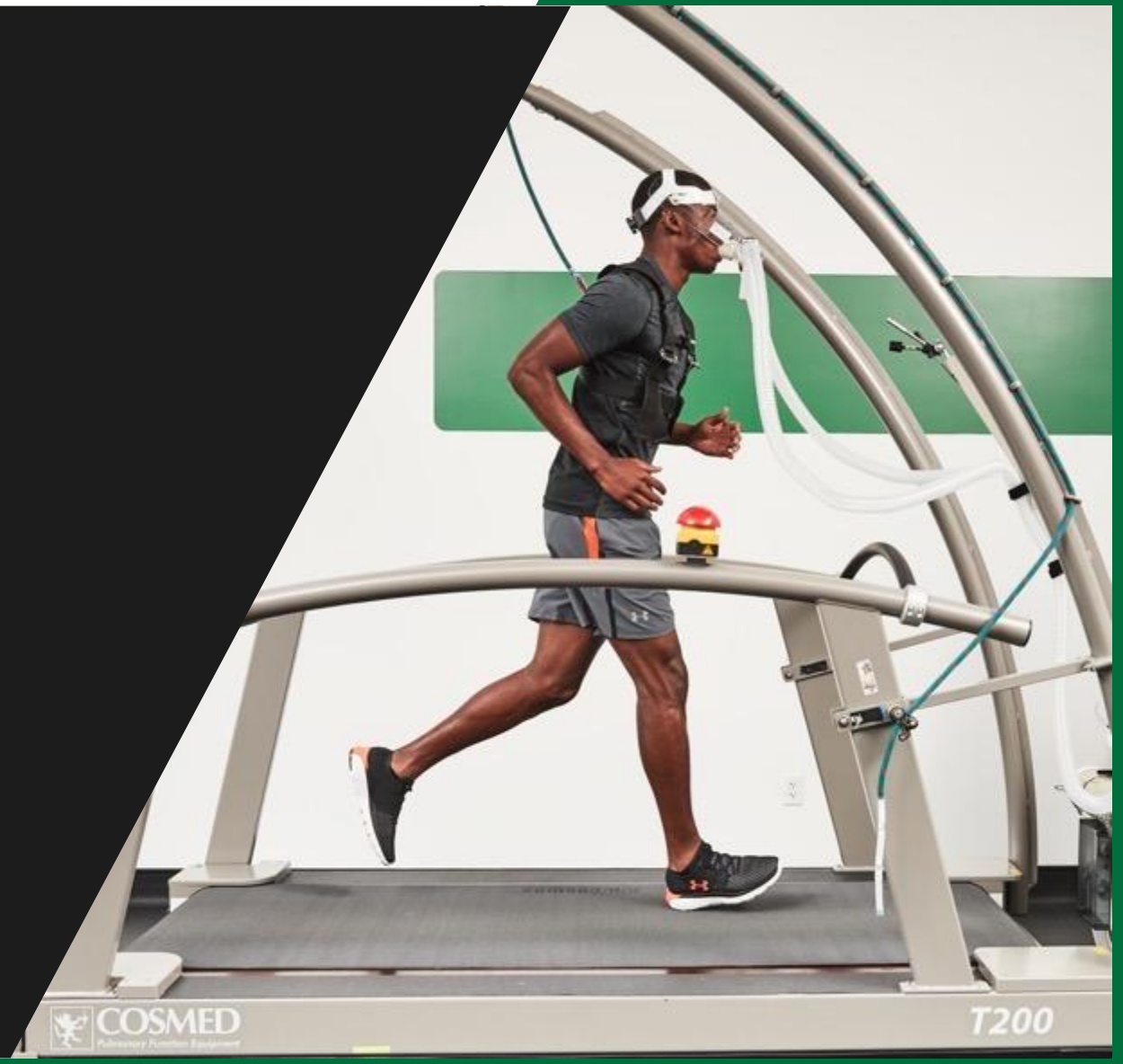
Recent research has emerged examining polymorphisms of certain genes

- CYP1A2
- AD0RA2A

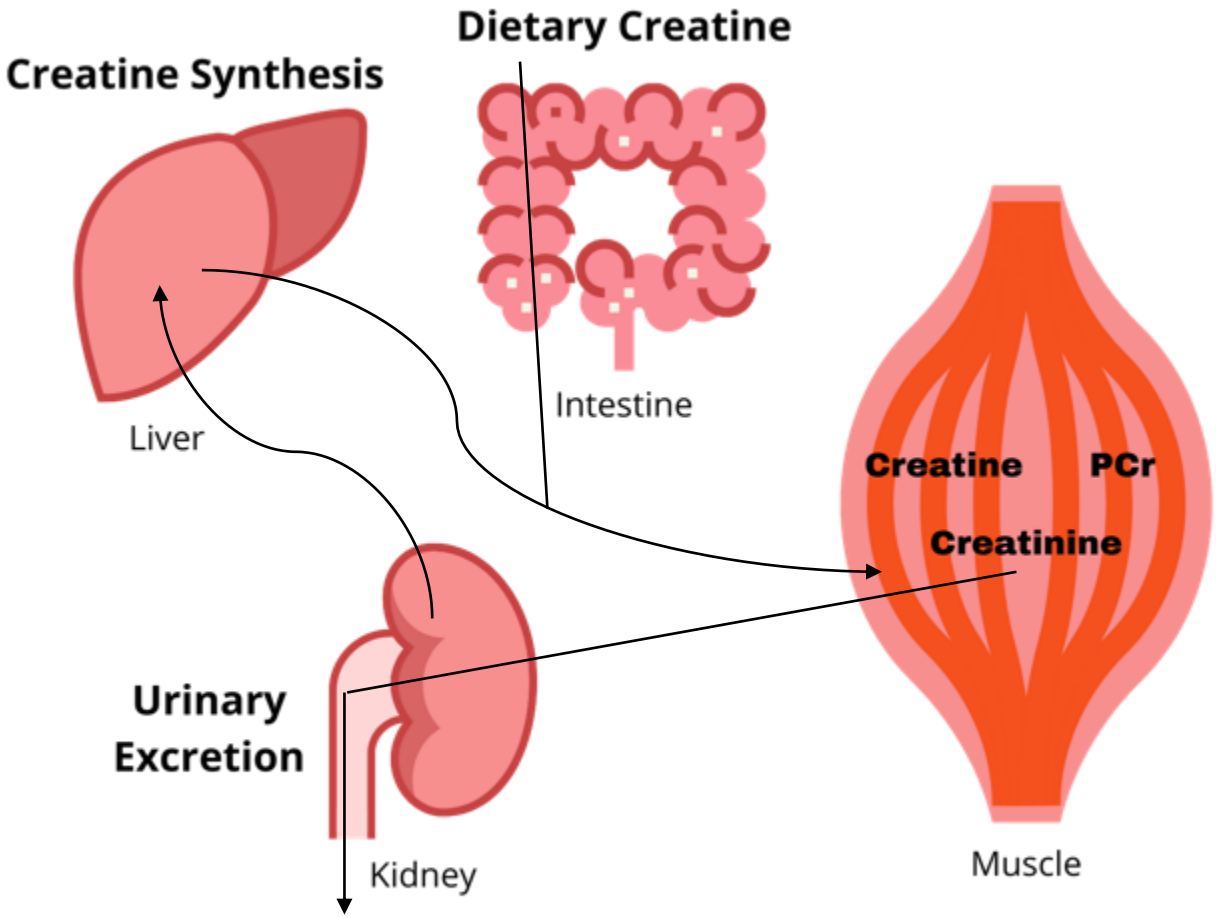
Further research is necessary, but clear that some individuals do not respond to caffeine ingestion



CREATINE



Creatine



- Creatine is synthesized in the kidney, liver, pancreas, and, to a lesser extent, the brain
- Synthesis is from the amino acids glycine, arginine, and methionine.
- The total body creatine pool includes creatine and phosphocreatine (PCr)
- Skeletal muscle is the primary site of storage accounting for up to 90% of total body pool
- Total body creatine pool can be increased by ingestion of foods high in creatine (i.e. meat and fish) or nutritional supplementation

Mesa JLM, Ruiz JR, Gonzalez-Gross MM, et. al. *Sports Med*. 2002;32(14):903-944

Mechanism of Action in Muscle

PCr is an important energy source for high intensity, short duration muscle contraction

Creatine is essential for the regeneration of PCr

The creatine kinase (CK) phosphocreatine (PCr) system serves as an energy buffer in cells with high and fluctuating energy requirements

Walliman T, Tokarska-Schlattner M, Schlattner U. *Amino Acids.* 2011;40(5):1271-1296

Performance	Time/ Nature of Activity	Potential Benefit	Comments	Relevant Research
High intensity exercise - Laboratory tests	< 30 s	Increased peak/ mean power, decreased fatigue	Many supportive studies; more effective over repeated bouts of exercise	(reviewed in Branch, 2003; Gualano et al., 2012)
High intensity exercise - Field tests	< 30 s	Increased speed/ decreased time to complete a fixed distance	Supportive studies, fewer studies overall, theoretically the increase in body mass may reduce ergogenic effect in weight-bearing sports (e.g., running), but not known	
Swimming		Increased power/ decreased time to complete a fixed distance	Supportive studies for improved performance over repeated sprint intervals; probably not effective in single sprints	(reviewed in Hopwood et al., 2006)
Medium duration tasks	30 s to 5 min	Increased power output, speed / decreased time to complete a fixed distance	Some studies show enhanced performance, possibly due to increased muscle glycogen subsequent to creatine supplementation	(reviewed in Branch, 2003; Gualano et al., 2012)
Sprinting within or after endurance exercise		Increased power output, speed; decreased fatigue, time to complete a fixed distance	Supportive studies, but fewer studies overall	(Engelhardt et al., 1998; Vandebuerie et al., 1998; Tomcik et al., 2018)
Endurance exercise	> 5 min	Decreased oxygen cost of exercise	Most studies show no improvement in endurance performance	(Nelson et al., 2001; van Loon et al., 2003)
Strength and conditioning workouts	Intermittent	Spontaneous increase in total lifting volume, increased number of repetitions at a given weight, increased strength, increased lean body mass	Many supportive studies	(reviewed in Rawson & Volek 2003; Lanhers et al., 2017)

Table 1. Effects of Creatine Monohydrate Supplementation on Exercise Performance

Ergogenic Effects

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Short-term benefits following 5-7 day loading include increased

- **Power production**
- **Sprint performance**
- **Work performed (i.e. multiple sets of maximal effort)**

Chronic training with elevated creatine levels

- **Increases lean mass gains**
- **Improves strength**
- **Improves power**

Less common improvements noted in endurance performance, but studies limited especially with chronic training

- **Reduced lactate at same relative workload**
- **Decreased oxygen cost**

Is Supplementation Necessary?

- Unlike the other ergogenic aids discussed, creatine is produced by the body. So is supplementation really necessary?
- Pre-supplement muscle creatine concentration is critical to consider
- However, few individuals know their baseline creatine concentrations (muscle biopsy can determine)
- Genetics determines baseline concentration
- Those with higher type II fibers have higher concentrations
- Most individuals are below saturation levels and can benefit from supplementation

Mesa JLM, Ruiz JR, Gonzalez-Gross MM, et. al. *Sports Med*. 2002;32(14):903-944

How do you like your meat?

- 3 ounces of raw beef equals approximately 0.4 grams of creatine
- 3 to 6 grams per 2.5 lbs of raw meat (estimated)
- Cooking affects creatine in meat by reducing total content
- Consideration: Athletes or individuals attempting to lose or maintain weight should consider the additional calories associated with consumption of large amounts of meat or fish for creatine

Harris RC, Nevill M, Harris DB, et. al. *Journal of Sport Sciences*. 2002;20(2):147-151

Creatine Supplements

- Creatine monohydrate, most common form on the market, in solution may increase whole body creatine to a greater extent than meat
- Other forms (ethyl ester, etc.) have not been found to increase muscle creatine to a greater extent and in some cases have been reported to result in less muscle creatine

Harris RC, Nevill M, Harris DB, et. al. *Journal of Sport Sciences*. 2002;20(2):147-151

Recommended Use

Loading phase:

~20 g/d for 5 days OR 5 g/d for 4 weeks will similarly load (but benefit delayed accordingly)

Maintenance:

5 g/d

To cycle or not to cycle?

Cycling is not recommended

Creatine supplementation attenuates endogenous production

Consideration: Consuming carbohydrate with creatine enhances uptake

Potential Side Effects

Potential Concern	Evidence of Reduced Function	Evidence of Improved Function	Evidence of No Detrimental Effect	Relevant Reviews
Renal stress	Case studies, confounded by drugs/medication, prior disease, other supplements	No trials show improved renal function	Multiple trials (> 20) using various methods, show no effect on renal function	(Gualano et al., 2012)
Muscle dysfunction	Case studies of exertional rhabdomyolysis, confounded by unaccustomed/extreme exercise, drugs/medication, dehydration, traumatic injury, other supplements	Several trials show decreased muscle cramps, tightness, strains and total injuries in habitual creatine users. Several studies show decreased post-exercise inflammation, increased strength recovery, decreased delayed onset muscle soreness (DOMS)	Several trials show no evidence of improved or reduced muscle function	(Rawson et al., 2017)
Thermo-regulatory strain	None	Some trials show decreased exercise body temperature	Several trials show no evidence of improved or reduced thermoregulatory function	(Lopez et al., 2009)
Other organ strain	None	None	Several trials show no change in markers of cardiac or liver function	

Table 3. Potential Safety Concerns with Creatine Monohydrate Supplementation

After several decades of research, there is no persuasive evidence suggesting that oral creatine supplementation causes muscle cramps or adversely affects renal function or thermoregulation

The only potential side effect is weight gain

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Genetics and Creatine

- Responder vs. Non-Responder
- Like caffeine, some individuals will not respond to supplemental creatine ingestion

Why?

- As previously noted, individuals with a greater proportion of type II muscle fibers are more likely to have higher concentrations of creatine in muscle
- Unfortunately, all tests to determine muscle creatine content are invasive and/or expensive
- Most individuals are likely to benefit from supplementation

Mesa JLM, Ruiz JR, Gonzalez-Gross MM, et. al. *Sports Med*. 2002;32(14):903-944

BETA-ALANINE

Beta-Alanine

- Non-proteogenic amino acid (not naturally encoded)
- Rate limiting pre-cursor to carnosine (beta-alanine alone has little to no ergogenic benefit)
- Endogenously produced in liver
- Total body beta-alanine can be increased by ingesting meat, including poultry, or through supplementation

Jones AM. *Sports Science Exchange*. 2014;27(124):1-5

Mechanism of Action

- Beta-alanine is a pre-cursor to carnosine
- Carnosine has numerous physiological functions and is formed by the amino acids L-histidine and beta-alanine
- The ergogenic benefits are due to carnosine's intracellular proton buffering capacity
- Ingestion of carnosine does not result in increased muscle concentration due to lack of a specific enzyme in the muscle which results in carnosine being metabolized prior to reaching the muscle
- However, beta-alanine, being rate limiting, allows carnosine to be increased in the muscle

SSE #124

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Culbertson JY, Kreider RB, Greenwood M, et. al. *Nutrients*. 2010;2(1):75-98
Jones AM. *Sports Science Exchange*. 2014;27(124):1-5

Ergogenic Benefits

- Improved exercise capacity in high-intensity events lasting 60 to 240s
- Allows for greater training volume in short event (i.e. lifting weight, sprinting)
- May benefit, though modest, in longer events (> 4 min) up to 10 minutes
- Attenuates neuromuscular fatigue

SSE #124

GATORADE SPORTS SCIENCE INSTITUTE

Culbertson JY, Kreider RB, Greenwood M, et. al. *Nutrients*. 2010;2(1):75-98
Jones AM. *Sports Science Exchange*. 2014;27(124):1-5

Recommended Use & Potential Side Effects

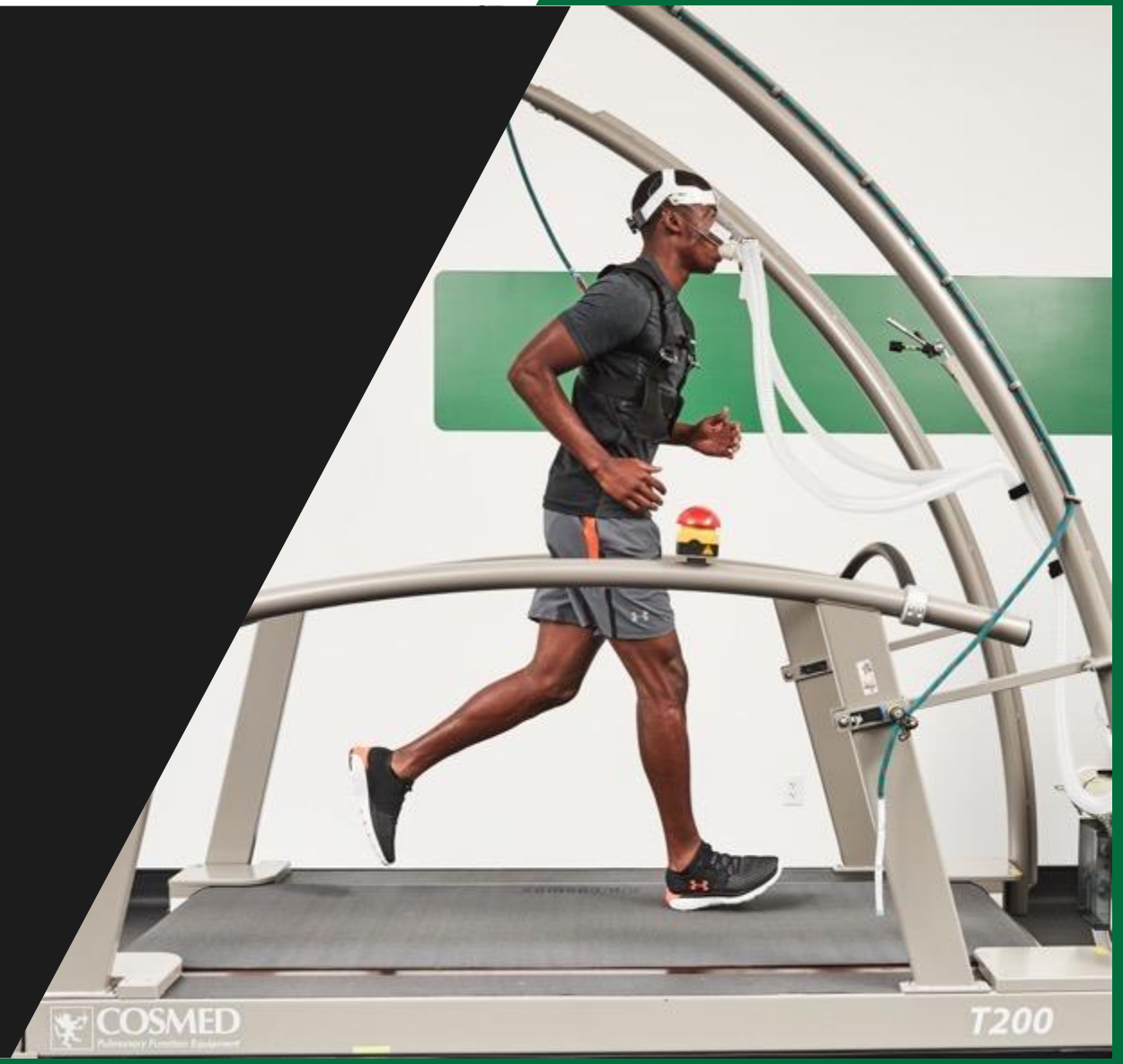
Recommended Use

- Acute effects not realized
- Chronic loading of 4 to 6 g/d (~65 mg/kg body mass) divided in doses of 2 or less for minimum of 2 weeks produces benefit
- Great benefit after 4 weeks
- Single bolus not recommended due to acute paraesthesia (i.e. skin tingling) and no performance benefit

Potential Side Effects

- Paraesthesia (i.e. tingling) typically experienced in the face, neck, and back of hands
- Dose dependent with higher doses resulting in greater effect
- Time released formulations reduce paraesthesia
- No long-term (> 1 yr) safety data

NITRATE



Nitrate

- Nitrate (NO_3^-) is a naturally occurring anion in the body involved in the biosynthesis of nitric oxide (NO) which has many physiological functions in the body
- Green leafy and root vegetables are rich in nitrate
- Ingestion of nitrate rich foods contributes to the formation of nitric oxide

SSE #110 GATORADE SPORTS SCIENCE INSTITUTE

SSE #156 GATORADE SPORTS SCIENCE INSTITUTE

Jones AM. *Sports Science Exchange*. 2013;26(110)1-5
Jones AM. *Sports Science Exchange*. 2016;28(156)1-6

Mechanism of Action

The ergogenic effect of nitrate is not related directly to nitrate, but to **nitric oxide**

Improved coupling between ATP hydrolysis and force production, resulting in reduced energy cost

Changes in redox status may also be a potential mechanism by which the ergogenic benefits are realized

Jones AM. *Sports Science Exchange*. 2013;26(110)1-5
Jones AM. *Sports Science Exchange*. 2016;28(156)1-6

Ergogenic Benefits

Improved exercise efficiency (lower oxygen uptake at same workload), but depends on…

- Training status
- Dose
- Duration
- Intensity

SSE #156

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Though increases capacity, results of time trial are less likely (other contributing factors)

More rapid development of muscle force

Higher intensity intermittent running & short distance sprinting

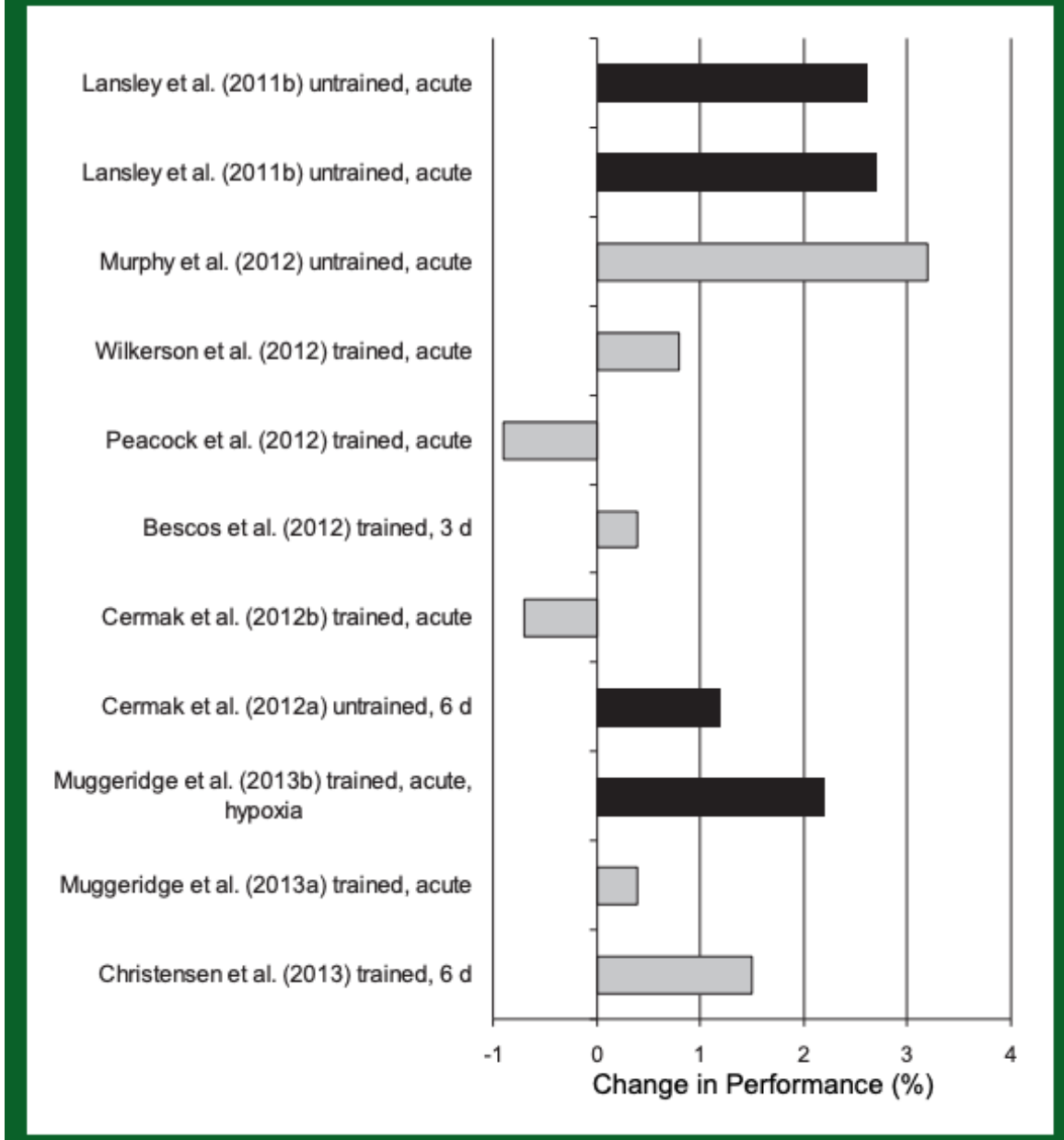

Figure 2: Effects of dietary nitrate supplementation vs. placebo on time trial performance. Black bars represent a significant improvement in performance and grey bars represent no significant change in performance.

Recommended Use & Potential Side Effects

Recommended Use

5-7 mmol nitrate (~0.1 mmol/kg body mass)

Typically peaks within 2 to 3 hours and remains elevated for 6 to 8 hours

A daily dose is required to keep NO elevated

Potential Side Effects

No known side effects at recommended dose

Senefeld JW, Regimbal RJ, Wiggins C, et. al. *Medicine & Science in Sports & Exercise*. 2020

SODIUM BICARBONATE

Sodium Bicarbonate

- The study of alkalosis to enhance performance goes as far back as 1930
- Sodium bicarbonate ($NaHCO_3$) has been purported to be the most effective ergogenic aid
- Sodium bicarbonate increases the level of bicarbonate in the blood which is a natural buffer accepting a proton from carbonic acid

$$H^+ + HCO_3^- \leftrightarrow H2CO_3 \leftrightarrow CO_2 + H_2O$$

SSE #124

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Mechanism of Action

- Bicarbonate alone is a buffer and plays a role in maintaining pH and the electrolyte gradient between intracellular and extracellular space
- In that role, inducing alkalosis and impacting the role of intra- and extracellular balance, contributes to the maintenance of muscle function
- While recognized as the primary mechanism, recent evidence suggests that a more integrative approach is necessary as bicarbonate does not just affect metabolism, but also muscle physiology and motor pathways

Ergogenic Benefit

- Enhanced performance in exercise or event in which there is a reliance on anaerobic glycolysis
- Most common in event > than 30 seconds, but less than 120 seconds
- However, recent review highlighted no difference in effect size in medium (2 to 10 minutes) and long (>10 minute) exercise
- The latter may be due to lower oxygen cost
- Benefits realized in high intensity intermittent exercise (team sports)
- Evidence suggests more beneficial for untrained

Peart DJ, Siegler JC, Vince RV. *Journal of Strength and Conditioning Research*, 2012;26(7):1975-1983

Recommended Use & Potential Side Effects

Recommended Use

0.2 to 0.4 g/kg body mass ingested 60 to 120 minutes before exercise or competition

Potential Side Effects

Gastrointestinal distress including….

- Pain
- Diarrhea
- Vomiting
- Gas
- Nausea

The above side effects are not rare occurrences. Individuals should experiment in training prior to use in competition.

Peart DJ, Siegler JC, Vince RV. *Journal of Strength and Conditioning Research*, 2012;26(7):1975-1983

Indirect Performance Enhancing (Ergogenic)

The IOC characterizes some supplements as “indirect performance enhancing” due to their effect on return to performance (injury recovery), soreness, or training capacity

Creatine

In addition to performance enhancing benefits, creatine also play a vital role in recovery

- Enhanced adaptive response
- Reduced muscle soreness (delayed onset muscle soreness)
- Improved cognitive processing
- Enhanced recovery from mild traumatic brain injury (mTBI) (i.e. concussion)

Supplementation for recovery is the same as for performance

Omega-3 Fatty Acids

- Like creatine, the body can produce the omega-3 fatty acids docosahexaenoic (DHA) and eicosapentaenoic acid (EPA); however, that process is limited and inefficient.
- Dietary sources of DHA and EPA are limited to fish due to a diet rich in algae
- Therefore, most individuals are deficient. In fact, several studies have highlighted deficiency in college athletes

Anzalone AJ, Carbuhn A, Jones L, et. al. *Journal of Athletic Training*. 2019;54(1):7-11

Omega-3 Fatty Acids

Benefits include….

- Increased muscle protein synthesis
- Improved cognitive processing
- Enhanced recovery from mTBI
- Enhanced recovery from exercise (may be due to anti-inflammatory properties of EPA)
- Recommended dose is 2 g/d; though optimal ratio is unknown. 2 g/d DHA is recommended for enhanced mTBI recovery

Maughan RJ, Burke LM, Dvorak J, et. al. *Int J of Sport Nutr and Exerc Metab*. 2018;28(2):104-125

Vitamin D

- Essential fat-soluble vitamin
- Obtained from exposure to sun
- Interestingly, even in many southern state, low vitamin D levels are observed
- Vitamin D is associated with numerous important biological actions relevant to the athlete including regulating bone health, immune function, cell cycle and skeletal muscle homeostasis

SSE #147

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Gelatin & Vitamin C

- Collagen is the primary protein in connective tissue (tendons and ligaments)
- Gelatin is a food used in jellies, jello, and gummies to produce the gelatinous texture which is made from collagen from skin, bones, and tissues of animal
- Increased collagen production has been observed following consumption of gelatin + vitamin C
- Additionally, decreased joint pain has been observed
- Recommended dosing: 15 g gelatin with 50 mg vitamin C 1 hour before intermittent activity (jump rope)

SSE #187

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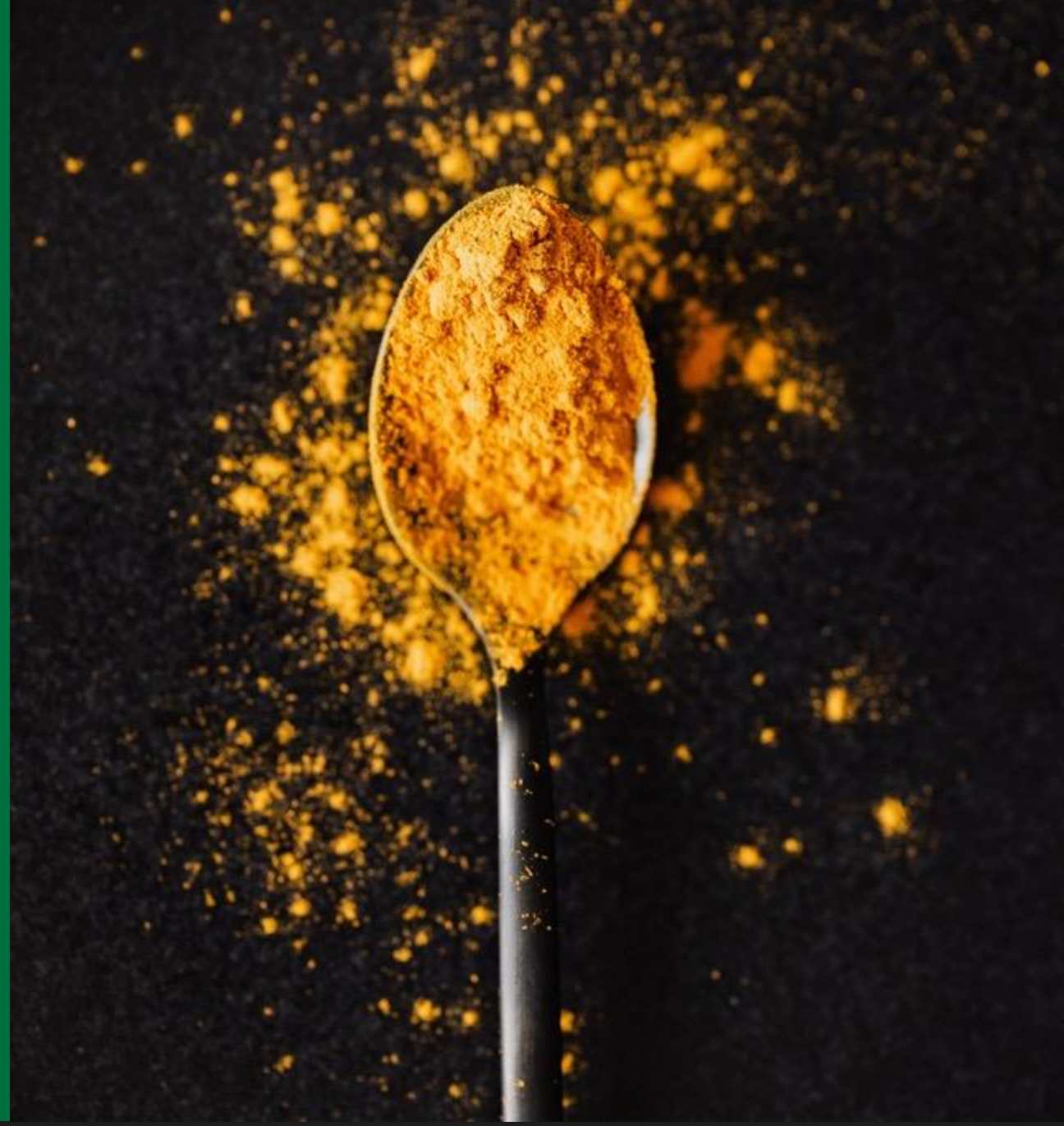
Non-Drug Anti-Inflammatories

- Some foods have anti-inflammatory properties which may reduce the symptoms associated with muscle soreness and enhance recovery
- **Curcumin**, the bioactive ingredient in the spice turmeric, has anti-inflammatory properties
- **Tart cherries** also have bioactive ingredients purported to promote recovery
- Recommended dose: 250-350 mL (30 mL concentrate) tart cherry juice twice daily for 4 to 5 days before even or 2 to 3 after to promote recovery



Maughan RJ, Burke LM, Dvorak J, et. al. *Int J of Sport Nutr and Exerc Metab*. 2018;28(2):104-125

Summary

Supplements Identified by the IOC to Have a Performance Benefit:

Caffeine

Creatine

Beta-Alanine

Nitrate

Sodium Bicarbonate

Supplements Identified by the IOC to Have an *Indirect* Performance Benefit:

Omega-3 Fatty Acids

Vitamin D

Gelatin + Vitamin C

Anti-Inflammatories

(Curcumin, Tart Cherry)