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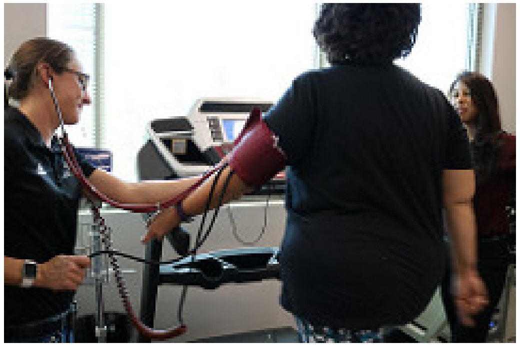
Nutritional Strategies to Enhance Performance



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Serves as scientific and legal consultant.

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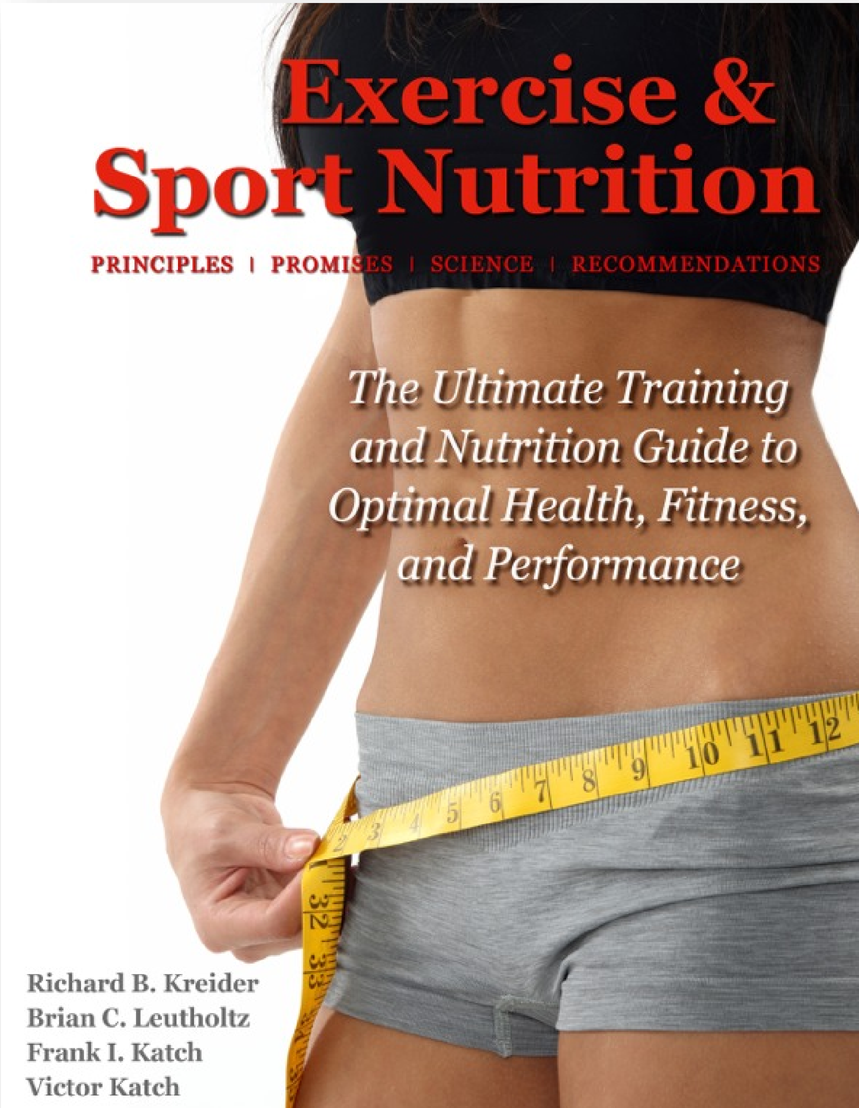

Kerksick et al. Journal of the International Society of Sports Nutrition (2018) 15:38
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Journal of the International Society of Sports Nutrition

REVIEW

Open Access

ISSN exercise & sports nutrition review update: research & recommendations

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Abstract

Background: Sports nutrition is a constantly evolving field with hundreds of research papers published annually. In the year 2017 alone, 2082 articles were published under the key words 'sport nutrition'. Consequently, staying current with the relevant literature is often difficult.

Methods: This paper is an ongoing update of the sports nutrition review article originally published as the lead paper to launch the Journal of the International Society of Sports Nutrition in 2004 and updated in 2010. It presents a well-referenced overview of the current state of the science related to optimization of training and performance enhancement through exercise training and nutrition. Notably, due to the accelerated pace and size at which the literature base in this research area grows, the topics discussed will focus on muscle hypertrophy and performance enhancement. As such, this paper provides an overview of: 1.) How ergogenic aids and dietary supplements are defined in terms of governmental regulation and oversight; 2.) How dietary supplements are legally regulated in the United States; 3.) How to evaluate the scientific merit of nutritional supplements; 4.) General nutritional strategies to optimize performance and enhance recovery; and, 5.) An overview of our current understanding of nutritional approaches to augment skeletal muscle hypertrophy and the potential ergogenic value of various dietary and supplemental approaches.

Conclusions: This updated review is to provide ISSN members and individuals interested in sports nutrition with information that can be implemented in educational, research or practical settings and serve as a foundational basis for determining the efficacy and safety of many common sport nutrition products and their ingredients.

Keywords: Sports nutrition, Performance nutrition, Position stand, Review, Recommendations, Efficacy, Double-blind, Randomized, Placebo-controlled, Dietary supplements, Ergogenic aids, Weight gain, Hypertrophy, Strength, Capacity, Power

Background

Evaluating the scientific merit of articles and advertisements about exercise and nutrition products is a key skill that all sports nutrition professionals must possess. To assist members and other advocates of the International Society of Sports Nutrition (ISSN) in keeping up to date about the latest findings in sports nutrition, the ISSN Exercise & Sports Nutrition Review: Research & Recommendations has been updated. The initial version of this paper was the first publication used to help launch the Journal of the International Society of Sports Nutrition (JISSN, originally called the Sports Nutrition Review Journal). This paper provides a definition of ergogenic aids and dietary supplements and discusses how dietary supplements are legally regulated. Other sections highlight how to evaluate the scientific merit of nutritional supplements and provide general nutritional strategies to optimize performance and enhance recovery. Finally, a brief overview of the efficacy surrounding many supplements commonly touted to

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Nutritional needs of active individuals and athletes

Energy Needs

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- ***General Fitness Training*** (e.g., 30 - 40 min/d; 3 d/wk)
  - Exercise energy expenditure generally 200 – 400 kcals/workout
  - Energy needs can be met on normal diet (e.g., 1,800 – 2,400 kcals/day or about 25 - 35 kcals/kg/day for a 50 – 80 kg individual)
- ***Moderate Training*** (e.g., 2-3 hrs/d; 5-6 d/wk)
  - Exercise energy expenditure generally 600 – 1,200 kcals/hour
  - Caloric needs may approach 40 – 70 kcals/kg/day (2,000 – 7,000 kcals/day for a 50 – 100 kg athlete)
- ***Elite Athletes*** (e.g., 3-6 hrs/d; 5-6 d/wk)
  - Caloric needs are typically 70 – 90 kcals/kg/day (3,500 – 9,000 kcals/day for a 50 – 100 kg athlete) with energy expenditure in Tour de France reported as high as 12,000 kcals/day (150 - 200 kcals/kg/d for a 60 – 80 kg athlete)
  - Caloric needs for large athletes (i.e., 100 – 150 kg) may range between 6,000 – 12,000 kcals/day depending on the volume/intensity of training
  - Often difficult for athletes to eat enough food in order to meet caloric needs

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Nutritional Guidelines

General Fitness / Active Populations

- Diet focused on goals (maintenance, weight gain/loss)
- **Carbohydrate** (45%-55% of calories)
    - 3 – 5 g/kg/d
- **Protein** (15%-20% of calories)
    - 0.8 – 1.0 g/kg/d (younger)
    - 1.0 – 1.2 g/kg/d (older)
- **Fat** (25-35% of calories)
    - 0.5 – 1.5 g/kg/d
- Make Good Food Choices
- Meal timing can optimize training response

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Nutritional Guidelines

Athletes

- **Carbohydrate** (55%-65% of calories)
  - 3 – 5 g/kg/d – Resistance / Power
  - 5 – 8 g/kg/d – Field / Endurance
  - 8 – 10 g/kg/d – heavy training
- **Protein** (15-20% of calories)
  - 0.8 – 1.2 g/kg/d - general fitness
  - 1.2 – 2.0 g/kg/d - moderate training
  - 1.7 – 2.2 g/kg/d - heavy training
- **Fat** (25-30% of calories)
  - 0.5 – 1.5 g/kg/d
- Meal Timing Important
- Use of energy supplements helpful

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Nutritional Guidelines

Nutrient Timing

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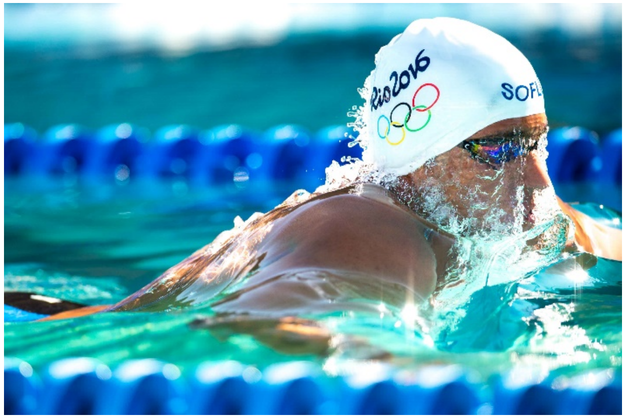
- Pre-exercise meals (4-6 h)
- Pre-exercise snack (30-60 min)
  - 40-50 g CHO, 10 g PRO
- Sports drinks during exercise (> 60 min)
  - 6%-8% glucose-electrolyte solution
  - Sports gels/bars at half-time
- Post-exercise snack (within 30 min)
  - 1 g/kg CHO, 0.5 g/kg PRO
- Post-exercise meal (within 2 hrs)
- CHO loading (2-3 days prior to competition)
  - Taper training by 30%-50%
  - Ingest 200-300 extra grams of CHO



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Ergogenic Aid

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Any training technique, mechanical device, nutritional practice, pharmacological method, or psychological technique that can improve exercise performance capacity and/or enhance training adaptations.

Ergogenic Aid

Ergogenic aids may help prepare an individual to exercise, improve exercise efficiency, enhance recovery from exercise, or assist in injury prevention during intense training.

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Sport Supplement Categories

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- Pre-Workout Supplements
  - Carbohydrate (30-40 g)
  - Protein / AA (5-10 g)
  - Stimulate metabolism
  - Improve cognitive function
  - Lessen exercise-induced catabolism, inflammation, and/or immunosuppression
  - Ergogenic Nutrients that support training

- During Exercise Supplements
  - Prevent dehydration
  - Maintain blood glucose (20-40 g/hr of CHO, 6-8%)
  - Provide amino acids (BCAA or EAA) to limit exercise-induced protein degradation
  - Minimize mental fatigue and central fatigue

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Sport Supplement Categories

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- Post-Workout Supplements
  - CHO for glycogen replenishment
  - Protein / AA to enhance protein synthesis
  - Support immune function
  - Reduce inflammation and promote recovery
  - Ergogenic nutrients

- Specialty Ingredients/Ergogenic Nutrients
  - Creatine
  - HMB
  - B-alanine
  - Nitrates
  - Sodium Phosphate
  - Glycerol

Kerksick et al., JISSN. 15:38, 2018

Performance Enhancement Nutrition Strategies

Strength / Power Athletes

Nutritional Goals

Strength/Power Athletes

- Provide CHO & PRO
- Maintain Hydration
- Increase power and recovery from high intensity exercise
- Improve high intensity exercise performance
- Increase muscle mass

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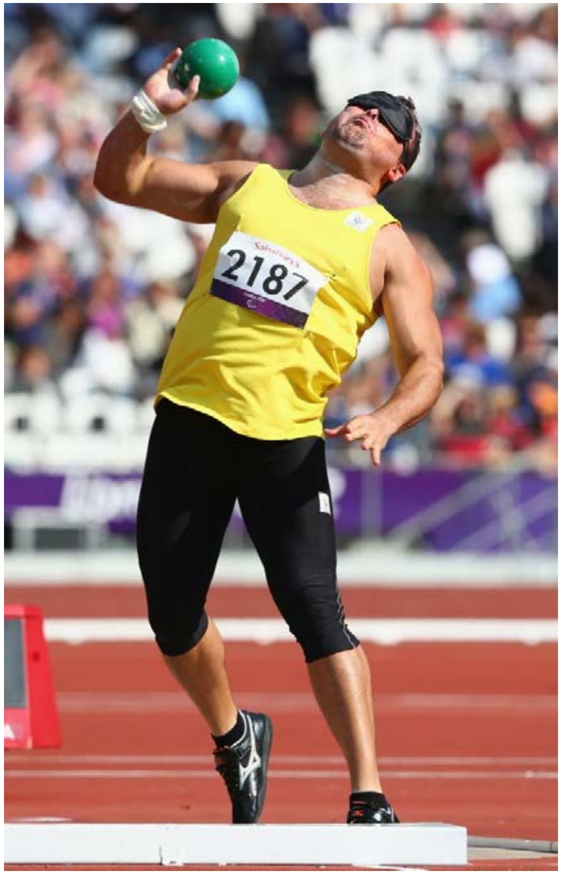
Dietary Guidelines

Strength/Power Athletes



- Caloric needs typically range between 40–70 kcals/kg/day (2000–7000 kcals/day) for a 50–100 kg athlete engaged in moderate training.
- **Carbohydrate** (40-55% of calories)
  - 3 – 5 grams/kg/day typically sufficient
- **Protein** (15-30% of calories)
  - 1.4 – 2.0 grams/kg/day general
  - 1.7 – 2.2 grams/kg/day during heavy training and/or at altitude
- **Fat** (20-30% of calories)
  - 1 – 1.5 grams/kg/day
- Greater emphasis on meal timing
- May need more education about nutritional ergogenic aids

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Ergogenic Aids

Strength/Power Athletes

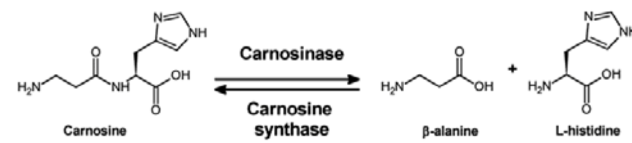
- β-alanine
- Creatine
- Nitrates *
- Sodium Bicarbonate

* Classified by ISSN as Limited / Mixed Efficacy

Kerksick et al., JISSN. 15:38, 2018

Beta Alanine

- ß-alanine, a non-essential amino acid, has ergogenic potential based on its role in carnosine synthesis
- Carnosine is a dipeptide comprised of the amino acids, histidine and ß-alanine, that naturally occur in large amounts in skeletal muscles.
- Carnosine is believed to be one of the primary muscle-buffering substances available in skeletal muscle.
- Studies have demonstrated that taking 4 to 6 g of ß-alanine orally, in divided doses, over a 28-day period is effective in increasing carnosine levels, while more recent studies have demonstrated increased carnosine and efficacy up to 12 g per day.



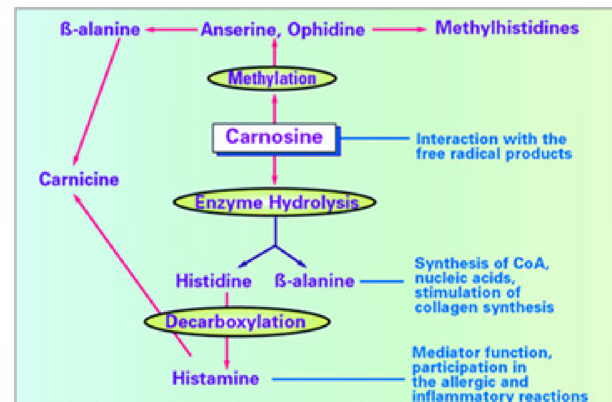
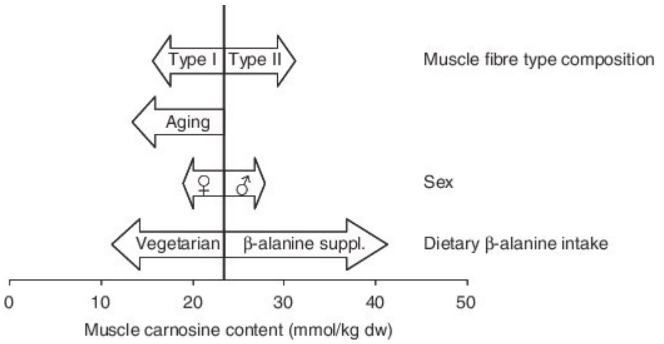


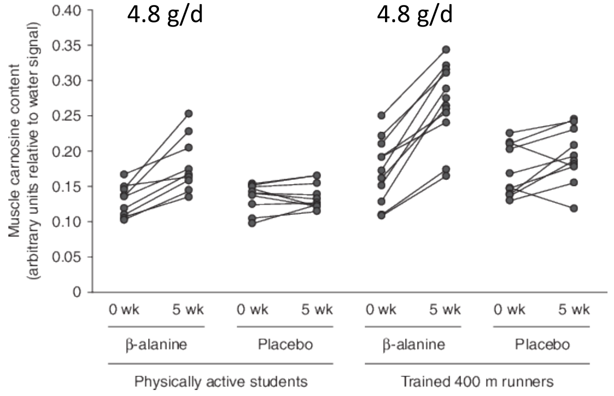
Fig. 2. The metabolic pathway of carnosine.

Trexler et al. JISSN. 12:30, 2015

Beta Alanine

- Consuming 4 to 6 g/d in divided doses of 2 g or less, for a minimum of two weeks results in a 20-30 % increase in muscle carnosine concentrations.
- Ingesting 2–6 g/d for more than 4-wks increases muscle carnosine concentrations by 20–80%. (*Culbertson et al, 2010*).
- There does not appear to be an upper ceiling to muscle carnosine levels.
- Single large boluses of BA have been reported to induce paraesthesia (i.e. tingling).
- Most studies use a sustained release form of BA to reduce parethesia.



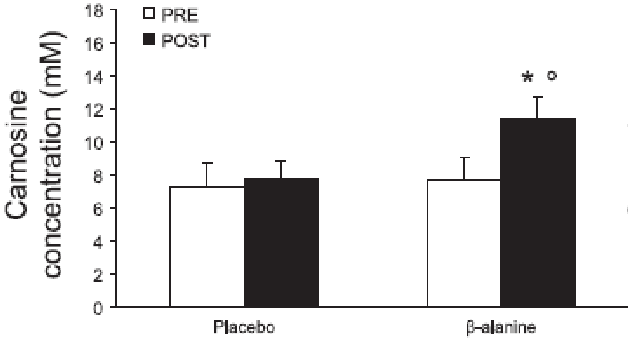


Derave et al. Sports Med. 40(3), 247-63, 2010

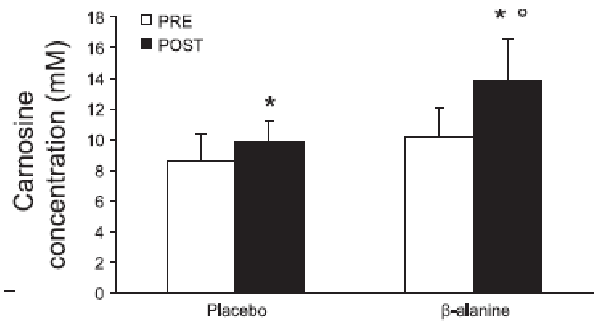
β-Alanine supplementation augments muscle carnosine content and attenuates fatigue during repeated isokinetic contraction bouts in trained sprinters

Dareve et al, JAP, 103(5): 1736-43, 2007

- 15 male athletes participated in a placebo-controlled, double-blind study and were supplemented orally for with either ***4.8 g/day β-alanine or placebo for 4-wks***.
- Muscle carnosine concentration was quantified in soleus and gastrocnemius by proton MRS.
- Performance was evaluated by isokinetic testing during 5 x 30 MVC knee extensions, by endurance during isometric contraction at 45% MVC, and by the indoor 400-m running time.
- β-Alanine supplementation significantly ***increased the carnosine content in both the soleus (+47%) and gastrocnemius (+37%).***
- Dynamic ***knee extension torque*** during the fourth and fifth bout was ***significantly improved with β-alanine*** but not with placebo.
- Isometric endurance and 400-m race time were not affected by treatment.



Soleus



Gastrocnemius

Dareve et al. JAP, 2007

β-Alanine supplementation slightly enhances repeated plyometric performance after high-intensity training in humans

Belinger et al. Amino Acids 47:1479-1483, 2015

- 14 cyclists performed a supramaximal cycling test, 4- and 10-km TT's, and 4 x 1-km sprints prior to and following 28 d of loading (***6.4 g/d***) with BA or a PLA and after a 5-wk of HIT (repeated 1-km sprints – 2 x/ wk) while taking (1.2 g/d) of BA or a PLA.
- BA loading improved sprint 3 and 4 of the 4 x 1-km sprints (4.5 +/- 3.4% and 7.0 +/- 4.0%).
- After HIT, training intensity increased to a greater degree with BA (9.9 +/- 5.0% vs. 4.9 +/- 5.0).
- BA improved maximal cycling time to exhaustion (14.9 +/- 9.2% vs. 9.0 +/- 6.9%) and anaerobic capacity (5.5 +/- 4.2%)
- ***BA enhances training intensity during HIT and provides benefits to exhaustive supramaximal cycling compared to HIT alone.***

Metabolic consequences of beta-alanine supplementation during exhaustive supramaximal cycling and 4000-m time-trial performance

Belinger et al. Appl Physiol Nutr Metab 41(8):864-71, 2016

- 17 cyclists ingested ***6.4 g/d*** of BA or PLA for ***4-wks***
- Participants performed a supramaximal cycling tests to exhaustion and a 4k TT before and after supplementation
- BA increased time to exhaustion (+12.8 +/- 8.2 s) and anaerobic capacity (+1.1 +/- 0.7 kJ)
- 4000-m TT performance was improved with BA (-6.3 +/- 4.6 s) and the mean anaerobic power output was greater (+6.2 +/- 4.5 W).
- ***BA supplementation increased time to exhaustion concomitant with an augmented anaerobic capacity during supramaximal intensity cycling***, which was also mirrored by a meaningful increase in the anaerobic contribution to power output during a 4000-m cycling TT, resulting in an enhanced overall performance.

The effects of beta alanine plus creatine administration on performance during repeated bouts of supramaximal exercise in sedentary men

Okudan et al. J Sports Med Phys Fitness 55(11):1322-8, 2015

- 44 untrained men were assigned to one of four treatment groups randomly:
  - P (10 g maltodextrose)
  - Cr (5 g creatine plus 5 g maltodextrose);
  - BA (1,6 g BA plus 8.4 g maltodextrose); or,
  - BA + Cr (,6 g BA + 5 g creatine plus 3.4 g maltodextrose).
- Supplements were taken twice a day for 22 days, then four times a day for the following 6 days.
- Prior to and following 28 days, peak power (PP), mean power (MP), and fatigue index (FI) was determined.
- PP increased in the Cr (from 642.7+/-148.6 to 825.1+/-205.2 in PP2 and from 522.9+/-117.5 to 683.0+/-148.0 in PP3, respectively). MP was increased in BA+Cr
- ***BA and BA+Cr have strong performance enhancing effect by increasing mean power and delaying fatigue Index during the repeated WAnT.***

Beta Alanine

ISSN Position Stand

1. Four weeks of beta-alanine supplementation (4–6 g daily) significantly augments muscle carnosine concentrations, thereby acting as an intracellular pH buffer.
2. Beta-alanine supplementation currently appears to be safe in healthy populations at recommended doses
3. The only reported side effect is paraesthesia (tingling), but studies indicate this can be attenuated by using divided lower doses (1.6 g) or using a sustained-release formula.
4. Daily supplementation with 4 to 6 g of beta-alanine for at least 2 to 4 weeks has been shown to improve exercise performance, with more pronounced effects in open end-point tasks/time trials lasting 1 to 4 min in duration.

Trexler et al. JISSN. 12:30, 2015

Beta Alanine

ISSN Position Stand

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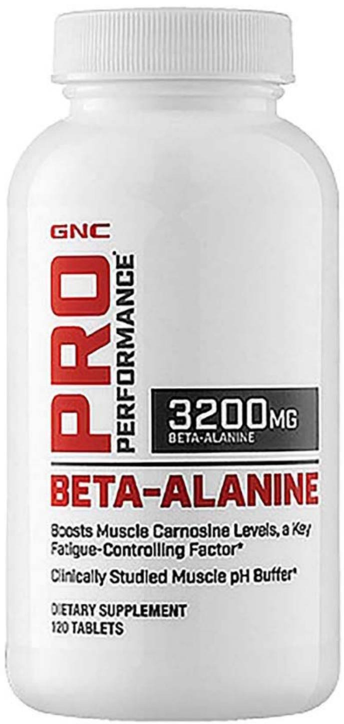
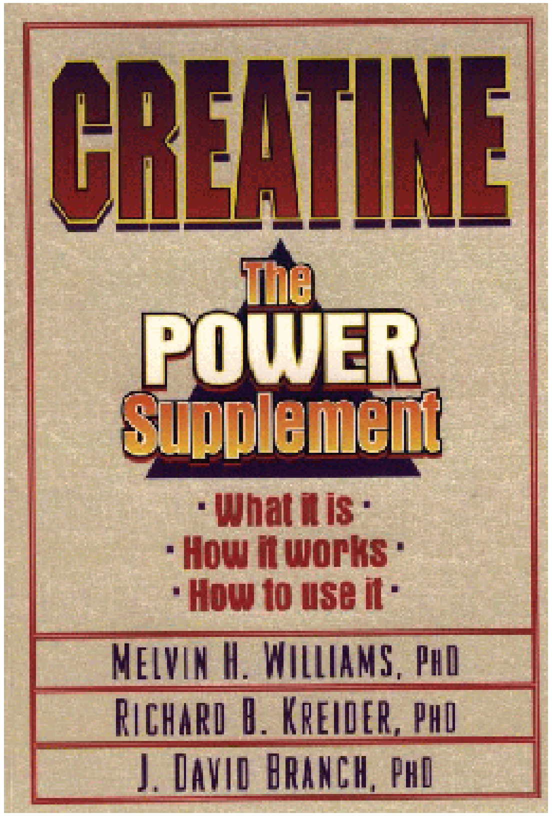
5. Beta-alanine attenuates neuromuscular fatigue, particularly in older subjects, and preliminary evidence indicates that beta-alanine may improve tactical performance.
6. Combining beta-alanine with other single or multi-ingredient supplements may be advantageous when supplementation of beta-alanine is high enough (4–6 g daily) and long enough (minimum 4 weeks);
7. More research is needed to determine the effects of beta-alanine on strength, endurance performance beyond 25 min in duration, and other health-related benefits associated with carnosine.



Trexler et al. JISSN. 12:30, 2015

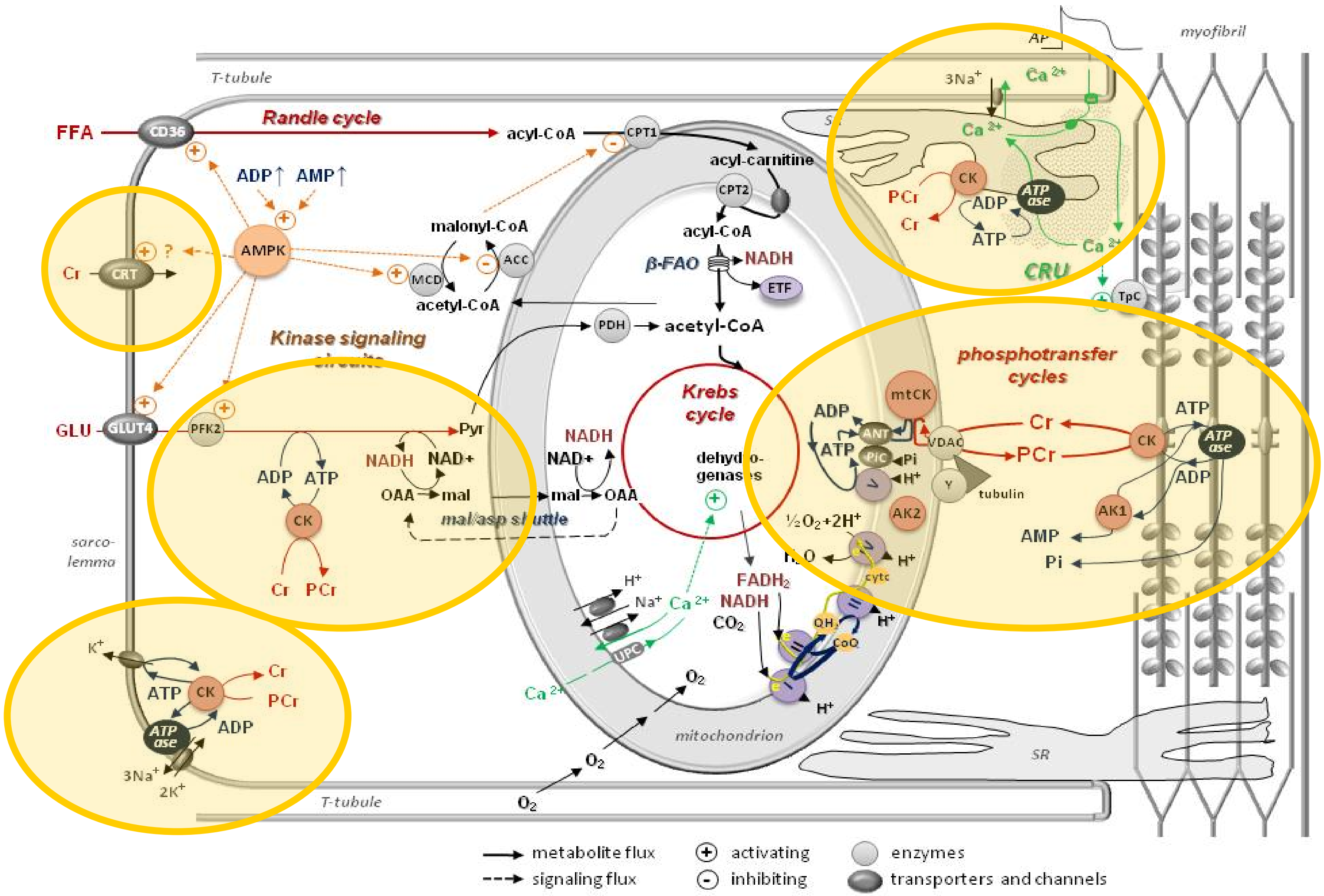
Creatine



- Creatine is a naturally occurring non-essential amino acid discovered in 1832.
- Creatine supplementation studies began in early 1900s with interest rekindled by Ingwall and Hultman in 1970s.
- Athletes reported to be using creatine as an ergogenic aid since 1960's.
- Potential therapeutic role investigated since 1970's.
- Emphasis on ergogenic value in athletes since early 1990s as synthetic creatine became available.
- Current research on potential medical uses

Metabolic Role of Creatine

Saks et al. (2013) in: Systems biology of metabolic and signalling networks, Springer



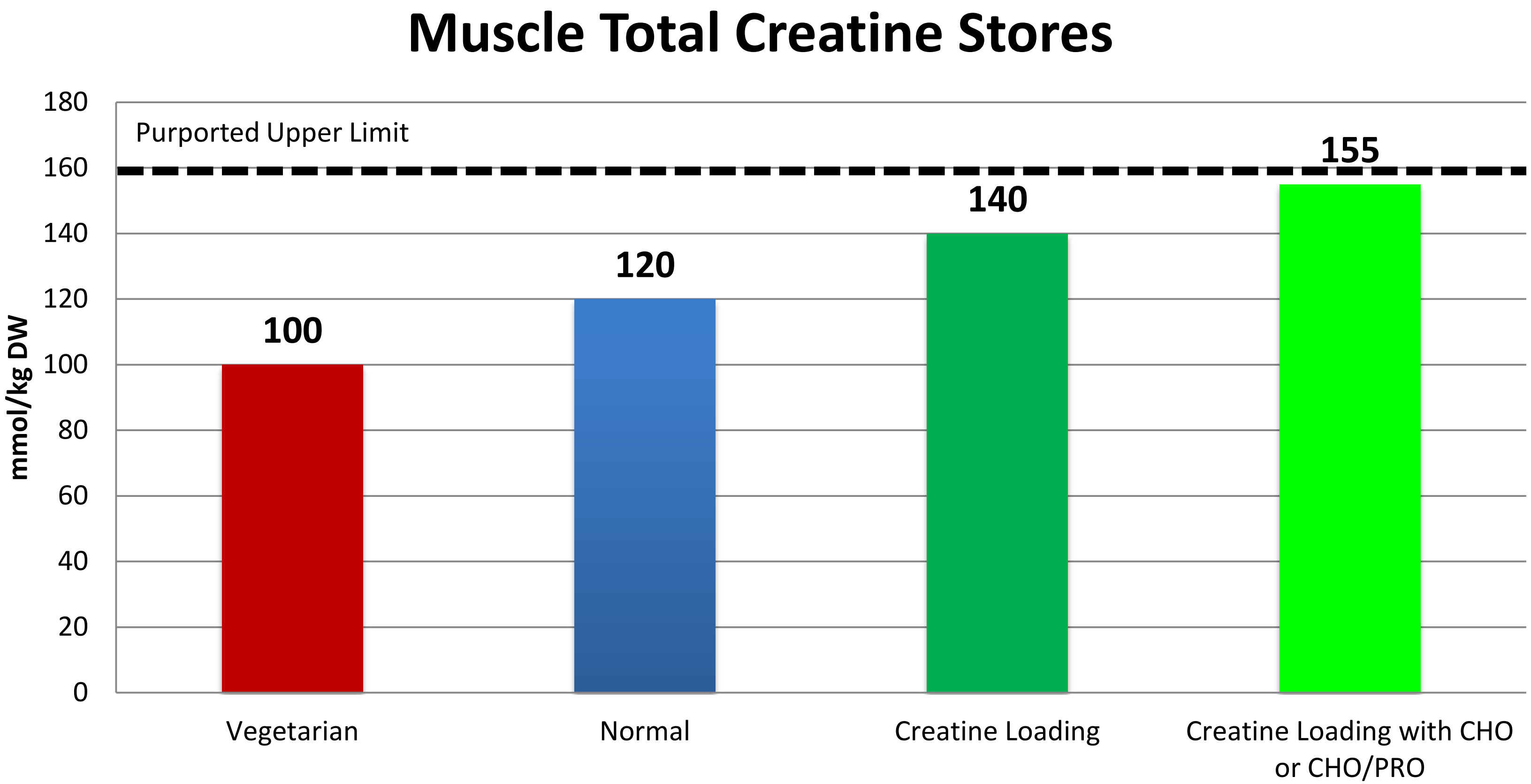
Creatine

Supplementation Protocols

- High Dose Protocol
  - Ingest 15-25 g/d (0.3 g/kg/d) during training
- ***Loading/Maintenance Protocol***
  - ***Ingest 0.3 g/kg/d (15-25 g/d) for 5-7 d***
  - ***Ingest 0.03 g/kg/d (3-5 g/d) to maintain***
- Low Dose Protocol
  - Ingest 0.03 g/kg/d (3-5 g/d)
- Cycling Protocol
  - Load/maintain during training and reduce/abstain between training periods

- Takes about 4-6 weeks for muscle creatine levels to return to baseline after loading

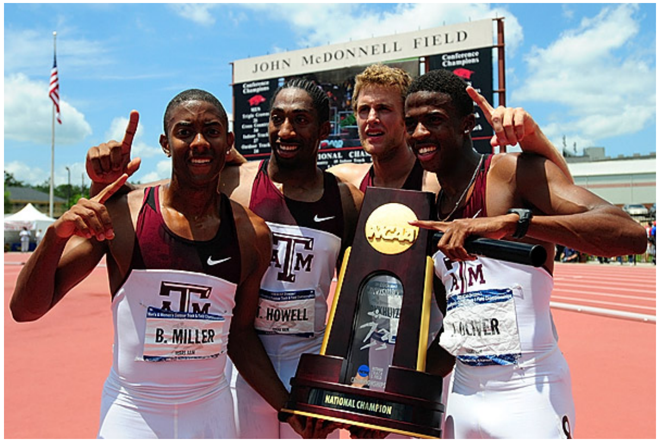
Bioavailability



Approximate muscle total creatine levels in mmol/kg dry weight muscle reported in the literature for vegetarians, individuals following a normal diet, and in response to creatine loading with or without carbohydrate (CHO) or CHO and protein (PRO). From Kreider & Juhn, JENB, 2011.

Ergogenic Value

- Increased single and repetitive sprint performance
- Increased work performed during sets of maximal effort muscle contractions
- Increased muscle mass & 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



Effects of Creatine Supplementation on Body Composition, Strength, and Sprint Performance

Kreider et al. MSSE 30:73-82, 1998

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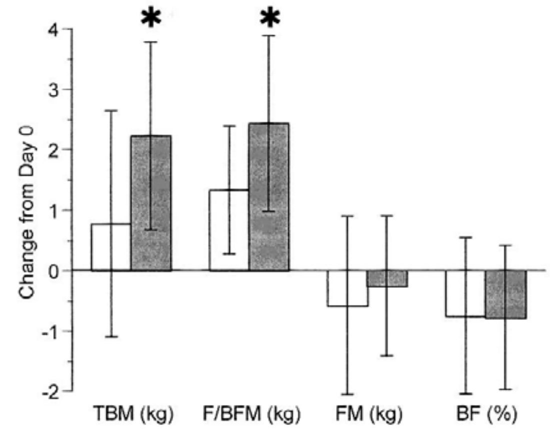
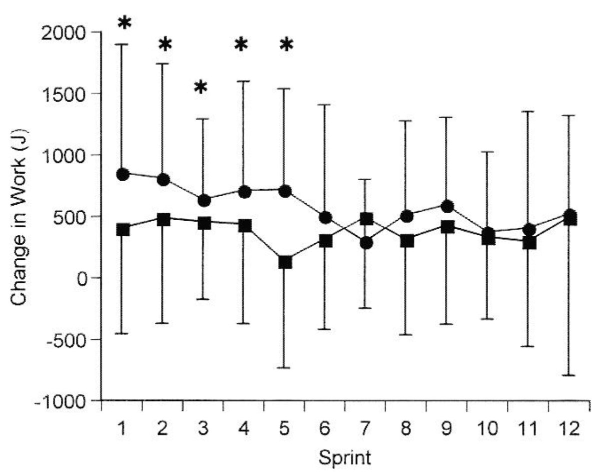
- 25 NCAA division IA football players were matched-paired and assigned to supplement their diet for 28 d during resistance/agility training (8 h·wk-1) with a placebo (P) or supplement 15.75 g/d of CrM.
- Hematological parameters remained within normal clinical limits with no side effects reported.
- DEXA scanned body mass (P 0.77 ± 1.8; CrM 2.22± 1.5 kg) and FFM (P 1.33 ± 1.1; CrM 2.43 ± 1.4 kg) were significantly increased in the CrM group.
- Gains in bench press lifting volume (P -5 ± 134; CrM 225 ± 246 kg), the sum of bench press, squat, and power clean lifting volume (P 1,105 ± 429; CrM 1,558± 645 kg), and total work performed during the first five 6-s sprints were greater in the CrM group.
- CrM promoted greater gains in FFM, isotonic lifting volume, and sprint performance during intense resistance/agility training.





*Cited over 600 times

Creatine Supplementation and Upper Limb Strength Performance: A Systematic Review and Meta-Analysis

Lanthers et al. Sports Med. June 21, 2016

- Conducted a meta-analysis on 53 studies (563 individuals in the creatine supplementation group and 575 controls).
- Results did not differ at T0, while, at T1, the effect size (ES) for bench press and chest press were 0.265 (95 % CI 0.132-0.398; $p < 0.001$) and 0.677 (95 % CI 0.149-1.206; $p = 0.012$), respectively.
- Overall, pectoral ES was 0.289 (95 % CI 0.160-0.419; $p = 0.000$), and global upper limb ES was 0.317 (95 % CI 0.185-0.449; $p < 0.001$).
- Meta-analysis of changes between T0 and T1 gave similar results.
- The meta-regression showed no link with characteristics of population or supplementation, demonstrating the efficacy of creatine independently of all listed conditions.
- ***Creatine supplementation is effective in upper limb strength performance for exercise with a duration of less than 3 min, independent of population characteristics, training protocols, and supplementary doses or duration.***

Creatine

ISSN Position Stand

1. Creatine monohydrate is the most effective ergogenic nutritional supplement currently available to athletes with the intent of increasing high-intensity exercise capacity and lean body mass during training.
2. Creatine monohydrate supplementation is not only safe, but has been reported to have a number of therapeutic benefits in healthy and diseased populations ranging from infants to the elderly. There is no compelling scientific evidence that the short- or long-term use of creatine monohydrate (up to 30 g/day for 5 years) has any detrimental effects on otherwise healthy individuals or among clinical populations who may benefit from creatine supplementation.

Kreider et al. JISSN 14:18, 2017

Creatine

ISSN Position Stand

3. If proper precautions and supervision are provided, creatine monohydrate supplementation in children and adolescent athletes is acceptable and may provide a nutritional alternative with a favorable safety profile to potentially dangerous anabolic androgenic drugs. However, we recommend that creatine supplementation only be considered for use by younger athletes who: a.) are involved in serious/competitive supervised training; b.) are consuming a well-balanced and performance enhancing diet; c.) are knowledgeable about appropriate use of creatine; and d.) do not exceed recommended dosages.
4. Label advisories on creatine products that caution against usage by those under 18 years old, while perhaps intended to insulate their manufacturers from legal liability, are likely unnecessary given the science supporting creatine's safety, including in children and adolescents.
5. At present, creatine monohydrate is the most extensively studied and clinically effective form of creatine for use in nutritional supplements in terms of muscle uptake and ability to increase high-intensity exercise capacity.

Kreider et al. JISSN 14:18, 2017

Creatine

ISSN Position Stand

6. The addition of carbohydrate or carbohydrate and protein to a creatine supplement appears to increase muscular uptake of creatine, although the effect on performance measures may not be greater than using creatine monohydrate alone.
7. The quickest method of increasing muscle creatine stores may be to consume ~0.3 g/kg/day of creatine monohydrate for 5–7-days followed by 3–5 g/day thereafter to maintain elevated stores. Initially, ingesting smaller amounts of creatine monohydrate (e.g., 3–5 g/day) will increase muscle creatine stores over a 3–4 week period, however, the initial performance effects of this method of supplementation are less supported.
8. Clinical populations have been supplemented with high levels of creatine monohydrate (0.3 – 0.8 g/kg/day equivalent to 21–56 g/day for a 70 kg individual) for years with no clinically significant or serious adverse events.
9. Further research is warranted to examine the potential medical benefits of creatine monohydrate and precursors like guanidinoacetic acid on sport, health and medicine.

Kreider et al. JISSN 14:18, 2017

Beet Root Juices / Nitrates

- Dietary intake of food or juices with high nitrate levels has been reported to promote healthy blood pressure due to a vasodilatory effect
- Studies show consuming BRJ prior to exercise (e.g., 300-500 ml) improves aerobic endurance efficiency
- Some studies suggest nitrate supplementation can also enhance intermittent exercise performance and/or recovery

Kerksick et al., JISSN. 15:38, 2018

Ingestion of a nitric oxide enhancing supplement improves resistance exercise performance *Mosher et al. J Strength Cond Res. e-pub, April 2, 2016*

- 12 resistance trained males ingested either ***70 ml of "BEET It Sport" nitrate shot containing 6.4 millimoles (mmol/L) or 400 mg of nitrate; or a blackcurrant placebo drink.***
- Participants completed a resistance exercise session, consisting of bench press exercise at an intensity of 60% of their established 1 repetition maximum (1-RM), for three sets until failure with 2 minute rest interval between sets.
- ***Results showed a significant difference in repetitions to failure ($p < 0.001$) and total weight lifted ($p < 0.001$).***
- No significant differences were seen in lactate, local, or general indicators of fatigue.
- ***Nitrate supplementation before exercise improved resistance training performance and work output.***

The effects of nitrate-rich supplementation on neuromuscular efficiency during heavy resistance exercise *Flanagan et al. J Am Coll Nutr. 35(2):100-7, 2016*

- ***14 resistance-trained men consumed an nitrate-rich (NR) or nitrate-poor (NP) supplement for 3 d, performed a bout of heavy resistance exercise, completed a washout, and then repeated the procedures with the remaining supplement***.
- Before, during, and after exercise, individual and gross motor unit efficiency was assessed during isometric and dynamic muscle contractions and physical performance, heart rate, lactate, and oxygen consumption (VO_2) were determined.
- ***NR lowered initial muscle firing rates at rest and lower mean and maximum firing rates over the course of fatiguing exercise.***
- NP was accompanied by increased mean and maximum firing rates by the end of exercise and lower initial firing rates.
- Nitrate supplementation resulted in higher mean peak electromyography (EMG) amplitudes.
- ***Supplementation with an NR beetroot extract-based supplement provided neuromuscular advantages during metabolically taxing resistance exercise.***

Hematological and Hemodynamic Responses to Acute and Short-Term Creatine Nitrate Supplementation *Dalton et al. Nutrients. 9(12):1359, 2917*

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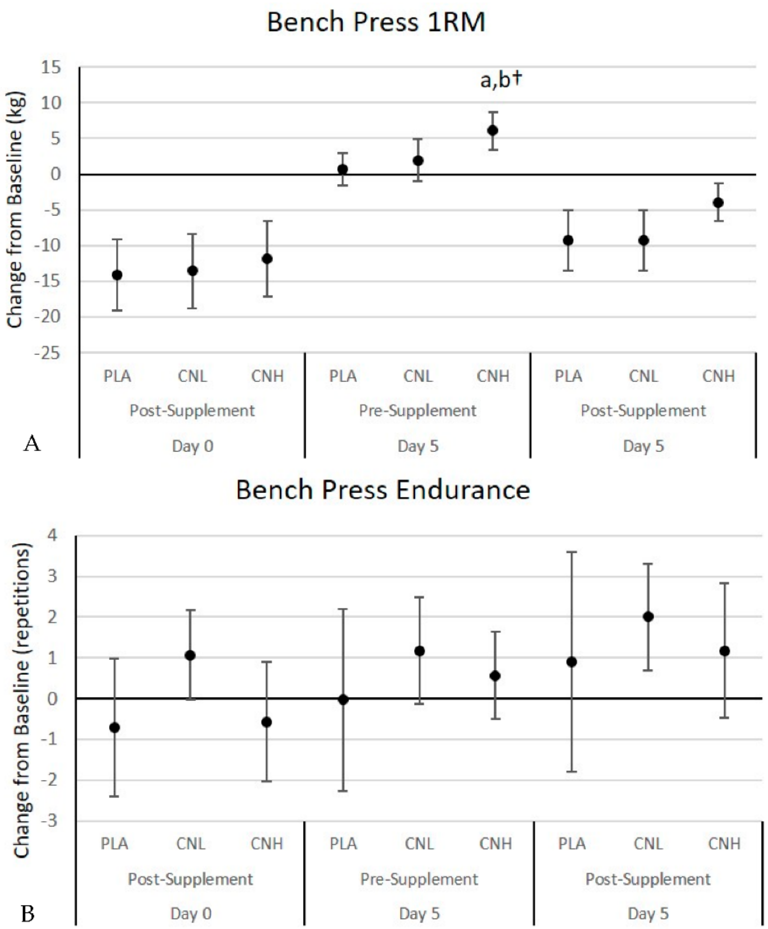
- 28 men and women ingested a PLA, 3 g of creatine nitrate (CNL), and 6 g of creatine nitrate (CNH) for 6-d in a repeated measures crossover manner with a 7-d washout.
- Hemodynamic responses to a postural challenge, fasting blood samples, and bench press, leg press, and cycling time trial performance and recovery were assessed
- No significant differences were found among treatments for hemodynamic responses, clinical blood markers or self-reported side effects.
- After 5-d of supplementation, *1RM BP improved significantly for CNH (6.1 [3.5, 8.7] kg)* but not PLA (0.7 [−1.6, 3.0] kg or CNL (2.0 [−0.9, 4.9] kg, CNH, $p = 0.01$).
- CNL treatment promoted an increase in BP repetitions at 70% of 1RM during recovery on day 5 (PLA: 0.4 [−0.8, 1.6], CNL: 0.9 [0.35, 1.5], CNH: 0.5 [−0.2, 0.3], $p = 0.56$), greater LP endurance prior to supplementation on day 5 (PLA: −0.2 [−1.6, 1.2], CNL: 0.9 [0.2, 1.6], CNH: 0.2 [−0.5, 0.9], $p = 0.25$) and greater LP endurance during recovery on day 5 (PLA: −0.03 [−1.2, 1.1], CNL: 1.1 [0.3, 1.9], CNH: 0.4 [−0.4, 1.2], $p = 0.23$).
- Cycling time trial performance (4 km) was not affected.
- ***Benefits related to nitrate supplementation.***



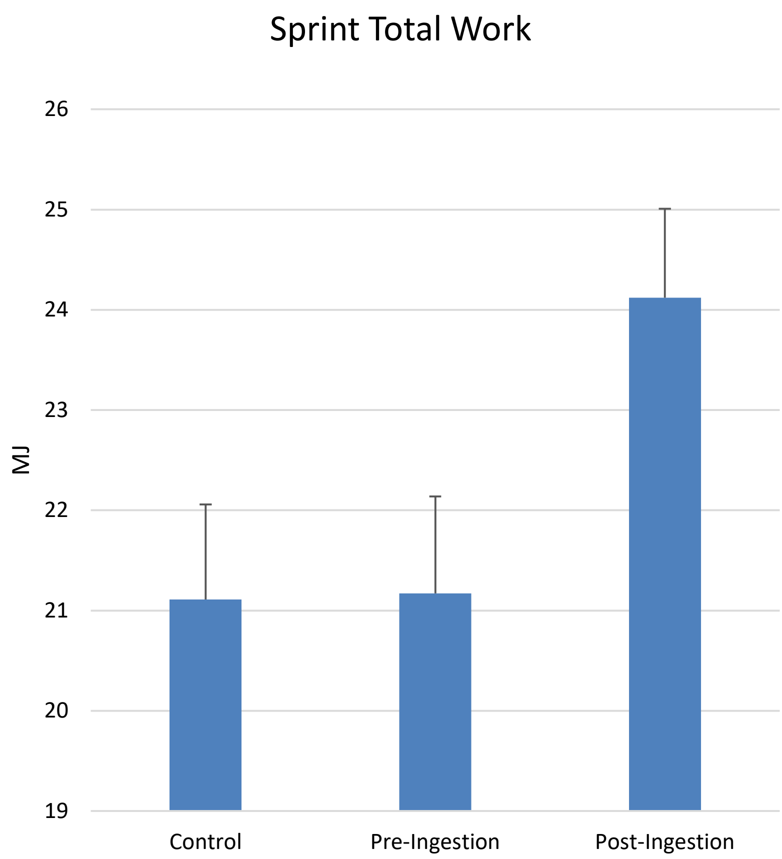
Sodium Bicarbonate

- Supplementation Protocols:
  - 0.3 g/kg of baking soda 1 to 2 hours before competition
  - 10 g/d for 5-d
- Reported to buffer acidity and improve high intensity exercise performance (1 - 3 min)
- Possible GI distress
- Start out with a small amount during training to build up tolerance

Kerksick et al., JISSN. 15:38, 2018

Effects of chronic bicarbonate ingestion on performance of high intensity work *McNaughton et al. EJAP, 80:333-6. 1999*

- 8 subjects performed a 60-s sprint on a CE prior to and following 5-d of supplementation of SB (0.5 g/kg/d) and following 1 month cessation
- SB significantly increased blood bicarbonate levels and pH levels
- SB increased work by 14% and peak power



Ergogenic effects of caffeine and sodium bicarbonate supplementation on intermittent exercise performance preceded by intense arm cranking

Marriott et al. JISSN, 12:13, 2015

- 12 male team-sports athletes (n = 12) ingested sodium bicarbonate (NaHCO3; 0.4 g/kg), caffeine (CAF; 6 mg/kg) or placebo (PLA) on three different occasions.
- Participants engaged in intense arm exercise prior to the Yo-Yo intermittent recovery test level-2 (Yo-Yo IR2).
- CAF and NaHCO3 elicited a 14 and 23% improvement ($P < 0.05$), respectively, in Yo-Yo IR2 performance, post arm exercise compared to PLA.
- RPE was lower ($P < 0.05$) during the Yo-Yo IR2 test in the NaHCO3 trial in comparison to CAF and PLA, while no difference in heart rate was observed between trials.
- ***Caffeine and sodium bicarbonate administration improved Yo-Yo IR2 performance and lowered perceived exertion after intense arm cranking exercise, with greater overall effects of sodium bicarbonate intake.***

Separate and Combined Effects of Caffeine and Sodium-Bicarbonate Intake on Judo Performance *Felippe et al. Int J Sports Physiol Perform, 11(2):221-6, 2016*

- 10 judo athletes performed 4 supplementation protocols-NaHCO3, CAF, NaHCO3 + CAF, and placebo (PLA) followed by 3 Special Judo Fitness Tests (SJFTs) interspaced with 5 min rest.
- The combined supplement (NaHCO3 + CAF) resulted in a higher number of throws than with PLA (24.4 +/- 0.9 and 23.2 +/- 1.5 throws, respectively, P = .02) during the first SJFT.
- In the 3rd SJFT, NaHCO3 and NaHCO3 + CAF resulted in more throws than with PLA (23.7 +/- 1.6, 24.4 +/- 1.0, and 22.0 +/- 1.6 throws, P = .001 and P = .03, respectively).
- Sum of throws performed in the 3 SJFTs were higher than PLA only for NaHCO3 + CAF (68.8 +/- 4.4 and 72.7 +/- 3.1 throws, respectively, P = .003).
- ***Combined supplementation of NaHCO3 + CAF increased judo performance compared with PLA.***

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Performance Enhancement Nutrition Strategies

Endurance Athletes

Nutritional Goals

Endurance Athletes

- Provide necessary dietary carbohydrate
- Maintain hydration and blood glucose levels during exercise
- Spare muscle glycogen utilization during exercise
- Promote glycogen resynthesis
- Increase endurance capacity
- Increase anaerobic threshold
- Maintain muscle mass

Kerksick et al., JISSN. 15:38, 2018

Dietary Guidelines

Endurance Athletes

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- Caloric needs may approach 40–70 kcals/kg/day (moderate training) to 70-150 kcals/kg/day (heavy training or competition)
- **Carbohydrate** (55%-65% of calories)
  - o 5 – 8 g/kg/d – moderate training
  - o 8 – 10 g/kg/d – heavy training
- **Protein** (15-20% of calories)
  - o 1.2 – 2.0 g/kg/d - moderate training
  - o 1.7 – 2.2 g/kg/d - heavy training
- **Fat** (20-30% of calories)
  - o 0.5 – 1.5 g/kg/d
- Meal Timing Important
- Use of energy supplements helpful

Kerksick et al., JISSN. 15:38, 2018

Ergogenic Aids

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- Water/GES during exercise
- Caffeine
- Sodium Phosphate
- Nitrates (Beet Root Juice)
- Creatine

Kerksick et al., JISSN. 15:38, 2018

Water/Glucose Electrolyte Solutions

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- Performance can be impaired when ≥ 2% of body weight is lost through sweat. Fluid loss of > 4% of body weight may lead to heat illness, exhaustion, stroke, or death.
- High intensity (> 70% VO_{2Max}) exercise bouts > 90 min challenge fuel supply and fluid regulation.
- It is advisable to consume CHO at a rate of 30–60 g of carbohydrate/hour in a 6–8% GES (6–12 fluid ounces) every 10–15 min during exercise.
- Addition of 0.5 - 1 g/L of salt in athletes with high sweat rate (>2 L/hr) can help maintain hydration in hot & humid environments.
- Use of GES during prolonged exercise has been reported to maintain BG, attenuate dehydration, improve performance, and lessen the immunosuppressive effects of exercise.

Kerksick et al., JISSN. 15:38, 2018

Glucose Electrolyte Solutions

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- The general consensus in the scientific literature is the body can oxidize 1 – 1.1 gram of CHO per minute of carbohydrate or about 60 grams per hour.
- The ACSM recommends ingesting 0.7 g/kg/hr during exercise in a 6-8% solution (i.e., 6-8 grams per 100 ml of fluid).
- Harger-Domitrovich et al (*MSSE, 2007*) reported that 0.6 g/kg/h of maltodextrin optimized carbohydrate utilization (30 - 70 grams of carbohydrate per hour for a 50 – 100 kg individual).
- Jeukendrup et al (*Scan J Med Sci Sports, 2008*), reported that ingesting a glucose and fructose beverage in a 2:1 ratio during exercise enhanced carbohydrate oxidation (1.8 g/min) better than glucose alone as well as helped promote greater fluid retention.

Glucose Electrolyte Drinks

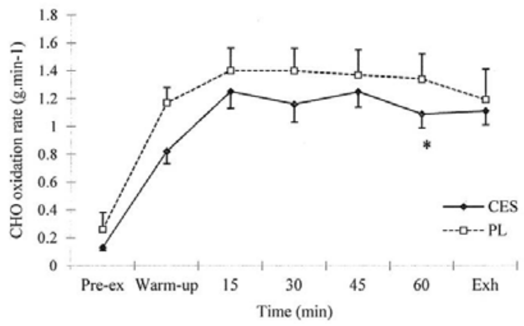
GI of Common Sugars

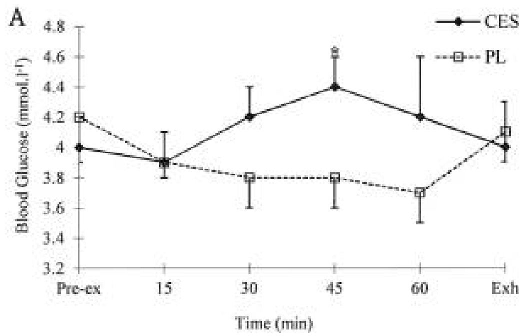
Type of Carbohydrate	Glycemic Index
Sugar Alcohols (e.g., mannitol, erythritol, lactitol, sorbitol, isomalt, xylitol)	0-15
Fructose	19
Galactose	20
Isomaltulose	32
Lactose	46
Honey	55
Trehalose	67
Sucrose	68
Dextrose	93
Glucose	99
Maltose	105
Maltodextrin	137

- Oxidation rates of sucrose, maltose, and maltodextrins are high while fructose, galactose, trehalose, and isomaltulose are lower.
- Combinations of glucose-sucrose or maltodextrin-fructose have been shown to maximize exogenous carbohydrate utilization during exercise but have short lived effects on blood glucose.
- Adding lower GI carbohydrates like fructose, trehalose, or galactose to a mixture of carbohydrate given prior or during exercise can spare glycogen depletion and have less of an effect on insulin.

Carbohydrate electrolyte solutions enhance endurance capacity in active females *Sun et al. Nutrients. 2015 May; 7(5): 3739–3750.*

- In a DBPCCO manner, 8 healthy active females performed a run to exhaustion at 70% VO_{2Max} on a TM during the follicular phase of their menstrual cycle on two occasions.
- During each run, the subjects consumed either ***3mL/kg of a 6% GES*** or a PLA every 20 min during exercise.
- She subjects ingested similar volumes of fluid in the two trials (GES: 644 ± 75 mL vs. PLA: 593 ± 66 mL, $p > 0.05$).
- The ***time to exhaustion was 16% longer during the GES trial (106.2 ± 9.4 min) than during the PAL trial (91.6 ± 5.9 min) (p < 0.05).***
- At 45 min during exercise, the BG in the GES trial was higher than that in PLA.
- No differences were observed in the plasma lactate level, RER, HR, RPE, sensation of thirst, or abdominal discomfort.





Kerksick et al., JISSN. 15:38, 2018

Low vs. high glycemic index carbohydrate gel ingestion during simulated 64-km cycling time trial performance

Earnest et al. Strength Cond Res. 18(3):466-72, 2004.

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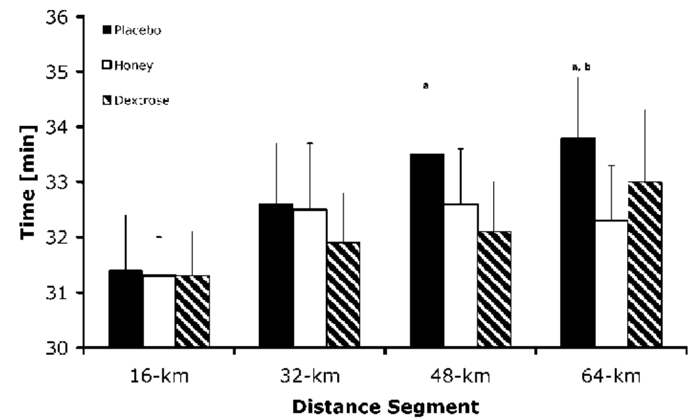
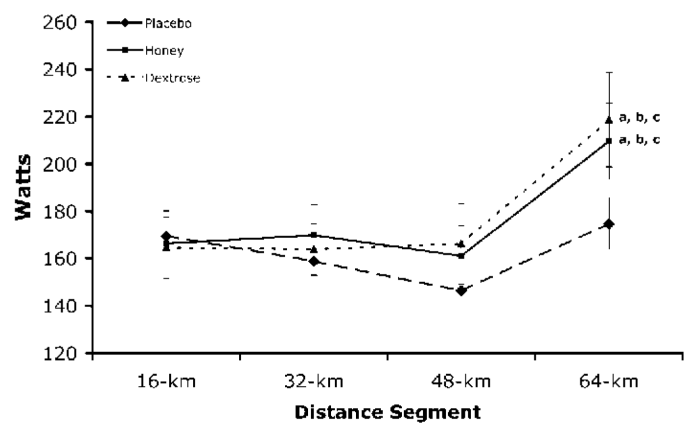
- In a RPCCO study, 9 trained cyclists performed 3 x 64-km time trials (TT).
- Every 16 km, subjects ingested a PLA, a low GI Gel (Honey – GI=35), or a High GI Gel (Dextrose – GI=100).
- No differences were seen for time to complete the TT (H 128:42 ± 3.6 min; D 128:18 ± 3.8 min; PLA 131:18 ± 3.9 min).
- The H condition (128:30 min) was faster than PLA condition (131:18 min; $p < 0.02$).
- TT performance with CHO was generally faster than PLA (PLA vs. D (2.36% [-0.69, 4.64]) and H (1.98% [-0.30, 5.02]).
- Power output (W) over the last 16 km vs. preceding segments was greater for D ($p < 0.002$) and H ($p < 0.0004$) treatments.
- The final 16-km W expressed as a percentage of pretest Wmax, the D treatment was > PLA ($p < 0.05$).
- A trend (p=0.06) for improvement in time and wattage over the last 16 km of a 64-km simulated TT regardless of glycemic index.

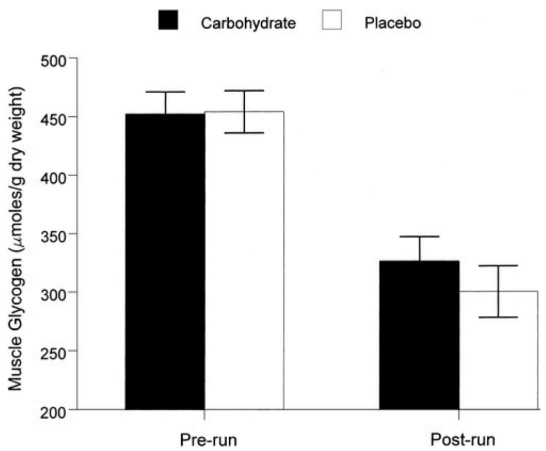


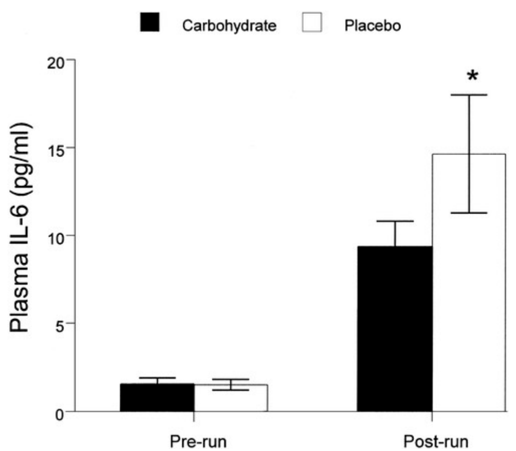


Carbohydrate ingestion influences skeletal muscle cytokine mRNA and plasma cytokine levels after a 3-h run

Nieman et al. J Appl Phys. 94: 1917–1925, 2003.

- 16 experienced marathoners ran on treadmills for 3 h at ~70% (VO_{2Max}) on two occasions while receiving 1 L/h CHO or PLA beverages.
- Plasma glucose and insulin were higher, and cortisol, IL-6, IL-10, and IL-1ra were significantly lower postexercise in CHO vs. PLA.
- Change in muscle glycogen content did not differ between CHO and PLA (P = 0.246).
- After subjects ran for 3 h, gene expression above prerun levels was measured for five of these cytokines: IL-1β, IL-6, and IL-8 (large increases), and IL-10 and TNF-α (small increases).
- The increase in mRNA (fold difference from preexercise) was attenuated in CHO (15.9-fold) compared with Pla (35.2-fold) for IL-6 (P = 0.071) and IL-8 (CHO, 7.8-fold; Pla, 23.3-fold; P = 0.063).
- CHO compared with Pla beverage ingestion attenuates the increase in plasma IL-6, IL-10, and IL-1ra and gene expression for IL-6 and IL-8 in athletes running 3 h at 70% VO_{2Max} despite no differences in muscle glycogen content.





Carbohydrate

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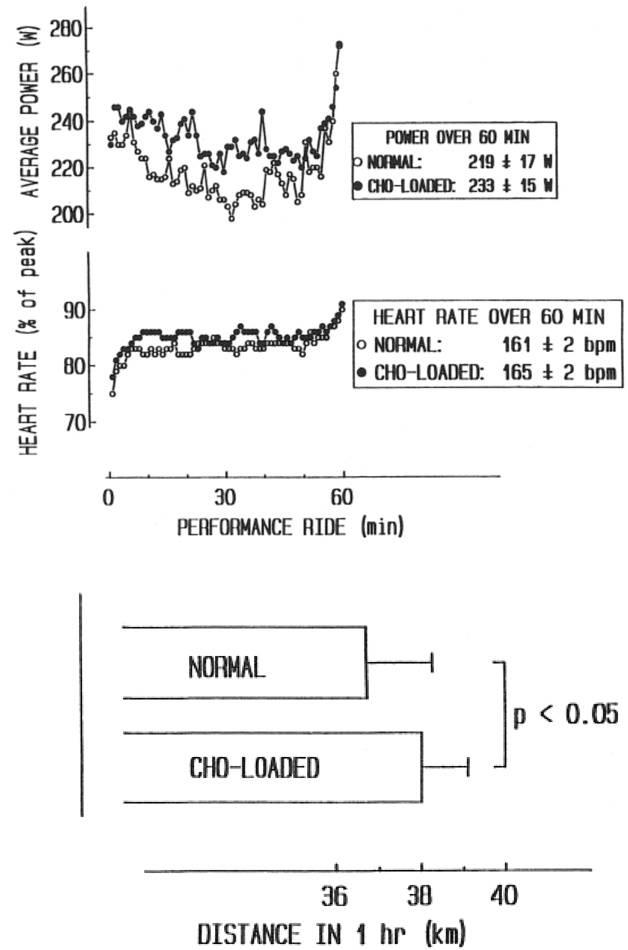
- Intramuscular and hepatic glycogen stores are best maximized by consumption of a high-CHO diet (5–8 g/kg/d during moderate training and 8–12 g/kg/d during heavy training).
- Athletes undergoing prolonged bouts (2–3 h) of exercise training can oxidize CHO at a rate of 1–1.1 g per minute or about 60 g/hr.
- Several reviews advocate the ingestion of 0.7 g of carbohydrate/kg/hr. during exercise in a 6–8% solution (i.e., 6–8 g per 100 ml of fluid).
- CHO feedings (> 8 g/kg/d or 1.2 g/kg/hour) during the first 4-hours following exercise that favor high-glycemic CHO (> 70) promote rapid restoration of glycogen stores.
- Athletes should emphasize CHO ingestion during the first 4 hrs after intense exercise.

Kerksick et al., JISSN. 15:38, 2018

The effects of carbohydrate loading on muscle glycogen content and cycling performance. *Rauch et al. In J Sport Nutr. 5(1):25-36, 1995.*

- 8 endurance-trained cyclists ingested in random order either their normal CHO intake of 6.15±0.23 g/kg/d or a high-CHO diet of 10.52±0.57 g/kg/d.
- Participants cycled for 2 hr at approximately 75% of VO_{2peak} with five 60-s sprints at 100% VO_{2peak} at 20-min intervals, followed by a 60-min performance ride.
- Increasing CHO intake by 72±9% for 3 days prior to the trial elevated pre-exercise muscle glycogen contents, improved power output, and extended the distance covered in 1 hr.
- Muscle glycogen contents were similar at the end of the 3-hr trial, indicating a greater utilization of glycogen when subjects were CHO loaded, which may have been responsible for their improved cycling performance.



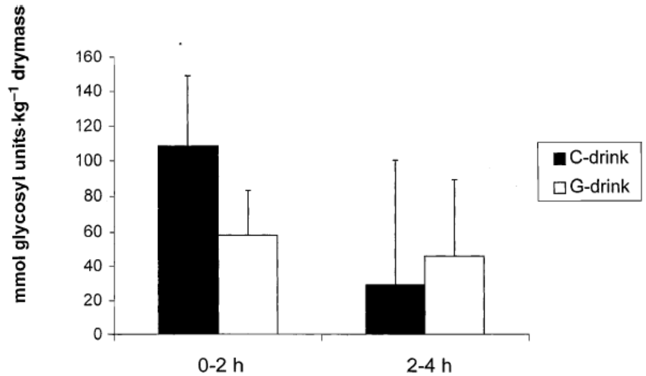
Muscle glycogen resynthesis rate in humans after supplementation of drinks containing carbohydrates with low and high molecular masses.

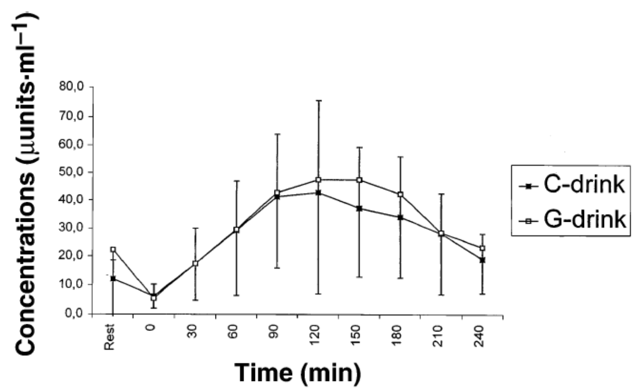
Piehl et al. Eur J Appl Physiol. 81(4):346-51, 2000

- 13 healthy well-trained men performed a glycogen depleting exercise bout followed by ingesting drinks containing 4.2 g/kg of CHO (75 g in 500 ml water) at 0, 30, 60 ad 90-min post exercise.
- One drink contained a polyglucoside with a mean molecular mass (MMM) of 500 000±700 000 (C drink) and the other contained monomers and oligomers of glucose with a MMM of approximately 500 (G drink).
- Mean glycogen synthesis rate was significantly higher during the initial 2 h for the C drink compared to the G drink: 50.2±13.7 mmol/kg/h in the C group and 29.9±12.5 mmol/kg/hr in the G group.
- During the last 2 h the mean synthesis rate was 18.8±33.3 and 23.3±22.4) mmol/kg/h in the C and G group, respectively.
- Mean blood glucose and insulin concentrations did not differ between the two drinks.
- Our data indicted that the osmolality of the carbohydrate drink may influence the rate of resynthesis of glycogen in muscle after its depletion by exercise.

	Glycogen, mmol · kg^{-1} (dry mass)			Synthesis rate, mmol · kg^{-1} (dry mass) · h^{-1}	
	0 h	2 h	4 h	0–2 h	2–4 h
C group	52.9 (27.4)	153.3 (27.4)*	190.8 (61.5)	50.2 (13.7)#	18.8 (33.3)
G group	58.3 (35.4)	118.1 (38.9)*	164.7 (49.9)	29.9 (12.5)	23.3 (22.4)

* $P < 0.06$, # $P < 0.06$





Ingestion of high molecular weight carbohydrate enhances subsequent repeated maximal power: a randomized controlled trial

Oliver et al. PLoS One. 16;11(9), 2016

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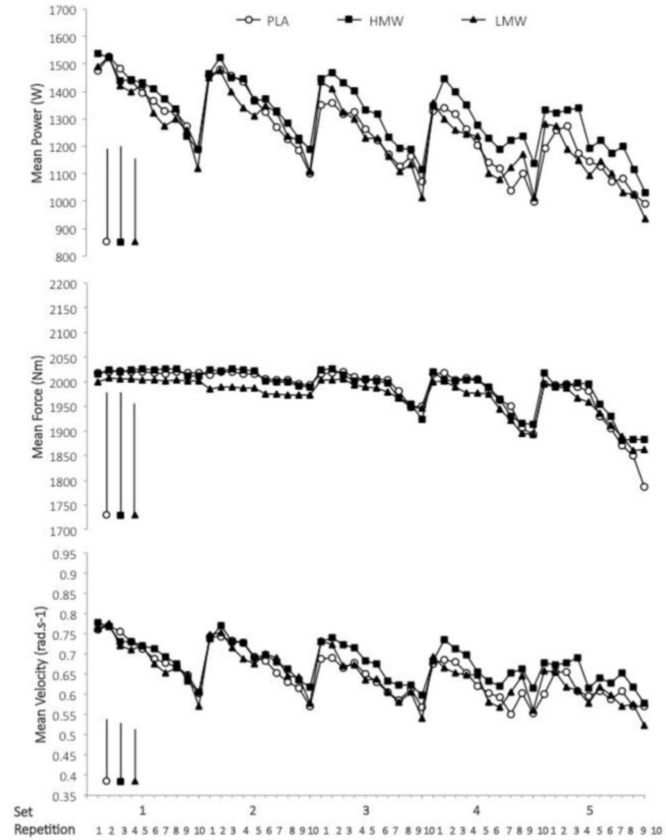
- 16 RT men participated in a DBPCRCO study comprising a muscle-glycogen depleting cycling exercise followed by ingestion of placebo (PLA), or 1.2 g/kg of LMW or HMW carbohydrate solution (10%).
- Participants then performed 5 sets x 10 maximal explosive repetitions of back squat @ 75% of 1RM.
- Compared to PLA, ingestion of HMW (4.9%, 90%CI 3.8%, 5.9%) and LMW (1.9%, 90%CI 0.8%, 3.0%) CHO solutions substantially increased power output during resistance exercise, with the 3.1% (90% CI 4.3, 2.0%) additional gain in power after HMW-LMW ingestion attributed to higher movement velocity after force kinematic analysis (HMW-LMW 2.5%, 90%CI 1.4, 3.7%).
- Both CHO solutions increased post-exercise plasma glucose, glucoregulatory and gut hormones compared to PLA.
- Ingestion of a HMW carbohydrate following prolonged intense endurance exercise provides superior benefits to movement velocity and power output during subsequent repeated maximal explosive resistance exercise.



ISSN Position Stand

Caffeine

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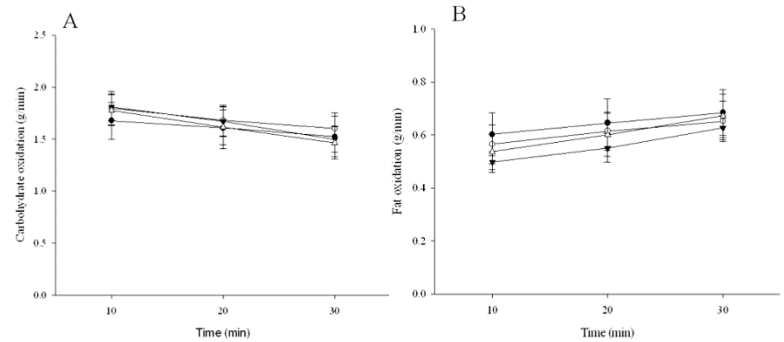
- Caffeine is effective for enhancing sport performance in trained athletes when consumed in low-to-moderate dosages (~3-6 mg/kg)
- Caffeine can enhance vigilance during bouts of extended exhaustive exercise, as well as periods of sustained sleep deprivation.
- Caffeine is ergogenic for sustained maximal endurance exercise, and has been shown to be highly effective for time-trial performance.
- Caffeine supplementation is beneficial for high-intensity exercise, including team sports such as soccer and rugby, both of which are categorized by intermittent activity within a period of prolonged duration.

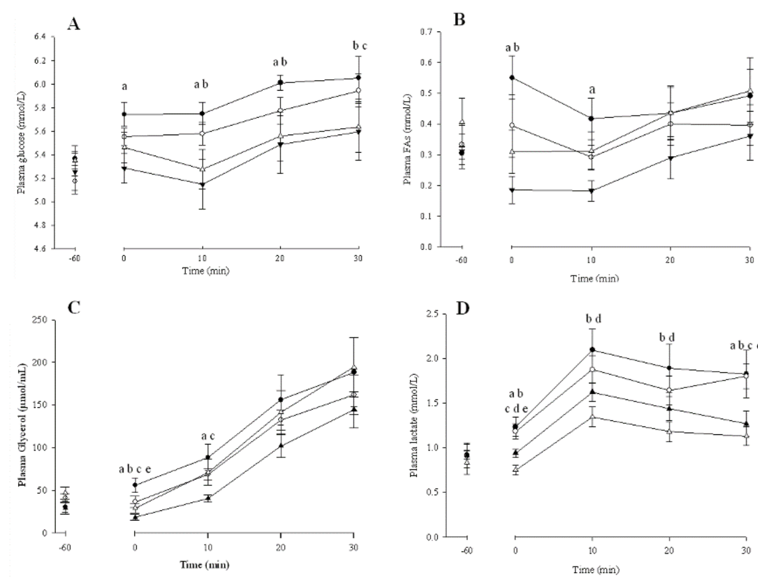
Goldstein et al. JISSN. 7:5, 2010

The metabolic and performance effects of caffeine compared to coffee during endurance exercise

Hodgson et al. PLoS One. 8(4): e59561, 20136

- In a SBCOR study, 8 trained male cyclists/triathletes completed 30 min of steady-state (SS) cycling at approximately 55% VO_{2max} followed by a 45 min energy based target time trial (TT).
- 1 hr prior to exercise, participants consumed drinks consisting of CAF (5 mg CAF/kg BW), instant coffee (5 mg CAF/kg BW), instant decaffeinated coffee or PLA.
- Performance times during the TT were significantly faster (~5.0%) for both caffeine and coffee when compared to PLA and decaf (38.35±1.53, 38.27±1.80, 40.23±1.98, 40.31±1.22 min respectively, $p<0.05$).
- Average power for CAF and coffee during the TT was significantly greater when compared to PLA and decaf (294±21 W, 291±22 W, 277±14 W, 276±23 W respectively, $p<0.05$).
- Both caffeine (5 mg/kg/BW) and coffee (5 mg/kg/BW) consumed 1 h prior to exercise can improve endurance exercise performance.

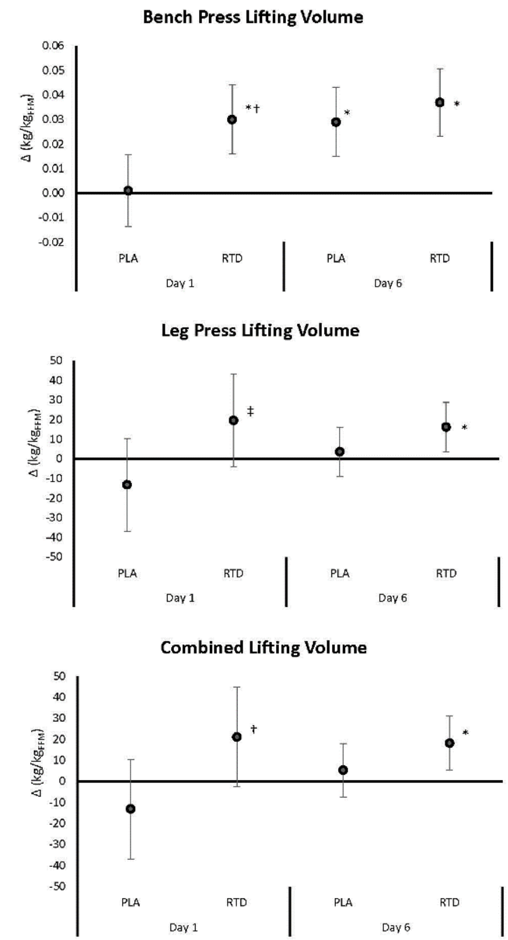




Short-term effects of a ready-to-drink pre-workout beverage on exercise performance and recovery

Collins et al. Nutrients. 8(4):9(8), 823, 2017.

- In a DBRCO manner, 25 RT participants ingested a placebo (PLA) containing or (RTD) containing caffeine (200 mg), β-alanine (2.1 g), arginine nitrate (1.3 g), niacin (65 mg), folic acid (325 mcg), and Vitamin B12 (45 mcg) for 7-days, separated by a 7–10-day.
- On day 1 and 6, participants donated a fasting blood sample and completed a hemodynamic challenge test, 1-RM and muscular endurance tests (3 × 10 repetitions at 70% of 1-RM with the last set to failure on the bench press (BP) and leg press (LP)) followed by ingesting the assigned beverage.
- After 15 min, participants repeated the hemodynamic test, 1-RM tests, and performed a repetition to fatigue (RtF) test at 70% of 1-RM.
- On day 2 and 7, participants donated a fasting blood sample, ingested the assigned beverage, rested 30 min, and performed a 4 km TT.
- Acute RTD ingestion better maintained LP 1-RM, increased LP RtF repetitions, increased BP LV, and, increased TLV.
- Short-term RTD ingestion maintained baseline LP 1-RM , LP RtF repetitions, and LP TLV to a greater degree than PLA.
- No significant differences were observed between treatments in cycling TT performance, hemodynamic assessment, fasting blood panels, or self-reported side effects.



Sodium Phosphate

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- Involved in acid-base balance, energy metabolism, and heart function.
- 4 gm/d x 3 to 6-d of sodium phosphate
- Increases VO_2 max & AT by 5 -10%.
- Effective aid primarily for endurance athletes but may also be helpful for short-duration and/or intermittent high intensity exercise.
- May cause stomach upset and stool softening.

Kerksick et al., JISSN. 15:38, 2018

Sodium Phosphate

Study	Findings
Cade et al. MSSE, 1984	Trained runners – 9% ↑ in VO_2max; ↓ submaximal lactate
Kreider et al. MSSE, 1990	Trained runners - 9% ↑ in VO_2max; 12% ↑ in VANT; NS but 14-s faster 5-mile run time
Stewart et al. Res Q, 1990	Trained cyclists - 9% ↑ in VO2max; 20% ↑ in time to exhaustion
Kreider et al. IJSN, 1992	Trained cyclists & triathletes - 9% ↑ in VO_2max; 10% ↑ in VANT; 17% ↑ in 40km time trial cycling power output; 13% ↑ in Ejection Fraction; 24% ↑ myocardial fractional shortening (2D Echo)

Kerksick et al., JISSN. 15:38, 2018

Effect of sodium phosphate supplementation on repeated high-intensity cycling efforts *Brewer et al. J Sports Sci. 33(11):1109-16, 2015*

- Trained male cyclists were randomized to 6 days of SP supplementation (50 mg/kg FFM/d) or PLA.
- Performance was assessed at baseline and 1 and 4 days post-supplementation on an air-braked cycle ergometer.
- Compared with baseline, the SP group recorded significantly improved ($P < 0.05$) work and mean power output values in both the sprint (baseline, 259 kJ/719 W; day 1, 271 kJ/754 W; day 4, 271 kJ/753 W) and time-trial (baseline, 225 kJ/374 W; day 1, 235 kJ/398 W; day 4, 236 kJ/393 W) aspects of the performance test post-loading.
- No differences were seen in total work or power output in the PLA group.
- ***SP supplementation improved repeated-sprint and time-trial cycling efforts both 1 and 4 days post-loading in trained cyclists.***

Effects of sodium phosphate and caffeine loading on repeated-sprint ability

Buck et al. J Sports Sci. 33(19):1971-9, 2015

- 12 female, team-sport players participated in four trials: 1) SP and CAF; 2) SP and PLA; 3) CAF and PLA; and 4) PLA + PLA with ~21 days separating each trial.
- Participants performed a simulated team-game circuit (4 x 15 min quarters) with 6 x 20-m repeated-sprints performed once before (Set 1), at half-time (Set 2), and after (Set 3).
- Total sprint times were faster after SP and CAF compared with PLA (Set 1: $P = 0.003$; Set 2: $d = -0.51$; Set 3: $P < 0.001$; overall: $P = 0.020$), CAF (Set 3: $P = 0.004$; overall: $P = 0.033$) and SP (Set 3: $d = -0.67$).
- Total sprint times were faster after SP supplementation compared with PLA (Set 1: $d = -0.52$; Set 3: $d = -0.58$).
- Best sprint results were faster after SP and CAF compared with PLA (Set 3: $P = 0.007$, $d = -0.90$) and CAF (Set 3: $P = 0.024$, $d = -0.73$).
- Best sprint times were also faster after SP compared to PLA $d = -0.54$ to -0.61 for all sets).
- ***Sodium phosphate and combined sodium phosphate and caffeine loading improved repeated-sprint ability.***

Effects of sodium phosphate and caffeine ingestion on repeated-sprint ability in male athletes *Kopec et al. J Sci Med Sport. 19(3):272-6, 2016*

- 11 team-sport males participated in four trials: 1) SP (50 mg/kg FFM / d for 6-d) and CAF (6 mg/kg FFM / d) ingested 1h before exercise); 2) SP and PLA; 3) CAF and PLA; and 4) PLA + PLA.
- Participants performed a simulated team-game circuit (STGC) consisting of 2x30min halves, with 6x20-m repeated-sprint sets performed at the start, half-time and end of the STGC.
- SP resulted in the fastest times for all sprints, as supported by moderate to large effect sizes (ES; d=0.51-0.83) and 'likely' to 'very likely' chances of benefit, compared with PLA.
- Compared with CAF, SP resulted in 'possible' to 'likely' chances of benefit for FS, BS and TS for numerous sets and a 'possible' chance of benefit compared with SP+C for BS (set 2).
- Compared with PLA, SP+C resulted in moderate ES (d=0.50-0.62) and 'possible' to 'likely' benefit for numerous sprints, while caffeine resulted in a moderate ES (d=0.63; FS: set 3) and 'likely' chances of benefit for a number of sets.
- Results suggest that ***SP supplementation may improve repeated-sprint performance when compared with PLA.***

Beet Root Juice/Nitrates

- Larsen et al. (*Acta physiologica. 2007;191:59–66*) reported a ***reduction in maximal oxygen consumption***; and a trend for improvement in time-to-exhaustion accompanying the ingestion of sodium nitrate intake at 0.1 mmol/kg/day for three days.
- Larsen et al. (*Free Radic Biol Med. 2010;48:342–7*) reported a *significant reduction in oxygen consumption and improvement in gross efficiency at sub-maximal workloads* using the same ingestion schema.
- Bescos et al., (*Med Sci Sports Exerc. 2011;43:1979–86*) found that the consumption of 10 mg/kg of sodium nitrate prior to a cycle ergometer test ***reduced VO_2peak without influencing time to exhaustion or maximal power output in highly trained cyclist and triathletes.***

Inorganic nitrate supplementation improves muscle oxygenation, O(2) uptake kinetics, and exercise tolerance at high but not low pedal rates

Bailey et al. J Appl Physiol. 118(11):1396-405, 2015

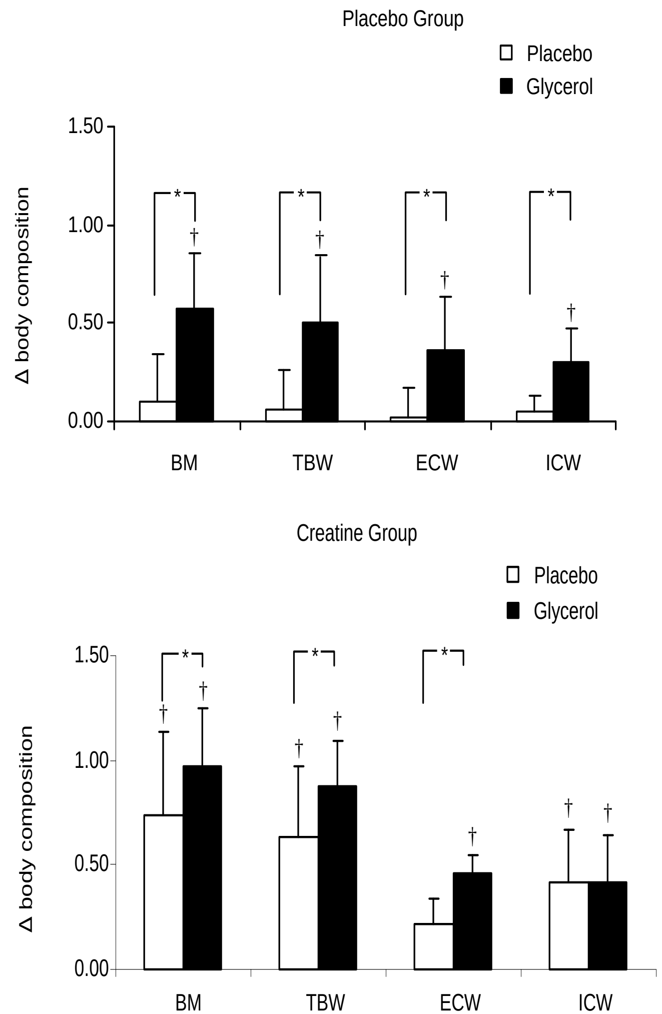
- 7 subjects completed ***severe-intensity step cycle tests at pedal cadences of 35 rpm and 115 rpm*** during separate 9-d supplementation periods with NO_3- rich beetroot juice (BR) (providing 8.4 mmol NO_3-/d) and PLA.
- Compared with PLA, ***plasma nitrite concentration increased 178% with BR*** ($P < 0.01$).
- There were no significant differences in muscle oxyhemoglobin concentration ([O_2Hb]), phase II Vo_2 kinetics, or Tlim between BR and PLA when cycling at 35 rpm ($P > 0.05$).
- ***When cycling at 115 rpm, muscle [O_2Hb] was higher at baseline and throughout exercise, phase II Vo_2 kinetics was faster*** (47 +/- 16 s vs. 61 +/- 25 s; $P < 0.05$), and ***Tlim was greater*** (362 +/- 137 s vs. 297 +/- 79 s; $P < 0.05$) with BR compared with PLA.
- Results suggest that ***short-term BR supplementation can increase muscle oxygenation, expedite the adjustment of oxidative metabolism, and enhance exercise tolerance when cycling at a high, but not a low, pedal cadence.***

Nitrate intake promotes shift in muscle fiber type composition during sprint interval training in hypoxia *De Smet et al. Front Physiol. 7: 233, 2016*

- ***27 moderately-trained participants*** were allocated to one of three experimental groups: ***Sprint Interval Training (SIT) in normoxia (20.9% FiO_2) + PLA (N), SIT in hypoxia (15% FiO_2) + PLA (H), or SIT in hypoxia + nitrate (HN).***
- All participated in 5 weeks of SIT on a cycle ergometer (30-s sprints interspersed by 4.5 min recovery-intervals, 3 weekly sessions, 4-6 sprints per session).
- Nitrate (6.45 mmol $NaNO_3$) or placebo capsules were administered ***3 h before each session***.
- SIT decreased the proportion of type IIx muscle fibers in all groups ($P < 0.05$).
- The relative number of type IIa fibers increased ($P < 0.05$) in HN ($P < 0.05$ vs. H), but not in the other groups.
- Compared with H, SIT tended to enhance 30-s sprint performance more in HN than in H ($P = 0.085$).
- ***SIT in hypoxia combined with nitrate supplementation increases the proportion of type IIa fibers in muscle, which may be associated with enhanced performance in short maximal exercise.***

Creatine and glycerol hyperhydration in trained subjects before exercise in the heat *Easton et al. Int J Sport Nutr Exerc Metab. 17(1):70-91, 2007.*

- 24 subjects ingested 11.4 g/d of CrM or placebo (PLA) twice daily for 7-d with and without 1 g of Gly/kg (twice daily)
- Exercise trials were conducted pre- and post-supplementation at 30°C and 70% RH.
- In the Pl group, total body water (TBW) increased by 0.50 +/- 0.28 L after Gly and in the Cr group by 0.63 +/- 0.33 L after Pl and by 0.87 +/- 0.21 L after Gly.
- Both Cr/Pl and Cr/Gly resulted in significantly attenuated heart rate, rectal temperature, and perceived effort during exercise, although no regimen had any effect on performance.
- The addition of Gly to Cr significantly increased TBW more than Cr alone (P=0.02) but did not further enhance the attenuation in HR, Tre, and RPE during exercise.
- These data suggest that combined Cr and Gly is an effective method of hyperhydration capable of reducing thermal and cardiovascular responses.



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Recovery Nutrition

Recovery Nutrition

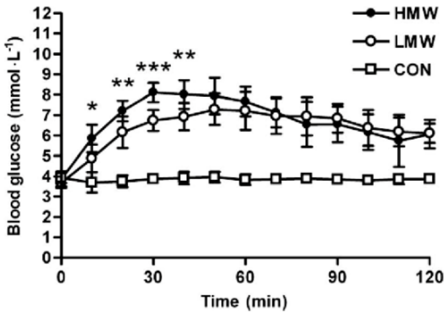
Considerations

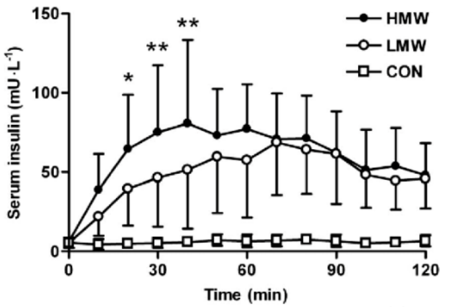
- Rehydration
- Glycogen replenishment
- Protein for synthesis
- Creatine
- Anti-inflammatory nutrients
    - Tart cherries
    - Nitrates
- Nutrients that support the immune system

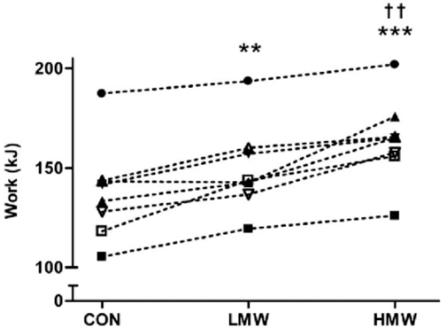
Post-exercise ingestion of a unique, high molecular weight glucose polymer solution improves performance during a subsequent bout of cycling exercise

Stephens et al. J Sports Sci. 26(2):149-54, 2008

- 8 healthy men cycled to exhaustion at 73.0% (s = 1.3) maximal oxygen uptake (90:15 min).
- Immediately after this, participants consumed a one-liter solution containing sugar-free flavoured water (control), 100 g of a low molecular weight glucose polymer or 100 g of a very high molecular weight glucose polymer, and rested on a bed for 2 h.
- After recovery, a 15-min time-trial was performed on a cycle ergometer, during which work output was determined.
- Post-exercise ingestion of the very high molecular weight glucose polymer solution resulted in faster and greater increases in blood glucose ($P < 0.001$) and serum insulin ($P < 0.01$) concentrations than the low molecular weight glucose polymer solution, and greater work output during the 15-min time-trial (164.1 kJ, s = 21.1) than both the sugar-free flavoured water (137.5 kJ, s = 24.2; $P < 0.05$) and the low molecular weight glucose polymer (149.4 kJ, s = 21.8; $P < 0.05$) solutions.
- These findings could be of practical importance for athletes wishing to optimize performance by facilitating rapid re-synthesis of the muscle glycogen store during recovery following prolonged sub-maximal exercise.

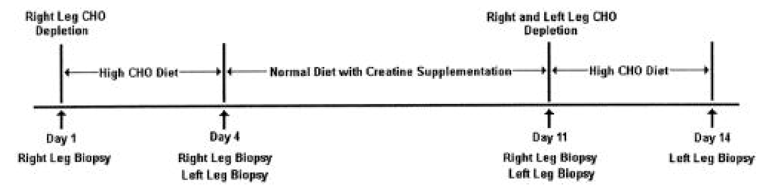


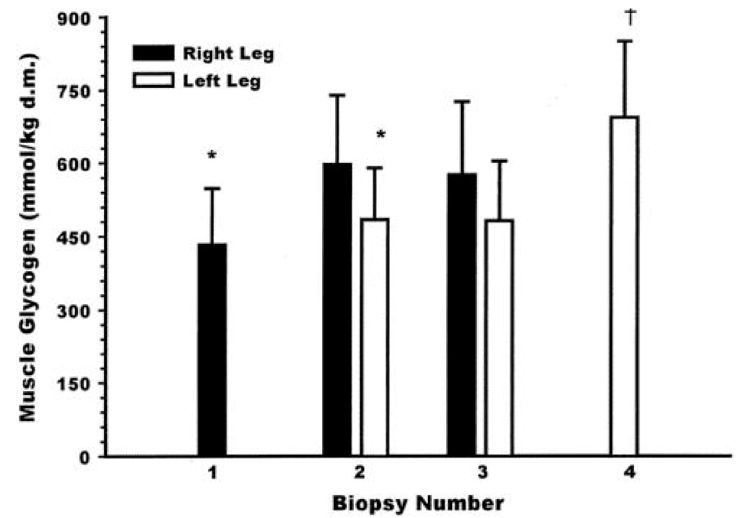




Muscle glycogen supercompensation is enhanced by prior creatine supplementation *Nelson et al. Med Sci Sports Exerc. 33(7):1,096-1,100, 2001.*

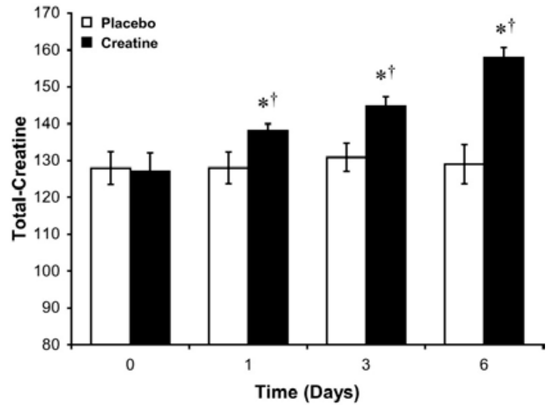
- 12 men performed two standard glycogen loading protocols interspersed with a standard creatine load of 20 g/d for 5 d.
- The initial glycogen loading protocol increased muscle glycogen by 4% with no change in total muscle creatine.
- Creatine loading showed significant increases in total muscle creatine levels in both the left leg (+ 41.1±31.1 mmol/kg DM) and the right leg (+36.6±19.8 mmol/kg DM with no change in either leg's muscle glycogen content.
- After the final glycogen loading, a significant 53% increase in muscle glycogen (+241±150 mmol/kg DM) was detected.
- The postcreatine load total glycogen content (694±156 mmol/kg DM) was significantly greater than the precreatine load total glycogen content (597±142 mmol/kg DM).
- Results reveal that a ***muscle's glycogen loading capacity is influenced by its initial levels of creatine*** and the accompanying alterations in cell volume.

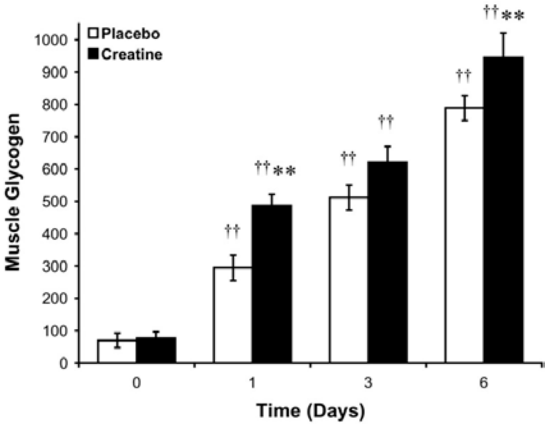




Creatine ingestion augments dietary carbohydrate mediated muscle glycogen supercompensation during the initial 24 h of recovery following prolonged exhaustive exercise in humans *Roberts et al Amino Acids. 48(8):1831-42, 2016*

- 14 healthy, male volunteers cycled to exhaustion at 70 % VO_{2peak}.
- Muscle biopsies were obtained at rest immediately post-exercise and after 1, 3 and 6 days of recovery, during which Cr or placebo supplements (20 g/d) were ingested along with a prescribed high CHO diet (37.5 kcal/kg/d, >80 % calories CHO).
- Oral-glucose tolerance tests (oral-GTT) were performed pre-exercise and after 1, 3 and 6 days of Cr and placebo supplementation.
- Exercise depleted muscle glycogen content to the same extent in both treatment groups.
- Creatine supplementation increased muscle total-Cr, free-Cr and phosphocreatine (PCr) content above placebo following 1, 3 and 6 days of supplementation (all $P < 0.05$).
- Creatine supplementation also increased muscle glycogen content noticeably above placebo after 1 day of supplementation ($P < 0.05$), which was sustained thereafter.
- This study confirmed dietary Cr augments post-exercise muscle glycogen super-compensation, and demonstrates this occurred during the initial 24 h of post-exercise recovery (when muscle total-Cr had increased by <10 %)

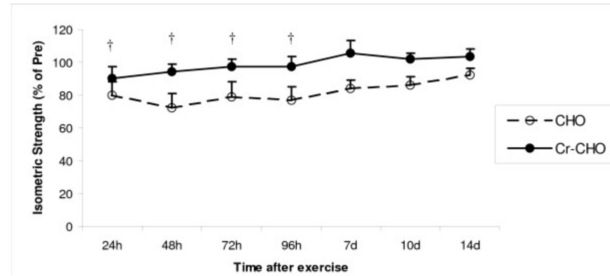


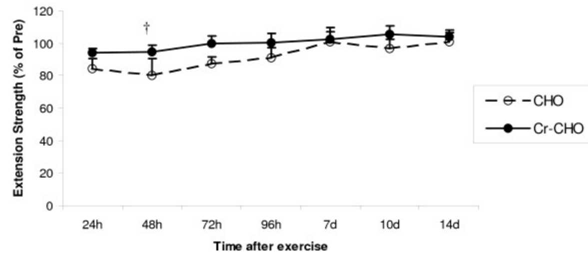


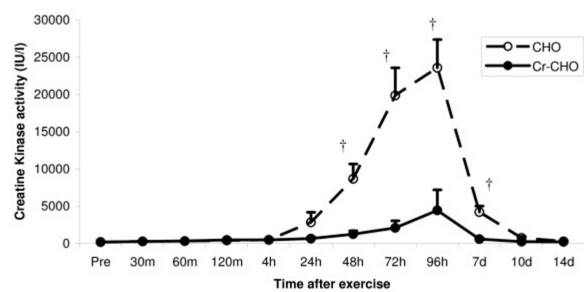
Creatine supplementation enhances muscle force recovery after eccentrically-induced muscle damage in healthy individuals

Cooke et al. J Int Soc Sports Nutri. 6:13, 2008.

- 14 untrained males were randomly assigned to ingest 0.3 g/kg/d of CM with CHO for 5-d and 0.1 g/kg/d of CM with CHO for 14 days or a CHO placebo.
- After 5-d of supplementation, performed ***4 x 10 eccentric-only repetitions at 120% of their 1-RM*** max on the leg press, leg extension and leg flexion exercise machine.
- Plasma CK and LDH activity were assessed as relevant blood markers of muscle damage.
- The Cr-supplemented group had ***significantly greater isokinetic (10% higher) and isometric (21% higher) knee extension strength during recovery*** from exercise-induced muscle damage.
- ***Plasma CK activity was significantly lower (by an average of 84%) after 48 hrs, 72 hrs, 96 hrs, and 7 days recovery*** in the Cr group.
- ***Creatine improved the rate of recovery of knee extensor muscle function after injury***.







The effects of creatine supplementation on muscular performance and body composition responses to short-term resistance training overreaching

Volek et al. Eur J Appl Physiol. 91(5-6):628-37, 2004.

- 17 men were randomly assigned to supplement with 0.3 g/kg per day of CM (n=9) or placebo (n=8) while performing ***resistance exercise (5 days/week for 4 weeks) followed by a 2-week taper phase***.
- 1RM squat and BP and explosive power in the BP were reduced during training in P but not CM.
- Explosive power in the BP, body mass, and LBM in the legs were augmented to a greater extent in CM by the end of the 6-week period.
- A tendency for greater 1-RM squat improvement (P=0.09) was also observed in CM.
- Changes were not related to changes in circulating hormone concentrations obtained in the resting, postabsorptive state.
- ***CM was effective for maintaining muscular performance during the initial phase of high-volume resistance training overreaching*** that otherwise results in small performance decrements.

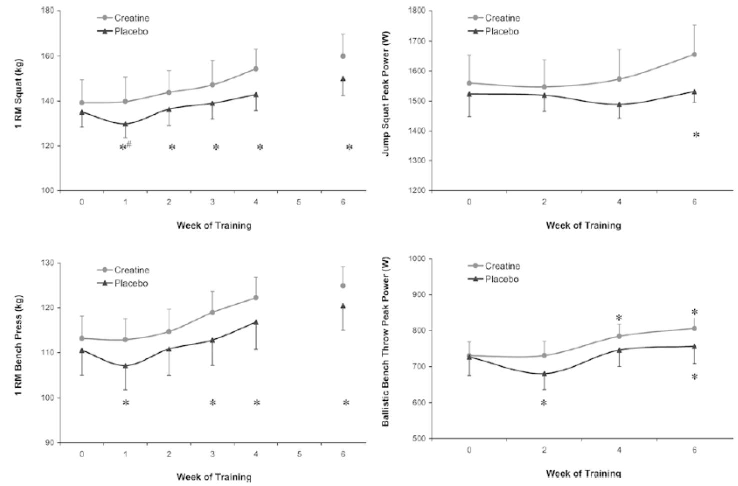


Table 5 Blood metabolite responses in subjects supplemented with creatine monohydrate (*CrM*) or placebo (*P*). Values are mean (SD). *CK* Creatine kinase, *TC* total cholesterol, *TG* triglycerides, *Hb* hemoglobin, *Hct* hematocrit

		Week 0	Week 1	Week 2	Week 3	Week 4	Main time effect	Group×time
Uric acid (mg/dl)	CrM	6.1 (1.3)	5.4 (1.5)**	5.3 (1.6)**	5.1 (1.4)**	5.0 (1.4)**	0.000	0.002
	P	6.1 (1.6)	7.2 (2.4)**	6.6 (1.7)	6.1 (1.7)	5.6 (1.8)		
Ammonia (μmol/l)	CrM	42.8 (19.1)	24.1 (21.3)*	23.8 (18.0)*	34.5 (17.4)	27.0 (19.0)	0.000	0.424
	P	38.2 (18.4)	20.5 (13.3)	17.1 (5.0)	35.5 (18.7)	37.2 (13.2)		
CK (IU/l)	CrM	91 (69)	836 (920)*	242 (124)	228 (146)	142 (74)	0.000	0.617
	P	72 (38)	1297 (1630)	177 (79)	162 (106)	88 (47)		
Glucose (mg/dl)	CrM	95.4 (10.5)	87.1 (7.2)*	92.8 (7.2)*	88.5 (6.3)*	90.4 (7.0)*	0.000	0.472
	P	97.9 (8.9)	90.0 (10.0)	92.8 (9.3)	89.0 (8.6)	88.2 (4.5)		
TC (mg/dl)	CrM	190 (38)	181 (38)	187 (45)	189 (41)	193 (30)	0.406	0.430
	P	189 (46)	181 (38)	191 (36)	180 (35)	180 (51)		
TG (mg/dl)	CrM	81 (31)	69 (32)	82 (40)	89 (42)	92 (44)	0.292	0.127
	P	126 (91)	99 (74)	126 (94)	102 (59)	90 (63)		
Hb (g/dl)	CrM	15.2 (1.0)	15.1 (1.2)*	14.9 (1.0)*	14.7 (0.9)*	14.9 (0.8)*	0.005	0.192
	P	15.7 (1.1)	14.6 (1.0)	15.0 (0.6)	14.8 (1.0)	14.8 (0.6)		
Hct (%)	CrM	44.9 (2.4)	42.2 (1.9)*	42.3 (1.9)*	43.1 (1.9)*	43.2 (1.5)*	0.000	0.957
	P	44.4 (2.0)	41.3 (2.4)	42.0 (1.6)	42.4 (2.0)	42.8 (1.3)		
Creatinine (mg/dl)	CrM	1.65 (0.09)	1.74 (0.09)**	1.76 (0.13)**, ***	1.77 (0.09)**, ***	1.79 (0.13)**, ***	0.005	0.000
	P	1.60 (0.07)	1.60 (0.07)	1.54 (0.04)	1.57 (0.03)	1.61 (0.06)		

*Significantly different ($P \leq 0.05$) from week 0 value for collapsed group means
**Significantly different ($P \leq 0.05$) from week 0 value for corresponding CrM or P group
***Significantly different ($P \leq 0.05$) from corresponding value for P group

The effect of creatine supplementation upon inflammatory and muscle soreness markers after a 30km race *Santos et al. Life Sci. 75(16):1917-24, 2004.*

- 34 experienced marathon runners were supplemented for 5 days prior to the 30km race with 4 x 5g of creatine and 15g/d of maltodextrin while the control group received the same amount of maltodextrin.
- Pre-race and 24-hour post blood samples were collected
- Athletes from the control group presented an increase in plasma CK (4.4-fold), LDH (43%), PGE2 6.6-fold) and TNF-alpha (2.34-fold) concentrations
- ***Creatine attenuated the changes observed for CK (by 19%), PGE2 and TNF-alpha (by 60.9% and 33.7%, respectively) and abolished the increase in LDH*** plasma concentration observed after running 30km.
- The athletes did not present any side effects such as cramping, dehydration or diarrhea, neither during the period of supplementation, nor during the 30km race.

Table 2
Creatine kinase (CK), lactate dehydrogenase (LDH), prostaglandin E_2 (PGE_2), tumour necrosis factor-alpha (TNFα) and creatinine plasma concentrations measured immediately before and 24h after a 30km running, in the plasma obtained from athletes subjected to a placebo (Con, n = 16) or a creatine supplementation protocol (CR, n = 18)

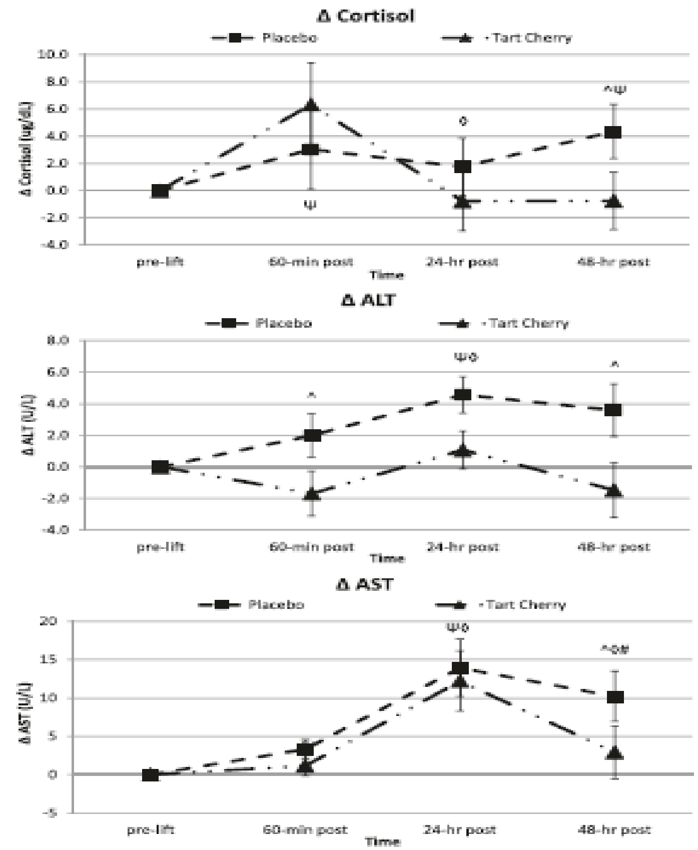
	Con Before	Con After	Cr Before	Cr After
CK (U/l)	48.26 ± 27.28	213.19 ± 113.60*	32.17 ± 16.42	170.95 ± 61.82*
LDH (U/l)	208.9 ± 17.6	298.7 ± 23.6*	198.7 ± 13.5	185.3 ± 21.5#
PGE2 (pg/ml)	42.76 ± 4.95	329.35 ± 17.96*	47.12 ± 8.76	110.42 ± 12.38*#
TNFα (pg/ml)	91.18 ± 7.55	213.76 ± 15.05*	97.77 ± 9.24	141.6 ± 3.32*#
Creatinine (mg/dl)	0.22 ± 0.03	0.34 ± 0.09	0.31 ± 0.05	0.41 ± 0.07

The results are expressed as mean ± SEM of 23 samples.
* $p < 0.05$ for comparison with the values obtained before the exercise bout.
\# $p < 0.05$ for comparison with the values obtained for the control group. The observed power was 1,00 for LDH, PGE_2 and TNFα.

Effects of powdered Montmorency tart cherry supplementation on an acute bout of intense lower body strength exercise in resistance trained males

Levers et al. JISSN. 12:41, 2015

- 23 resistance-trained men were randomly assigned to ingest, in a double blind manner, capsules containing 480 mg/d of a PL or powdered tart cherries (TC) for 10-d prior to and for 48-h post-exercise.
- Subjects performed 10 sets of 10 reps at 70% of a 1-RM back squat exercise after 10-d of supplementation.
- Fasting blood samples, isokinetic MVCs, and quadriceps muscle soreness ratings were taken pre-lift, 60-min, 24-h, and 48-h post-lift.
- *TC supplementation attenuated muscle soreness, strength decrement during recovery, and markers of muscle catabolism in resistance trained individuals.*

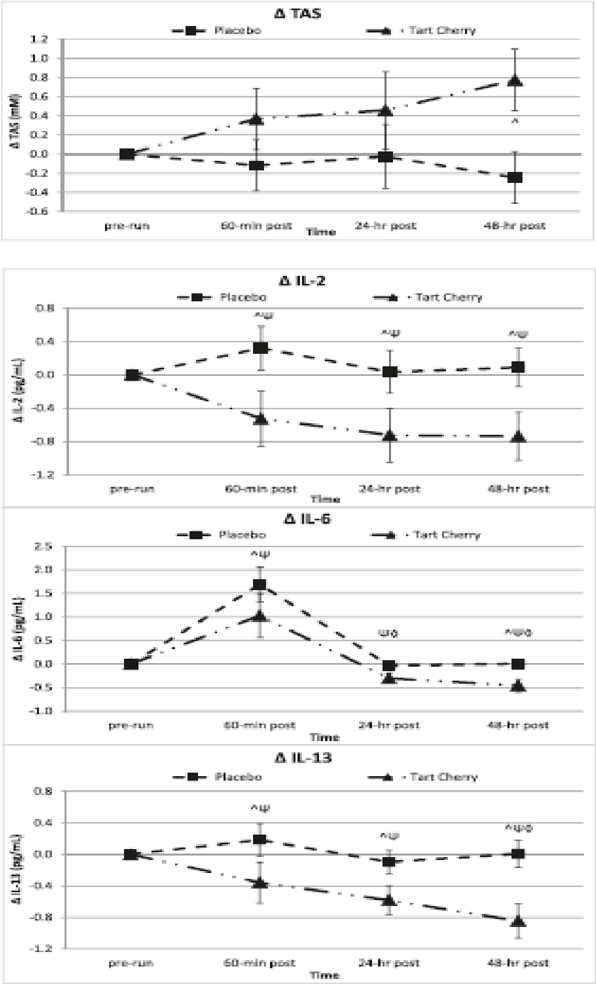


Effects of powdered Montmorency tart cherry supplementation on acute endurance exercise performance in aerobically trained individuals

Levers et al. JISSN. 13:22, 2016

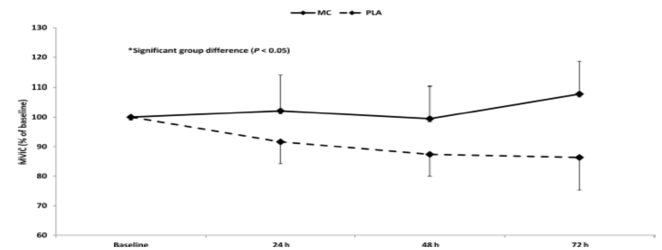
EXERCISE & SPORT NUTRITION LABORATORY
TEXAS A&M UNIVERSITY

- 27 endurance-trained athletes ingested, in a double-blind manner, capsules containing 480 mg of PL or powdered TC for 10-d prior to performing a half marathon and for 48-hr post-run.
- Fasting blood samples and quadriceps muscle soreness ratings were taken pre-run, 60-min, 24 and 48-h post-run.
- *TC supplementation attenuated markers of muscle catabolism, reduced immune and inflammatory stress, better maintained redox balance, and increased performance in aerobically trained individuals.*



Recovery facilitation with Montmorency cherries following high-intensity, metabolically challenging exercise *Bell et al. Appl Physiol Nutr Metab. 40(4):414-23, 2015*

- 16 trained cyclists consumed 30 mL of PL or MC twice per day for 8-d.
- On day 5. participants completed a 109-min cycling trial designed to replicate road race demands.
- Functional performance (MVIC) cycling efficiency, 6-s peak cycling power) and DOM were assessed at baseline, 24, 48, and 72 h post-trial.
- Blood samples collected at baseline, immediately pre- and post-trial, and at 1, 3, 5, 24, 48, and 72 h post-trial.
- MVIC ($P < 0.05$) did not decline in the MC group (vs. PLA) across the 72-h post-trial period and economy ($P < 0.05$) was improved in the MC group at 24 h.
- IL-6 ($P < 0.001$) and hsCRP ($P < 0.05$) responses to the trial were attenuated with MC (vs. PLA).
- ***MC concentrate can be an efficacious functional food for accelerating recovery and reducing exercise-induced inflammation following strenuous cycling exercise.***



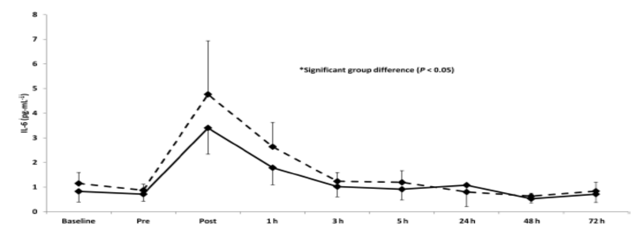
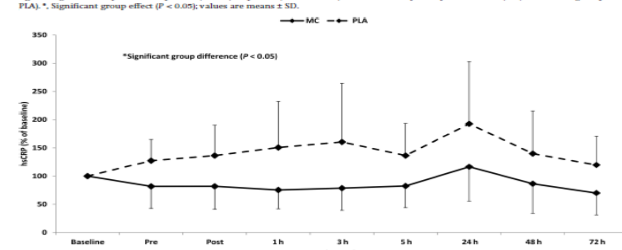
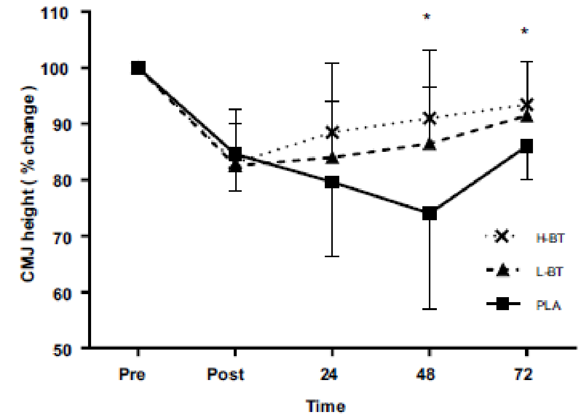


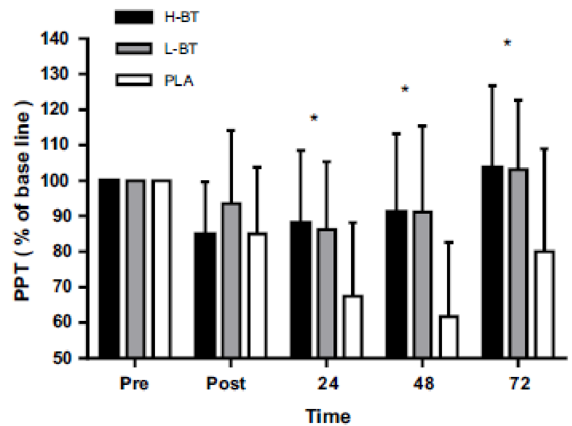
Fig. 5. High-sensitivity C-reactive protein (hsCRP) responses (% of baseline) to Montmorency cherry concentrate (MC) and isoenergetic placebo PLA). *, Significant group effect ($P < 0.05$); values are means ± SD.



The effects of beetroot juice supplementation on indices of muscle damage following eccentric exercise *Clifford et al. EJAP. 116(2): 2016*

- 30 males consumed high-dose BRJ (H-BT; 250 ml), a lower dose of BRJ (L-BT; 125 ml), or PLA immediately (x3 servings), 24 (x2 servings) and 48 h (x2 servings) following completion of 100-drop jumps.
- Maximal isometric voluntary contractions (MIVC), countermovement jumps (CMJ), pressure pain threshold (PPT), creatine kinase (CK), interleukin-6 (IL-6), interleukin-8 (IL-8) and tumour necrosis factor-alpha (TNF-alpha) were measured pre, post, 2 (blood indices only), 24, 48 and 72 h following the drop jumps.
- Acute BRJ supplementation attenuated muscle soreness and decrements in CMJ performance induced by eccentric exercise while MIVC, CK, IL-6, TNF-alpha and IL-8 were not affected.

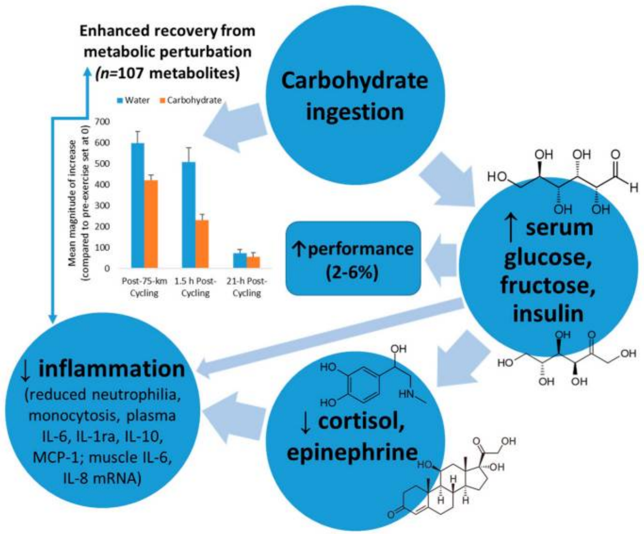




Potential impact of nutrition on immune system recovery from heavy exertion: a metabolomics perspective

Nieman et al. Nutrients. 9(5): 2017

- The most effective nutritional countermeasures, especially when considered from a metabolomics perspective, include acute and chronic increases in dietary ***carbohydrate*** and ***polyphenols***.
- Carbohydrate supplementation reduces post-exercise stress hormone levels, inflammation, and fatty acid mobilization and oxidation.
- Ingestion of fruits high in carbohydrates, polyphenols, and metabolites effectively supports performance, with added benefits including enhancement of oxidative and anti-viral capacity through fruit metabolites, and increased plasma levels of gut-derived phenolics.
- Future targeted lipidomics-based studies will help discover whether ***n-3-polyunsaturated fatty acid (n-3-PUFA)*** supplementation enhances inflammation resolution in athletes post-exercise.



Performance Enhancement Nutrition

Summary

- Strength/Power/Sprint Athletes
  - Moderate to High CHO/PRO diet
  - Water/GES
  - Post-Exercise PRO
  - Creatine
  - β-alanine
  - Sodium Bicarbonate
  - Nitrates (Beet Root Juice)
- Endurance Athletes
  - High CHO diet/CHO loading
  - Water/GES
  - Caffeine
  - Sodium Phosphate
  - Nitrates (Beet Root Juice)
  - Creatine
- Recovery Nutrition
  - Rehydrate
  - CHO
  - Post-Exercise PRO/EAA
  - Creatine
  - Tart Cherry
  - Nitrates (Beet Root Juice)

Kerksick et al., JISSN. 15:38, 2018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