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Nutritional Considerations for Bouldering

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Bouldering competitions are held up to International level and governed by the International Federation of Sport Climbing. Bouldering has been selected to feature at the 2020 Olympic Games in Tokyo, however, physiological qualities and nutritional requirements to optimize performance remain inadequately defined due to large gaps in the literature. The primary goals of training include optimizing the capacity of the anaerobic energy systems and developing sport-specific strength, with emphasis on the isometric function of the forearm flexors responsible for grip. Bouldering athletes typically possess a lean physique, similar to the characteristics of sport climbers with reported body fat values of 6–12%. Athletes strive for a low body weight to improve power to weight ratio and limit the load on the extremities. Specialized nutritional support is uncommon and poor nutritional practices such as chronic carbohydrate restriction are prevalent, compromising the health of the athletes. The high intensity nature of bouldering demands a focus on adequate carbohydrate availability. Protein intake and timing should be structured to maximize muscle protein synthesis and recovery, with the literature suggesting 0.25–0.3 g/kg in 3–4 hr intervals. Supplementing with creatine and b-alanine may provide some benefit by augmenting the capacity of the anaerobic systems. Boulderers are encouraged to seek advice from nutrition experts to enhance performance, particularly important when weight loss is the desired outcome. Further research is warranted across all nutritional aspects of bouldering which is summarized in this review.

***Keywords**:* bouldering, nutrition, physical performance, sport, weight loss

Rock climbing was once a fringe activity pursued by outdoorsmen; however, it is now an established sport with growing international recognition and that has been selected to feature at the Tokyo 2020 Olympic Games. It is estimated that 25 million people climb regularly, with athletes from 52 countries representing five continents competing in 2014 (IFSC, 2016). Bouldering, once primarily used as a training method, is now a well-established discipline of rock climbing with specialist training facilities and competitions. Unlike other forms of climbing, bouldering is performed rope-less with spotters and crash mats for protection, and indoor walls typically do not exceed 4 m in height. Bouldering routes, or "problems," feature a short sequence of unique and powerful moves that often require the athlete to support the full body mass on small parts of the fingers or toes. Difficulty or grading is manipulated using factors such as steepness and varying the size, shape, and positioning of the holds. The physical demands include high levels of specific isometric and dynamic strength, and a physique specifically developed to optimize power, while limiting the load on the extremities. Although no studies have assessed energy needs in boulderers, the metabolic demands are likely to differ depending on the training goal and duration, with sessions lasting several hours. Governed by the International Federation of Sport Climbing (IFSC), bouldering competitions are held up to International level, with annual World Cup competitions featuring 6–8 events and single event World Championships every other year. Competitions generally consist of three rounds (qualifying, semifinals & finals), with a maximum of 2 rounds per day, each with 4–5 problems to be attempted. Each problem is comprised of 4–8 handholds and multiple attempts are allowed within a 4–5 min period. A successful ascent typically requires around 40 s to complete (White & Olsen, 2010) and 4–5 min of rest are allowed between each boulder; with the exception of finals, where there may be up to 30 min between attempts.

Despite the development of bouldering into an elite sport, there have been no studies to date investigating the nutritional demands, and consequently, there is no consensus on requirements. Therefore, athletes often base their nutritional strategies on habits of experienced or successful athletes in the sport. However, research has shown inadequate energy availability, unbalanced food quality, and poor nutrient timing in the diets of elite climbers (Zapf et al., 2001). Consequently, this paper aims to explore the physiological demands of bouldering, the nutritional considerations to maximize performance, and directions for future research.

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Method

Articles were retrieved in accordance with an extensive search in several databases including MEDLINE (1966–2016); SPORTDiscus (1966–2016); PubMed (1966–2016) and Google Scholar (1980–2015). The following search terms were used in various combinations: recovery, nutrition, diet, food, climbing, bouldering, grip strength, hydration, supplements, ergogenic aids, glycogen re-synthesis, refuelling, repair, adaptation. Articles were selected based on their relevance and application to climbing and bouldering. References cited in the retrieved articles were also considered.

Physiological Demands of Bouldering

Energy Systems. Due to lack of scientific interest in the area, key training and physiological qualities required to produce an elite bouldering athlete remain inadequately defined. Due to the high-intensity and short duration nature of bouldering, there is an assumed predominant reliance on the anaerobic energy systems to perform. The rapid, high force contractions used in bouldering might initially rely on alactic metabolism for adenosine triphosphate (ATP) production; however, after just 10 s of repeated maximal isometric contractions, the yield of ATP from phosphocreatine (PCr) hydrolysis is reduced by more than 50% (Hultman et al., 1991). Successful ascents in elite competitive bouldering last an average of 40 s (White & Olsen, 2010), with rarely an opportunity to rest or allow adequate recovery in between holds. Therefore, there is likely to be an increased contribution from the lactic acid system to maintain power output, resulting in increased blood lactate concentration. Capillary blood lactate samples collected directly after two elite level national bouldering competition performances report mean peak levels from 6.2 ± 0.9–6.9 ± 1.2 mmol/L (La Torre et al., 2009). Similarly, in the longer duration discipline of sport climbing, mean blood lactate concentrations have been reported between 4.5–6.8 mmol/L postclimb (Watts, 2004).

Climbing Specific Strength. The upward propulsion during climbing typically relies on the ability to sustain powerful, intermittent forearm muscle contractions with a substantial, yet less intense, contribution of the lower limbs (Sheel et al., 2003). In modern sport climbing, one of the main limiting factors to performance is the anaerobic strength endurance of the forearm flexor muscles responsible for grip (Schöffl et al., 2006). The intermittent isometric contractions in these muscles that occur during bouldering may occlude blood flow to the active musculature leading to a disproportionate rise in heart rate in comparison with oxygen consumption, as demonstrated in sport climbing (Sheel et al., 2003). This effect is greater with increasing levels of climbing difficulty, where there is an increased reliance on anaerobic metabolism. Conversely, Ferguson and Brown (1997) found an enhanced vasodilatory capacity in the forearms of trained rock climbers attenuating this mechanism. During a simulated bouldering competition, heart rate was recorded in the range of 70–85% HR_{max} for 25.9% of the time and between 86–100% HR_{max} for 12% of the time in elite subjects, indicating significant engagement of the cardiovascular system (La Torre et al., 2009).

Due to the large demand placed on the hands and forearm flexors of climbers, handgrip strength in relation to body mass has been consistently reported to be significantly greater in comparison with nonclimbers (Watts, 2004). Finger flexor strength data collected from highly trained male boulderers is consistent with these findings, achieving the highest recorded values (494 ± 64 vs. 383 ± 79 N, $p = .001$) of any climbing specific study to date (Macdonald & Callender, 2011). Fanchini et al. (2013) found that isometric maximal voluntary contraction force (MVC) and rate of force development (RFD) were significantly greater in competitive male boulderers compared with lead climbers in crimp and open-crimp positions; similar findings were later reported by Laffaye et al. (2015). It was reported that the largest discriminatory outcome between the two groups was the RFD, which may reflect a unique requirement in bouldering, as high levels of rapid force generation is required by the finger flexors to stabilize the body following dynamic movements (Watts, 2004). Furthermore, the specific strength of the finger and hand bones are closely correlated with climbing styles that emphasize athletic difficulty, with the highest levels observed in sport climbing and bouldering (Sylvester et al., 2010); emphasizing the effect of the high mechanical load on the hands of boulderers. Handgrip strength has been shown to decline with increasing levels of blood lactate (Watts et al., 1996), which may provide a useful marker of climbing fatigue.

Aerobic Capacity. While the predominant energy source during bouldering is likely to be derived from the anaerobic pathways, it should be acknowledged that an elite individual training for many hours will largely rely on the oxidative system for continued muscle contraction and recovery from high-intensity bouts of exercise (Sheel et al., 2003).

There is currently no research outlining the aerobic capacity of boulderers, although studies that have examined sport climbers have reported values averaging between 52–55 ml/kg/min for maximum oxygen uptake (Watts, 2004). However, these studies have measured this using protocols that use the lower body on cycle ergometers or treadmills which is clearly a limitation as it lacks specificity to climbing. More recently, researchers have acknowledged that these methods neglect the use of upper-body musculature predominantly responsible for climbing performance and have developed an incremental maximal upper-body ergometer test (UBT) to evaluate climbers' aerobic fitness and sport-specific work capacity, performed on a vertically mounted rowing ergometer (Michailov et al., 2015). While studying sport climbers, Michailov et al. (2015) found UBT aerobic and work capacity results were strongly correlated to climbing-performance variables and reflected sport-specific fatigue, whereas treadmill results were not. Positive effects of nonspecific, aerobic based endurance training have been demonstrated to promote recovery in the forearms following anaerobic strength endurance tests (Schöffl et al., 2006), although it would seem more appropriate for climbing athletes to choose a form of exercise that will enhance upper body aerobic capacity to gain the most benefit.

Considering all of the physiological factors, a specific training program for elite level bouldering should include components for optimizing the capacity and power of the PCr and anaerobic glycolysis systems, developing reasonably high levels of upper body aerobic power, and sport specific muscular strength and endurance.

Optimal Physique

Anthropometric Characteristics. Anthropometric data obtained from the studies investigating the related discipline of sport climbing suggest that the athletic profile optimal for performance is a positive ape index, low body mass, small stature, and low body fat (Mermier et al., 2000;Watts, 2004; Giles et al., 2006; Laffaye et al., 2015). However, there are significant differences between the two styles of climbing so differences in the athletic profile are to be expected. Sport climbing involves increased ascent duration of 2–7 min and a route length up to 18 m. White and Olsen (2010) suggested that the strength requirements of bouldering are greater than sport climbing due to the shorter duration, greater number of attempts at each problem, and the lower time spent in a static position (25% vs 38%). Due to the strength nature of bouldering, it could be assumed that boulderers are required to be more muscular than other climbing athletes; however, a very high lean mass could have a detrimental effect on performance as excessive muscular hypertrophy will increase total body mass beyond the potential relative strength capacity of the finger flexors. With consideration to this issue, it has been suggested that boulderers should train to promote muscle hypertrophy with focus on the specific muscle groups most responsible for successful climbing motion (Michailov et al., 2009) including the finger flexors, elbow flexors, and shoulder adductors. It should also be noted that well-developed core and scapulohumeral muscles are likely to provide benefit through increased stability.

Anthropometric data of highly trained boulderers collected in a valid setting is sparse. The data presented in Table 1 show consistency between the studies when comparing the characteristics of boulderers, producing average height, weight and BMI values of 176.7 cm, 67.7 kg and 21.8 (BMI) for males; 162 cm, 60.2 kg and 19.4 (BMI) for females. However, in the only two studies that have measured body composition (Michailov et al., 2009; Macdonald & Callender, 2011) there is a notable difference in body fat percentage, with the earlier study reporting much lower values. The authors attributed this to a possible underestimation, however, other explanations might include differences in the method of assessment (DXA vs skinfold; Espana Romero et al., 2009), climbing ability between the groups and the timing of measurement, as the athletes in the earlier study are at a major competition and therefore, the values obtained should reflect peak conditioning.

Issues Determining a Link Between Physique & Performance. Based on the data currently available, the characteristics of elite boulderers are similar to that of elite sport climbers (Mermier et al., 2000). Although it is clear that boulderers exhibit a low percentage of body fat, there has been no positive or negative influence identified on performance (Michailov et al., 2009). Anecdotally, it is a commonly held belief in the climbing community that a reduction in body fat is beneficial, based on the theory that excess fat provides additional resistance during upward progression and reduces power to weight ratio. Due to the unique demands of each bouldering problem or competition, performance is very difficult to determine. The specific strengths of each athlete will differ and successful completion of a problem is dependent on a variety of physiological, psychological and skill based attributes which are impossible to isolate from one another.

An ideal physique may not exist in bouldering due to such variation in the demands of each boulder. Some routes, where holds are small and movement is slow, may favor a lighter and less muscular physique. In contrast, additional muscle and consequently, increased power development, may be beneficial on routes with larger holds and more dynamic, strength reliant moves. Furthermore, when anthropometric characteristics are similar, climbing performance is more dependent on trainable variables, rather than physique (58.9% vs 0.3% of total variance) (Mermier et al., 2000). Future studies to assess body composition and morphology of elite boulderers in relation to performance are required.

Nutritional Strategies to Promote Optimal Performance and Recovery

Due to the large gaps in the literature, there is no expert consensus on the nutritional recommendations for bouldering, therefore, this review outlines best informed suggestions.

Carbohydrate Intake. The recently updated position paper on Nutrition and Athletic Performance, recommends carbohydrate intakes for athletes ranging from 3 to 12 g/kg/day (Thomas et al., 2016). However, a carbohydrate intake of ~5 g/kg body weight/day is sufficient to maintain glycogen stores during other sports featuring similar elements of repetitive high-intensity bouts of exercise and resistance training (Tipton et al., 2007). It is important to tailor carbohydrate intake in line with training periodisation and daily energy goals.

Carbohydrate consumed 1–4 hr before training enhances skeletal muscle carbohydrate oxidation and glycogen resynthesis, particularly important in the morning after an overnight fast (Thomas et al., 2016). In sports

Table 1 Anthropometric Characteristics of Boulderers

Authors	Level	Gender	Age (yrs)	Experience (yrs)	Height (cm)	Body Mass (kg)	Body Mass Index	Body Fat (%)	Hand Grip Strength (kg)	Specific Strength (kg)	Training Volume (h/week)
Michailov et al. (2009)	Bouldering World Cup Competitors	M (*n* = 18)	25.8 ± 5.1	13.2 ± 5.6	174.6 ± 5.6	67.3 ± 6	22 ± 1.4	5.8 ± 1.8	58.6 ± 11	37.7 ± 6.9	15.4 ± 5.9
		F (*n* = 7)	25.1 ± 5.3	10.7 ± 2.9	162.6 ± 11.6	54 ± 6.8	20.4 ± 1.1	16.6 ± 3.6	28 ± 8.7	21.6 ± 3.2	11.6 ± 3.9
La Torre et al. (2009)	Elite Italian National Bouldering Competitors	M (*n* = 6)	29 ± 7		176 ± 6	63 ± 3	20.3 ± 1.3				
		F (*n* = 5)	33 ± 6.1		160.8 ± 4.1	51.8 ± 4.5	20 ± 1.8				
	"Elite Boulderers"—ability not specified	M (*n* = 6)	30 ± 5		171 ± 5	62 ± 5	21.4 ± 1.2				
		F (*n* = 3)	33 ± 2		163 ± 4	47 ± 5	17.8 ± 1.4				
Macdonald & Callender (2011)	³ Font 7b	M (*n* = 10)	25.3 ± 4.9	> 4	177.7 ± 4.9	70.2 ± 6.2	22.3 ± 2.0	12.1 ± 4.3	57.3 ± 7.0	39 ± 8	12.3 ± 3.1
Fanchini et al. (2013)	Boulderers: Font 7b—8a	M (*n* = 10)	26.8 ± 7.6	12.2 ± 7.7	180.4 ± 8.1	69.7 ± 9.2					
	Lead: 7c+—8c	M (*n* = 10)	27.0 ± 5.5	12.3 ± 3.2	179.1 ± 5.5	69.3 ± 7.4					
Medernach et al. (2015)	≥ Font 7a	M (*n* = 11)	26.3 ± 4.5	5.8 ± 2.4	178 ± 4	71 ± 5	22.4 ± 1.4		Pre:50.2 ± 4 Post:52.7 ± 4		
		M (*n* = 12)	25 ± 4.5	6.5 ± 3.2	177 ± 6	69.4 ± 5	22.1 ± 1.2		Pre:53.3 ± 5 Post:54.7 ± 5		

such as bouldering, where carbohydrate depletion is not a primary concern, the pretraining meal need not be carbohydrate focused and an intake of 1 g/kg of body weight before exercise should be sufficient (Maughan & Burke, 2012). The use of carbohydrate loading is not necessary for high-intensity, short duration events such as bouldering and may have an adverse effect on performance due to the associated weight gain.

Protein Intake and Timing. Maintaining and developing muscle strength is a key factor for bouldering performance, therefore, it would be appropriate to suggest protein intakes between 1.4–2 g / kg body weight / day depending on the athlete's goals (Thomas et al., 2016). Intakes above this level are generally not warranted (Tipton et al., 2007).

It has been established that muscle protein synthesis is maximally stimulated during exercise recovery by ingesting ~20 g of high quality protein (Macnaughton & Witard, 2014), or more specifically, 0.25 g/kg lean mass (Moore et al., 2015). Rates of protein turnover can be enhanced for 24–48 hr following a single bout of resistance type exercise (Miller et al., 2005); therefore, protein intake throughout this period may have a greater impact on skeletal muscle remodelling than pre/post exercise feedings alone. There is also a greater stimulation of muscle protein synthesis throughout the day when the pattern of protein feeding is consistent (0.25–0.3 g/kg in 3–4 hr intervals) and when protein is consumed immediately after exercise (Mamerow et al., 2014). During periods of maintaining strength rather than hypertrophy or heavy training, lower protein intakes of 1.4 g/kg/day (Thomas et al., 2016) may be adequate divided into ~20 g servings throughout the day (Areta et al., 2013). Bouldering athletes looking at maximizing strength gains and/or hypertrophy may benefit from the consideration of the type of protein and timing. Not all protein sources are the same, and it has been established that whey protein has a higher leucine content and greater absorption properties in comparison with soy protein (Tang et al. 2009), thus considered a better quality of protein for enhancing gains in strength and hypertrophy. It should be noted that while whey protein is easily found in everyday dairy foods, whey protein shakes have become a popular choice for postexercise recovery (Maughan & Burke, 2012) mainly because of convenience. Moreover, there is some evidence that consuming a dose of 40 g of slow releasing casein derived protein immediately before bedtime can lead to greater overnight muscle protein synthesis (Res et al., 2012). Casein makes up ~80% of the protein found in milk, however, a casein supplement might be more appropriate to achieve a large dose while avoiding excessive energy intake for athletes following an energy controlled diet.

Hydration. The hydration strategy of any athlete is dependent on the intensity and duration of exercise, the individuals' sweat rate, sodium loss, and opportunities to consume fluids during training or competition. Considering that bouldering is not a continuous activity as it comprises multiple rest opportunities, the loss of fluid through exercise is likely to be low. Nevertheless, in hotter and humid climates (i.e., World cup events in hotter climates) where sweat rates and electrolyte losses will be greater, boulderers should place a greater focus on replacing fluid and electrolytes. Dehydration in athletes concerned with anaerobic performance should not exceed 3–4% of bodyweight, marginally higher than the critical limit for endurance athletes (2%) (Kraft et al., 2012). During exercise in hotter climates, boulderers should be wary of hypohydration as this exacerbates environmental heat stress by decreasing plasma volume and impairing thermoregulation, resulting in elevated core temperature and premature fatigue (Nybo et al., 2014). The addition of ~20–30 meq/L sodium and ~2–5 meq/L potassium to beverages can replace associated losses through sweat, promote maintenance of plasma volume, and enhance absorption of glucose and fluids in the intestines (Baker & Jeukendrup, 2014). First morning body weight measurement is a simple and effective method of monitoring hydration status, typically varying by <1% and providing a stable marker of hydration status over longer periods of time (1–2 weeks) involving daily exercise and heat stress (Cheuvront et al., 2004). Studies are needed to accurately assess sweat rates and sweat sodium losses in boulderers in training and competition across a spectrum of climates.

Poor Dietary Practices and Implications. The issue of excessively low body weight in climbing is becoming recognized among governing bodies. In 2009, the Austrian Climbing Association introduced body mass index (BMI) restrictions, with a requirement of a BMI >17 for females and >18 for males to compete (Austria Climbing, 2016). The IFSC have also expressed concern toward weight loss in climbing athletes, implementing BMI screening and imposing disqualification to athletes who refuse to submit in-competition measurements (IFSC, 2016).

Anecdotally, one of the most common dietary practices is chronic calorie restriction, typically by reducing carbohydrate intake to very low levels irrespective of training volume or intensity and some boulderers are known to use this strategy to achieve or maintain a light mass and lean physique in an attempt to improve performance and reduce load on the extremities. This may be an effective, albeit suboptimal, solution to acute weight management; however, it is likely to have negative consequences when used for prolonged periods and could be considered a disordered eating behavior. Zapf et al. (2001) reported that 40% of elite climbers had energy intakes <2500 kcal/day, despite training over 2 hr daily. More recently, the term 'Relative Energy Deficiency in Sport' (RED-S) is a syndrome that refers to various health complications such as impaired physiological function in: metabolic rate; menstrual function; bone; health; immunity; protein synthesis; and cardiovascular health among other issues all caused by relative energy deficiency (Mountjouy et al., 2014).RED-S details the complex issue of relative energy deficiency which can affect both men and women. When energy availability falls below 30 kcal/kg fat-free mass/d, fat and lean tissue will be metabolized by the body to create fuel, resulting in the loss of strength and endurance, subsequently compromising performance and negating the benefits of training (Mountjoy et al., 2014). Other negative consequences include a significant increase in markers of exercise induced stress (Gleeson et al., 1998), a suppression of Type 1 immunity against intracellular pathogens like viruses (Loucks et al., 2011), and therefore, an increased susceptibility to infection. Female athletes are especially at risk, as low energy availability (with or without disordered eating) can severely impact menstrual function and bone mineral density. Early intervention is essential to prevent the development of serious health consequences including clinical eating disorders, amenorrhea and osteoporosis (Mountjoy et al., 2014).

Athletes who consume low-carbohydrate diets of low micronutrient density are at greatest risk of micronutrient deficiencies (Rodriguez et al., 2009); furthermore, a negative energy balance is also associated with a poor intake of key vitamins and minerals, and detrimental effects on psychological factors such as confusion, tension and vigor (Koral & Dosseville, 2009). The reliance on carbohydrate as the main fuel used during high-intensity exercise is well documented (Van Loon et al., 2001). A lack of carbohydrate is likely to have a direct effect on the ability of the muscles to produce and sustain maximal force production necessary during bouldering. A low glycogen state may also have a negative influence on cellular growth and attenuate adaptation in response to resistance training used by athletes to support the strength element of bouldering performance (Creer et al., 2005). When an athlete maintains a low carbohydrate diet (<2.5 g/kg/day), developing an unintentionally fat adapted metabolism is more probable due to the greater reliance on energy from the intake of fat. This adaptation reduces the activity of pyruvate dehydrogenase, down regulating carbohydrate metabolism; this subsequently impairs rates of glycogenolysis when the requirement is high and compromises the ability to perform at a high intensity (Stellingwerff et al., 2006).

Safe Long-Term Weight-Loss Strategies. As power-to-weight ratio may be a key determinant of bouldering performance, athletes will try and reduce body mass to enhance performance especially in weight sensitive and weight-making sports (Thomas et al., 2016).The recommended safe rate of weight loss in adults is 0.5–1 kg per week, equating to a calorie deficit from theoretical requirements of 500–1000 kcal per day (Jakicic et al., 2001). Accordingly, climbers seeking to lose fat mass should aim for the upper limits of protein intake (1.8–2 g/kg body weight/d) during periods of energy restriction as it appears that in an energy deficit state, as protein ingestion is increased, fat free mass retention increases, and that fat free mass is lost in greater amounts with the severity of energy restriction (Helms et al., 2014).

Vegetarian and Vegan Considerations. Anecdotally, vegan and vegetarian diets are prevalent practices among the climbing community, with most athletes choosing to exclude animal products from their diet due to ethical reasons, the belief that the diet is healthier, or to disguise disordered eating (Thomas et al., 2016). There is evidence to associate meat consumption with ill health, although in European populations, it seems the negative health effects of meat consumption are specifically associated with processed meats, rather than the total intake (Wang et al., 2016). Depending on the extent of dietary restrictions, nutrient concerns may include energy, protein, fat, iron, zinc, vitamin B-12, calcium and n-3 fatty acids (Craig & Mangels, 2009).

At present, there is limited research regarding long-term vegetarianism among athletic populations and the potential impact on athletic performance. However, there is some evidence to suggest that vegetarianism can be a dietary predictor for an increased risk of stress fractures due to low bone density (Wentz et al., 2012). This is particularly important in high impact sports such as bouldering, where joint and bone stress is high and falls are common. Considering the potential issues surrounding vegetarian practice, athletes may benefit from specialist dietary assessment and education to ensure their food intake is nutritionally complete to support health and performance (Thomas et al., 2016).

Supplements Which May Promote Optimal Bouldering Performance

To date, no studies have investigated the effects of any supplements on bouldering performance; therefore, findings are extrapolated from other sports with a high intensity, intermittent nature.

Creatine. Supplementing with creatine monohydrate can increase muscle creatine levels by ~20–50%, with muscle uptake optimized when coingested with carbohydrate (Rawson et al., 2004). The higher availability of creatine in the muscle has been shown to increase the rate of phosphocreatine resynthesis, increasing the energy directly available for high intensity exercise (Greenhaff et al., 1994) leading to significant increases in strength and power (Okudan & Gokbel, 2005).

Creatine supplementation has also be shown to have an ergogenic effect on the forearm flexors, which are specifically important in bouldering, with studies reporting an 18% increase in handgrip time-to-fatigue and a 15% increase in sustained maximal grip power (Urbanski et al., 1999, Kurosawa et al., 2003). Further beneficial mechanisms of creatine supplementation include a 38% increase in forearm blood flow and an up to 14% improvement in relaxation velocity, which may facilitate clearance of metabolic by-products and increase the rate and window for reoxygenation in the working muscles (Arciero et al., 2001, Jäger et al., 2008).

Loading protocols (5 days at 20 g/d in split doses) or longer periods of a maintenance dose (~3 g/d for ~4 weeks) appear to be the most effective strategies to increase and maintain muscle creatine stores (Buford et al., 2007). There has been no experimental support for any harmful effects of creatine supplementation in healthy subjects. The potential for associated acute weight gain (0.6–1 kg; Tarnopolsky, 2010) and the subsequent effects on performance have not been investigated in climbers.

Beta-Alanine. Supplementation with β-alanine has been shown to increase carnosine (a naturally occurring dipeptide formed from b-Alanine and L-Histidine) levels by up to 80% after 10 weeks of use (Hill et al., 2007). An elevated level of carnosine is thought to improve short-duration, high-intensity bouts of exercise by acting as an intracellular buffer, helping to maintain acid-base homeostasis. The accumulation of H^+ in skeletal muscle has been found to inhibit glycolysis (Trivedi & Daniforth, 1966), and disrupt PCr resynthesis (Harris et al., 1976) and contractile functioning (Fabiato & Fabiato, 1978), which is likely to a have negative effect on bouldering performance during longer problem attempts.

To replicate the increase in intracellular carnosine concentration reported in the literature, 4–10 weeks of beta-alanine supplementation (4–6 g/day) is recommended (Hill et al., 2007), while 1.2 g/day appears to maintain elevated muscle carnosine levels (Stegan et al., 2014). Athletes may decide to divide this into several smaller doses to minimize the likelihood of paraesthesia, a common side effect.

Caffeine. The primary effects of caffeine consumption include an increase in the release of circulating adrenaline, mobilization of fatty acids, and inhibition of adenosine receptors, resulting in an increased stimulation of the sympathetic nervous system (Graham et al., 2008). Anecdotally, caffeine is widely used in climbing, usually in the form of coffee. Potential benefits include decreased feelings of tiredness and improved mental alertness, mood, and arousal during extended sessions of training or enhanced focus at competition (Sokmen et al., 2008). Although caffeine has been found to have little to no effect on maximal strength or power performance (Crowe et al., 2006; Sokmen et al., 2008), it may be worthwhile when athletes are tired by increasing voluntary workload (Cook et al., 2012). Experimentally, caffeine has been shown to reduce the rating of perceived exertion during high-intensity resistance exercise (6mg/kg) and a grip to exhaustion task (100 mg) (Green et al., 2007; Bellar et al., 2011), which may be of benefit for a bouldering athlete.

Benefits from caffeine can occur with acute intakes as low as 1–3 mg/kg. High dosages (6–9 mg/kg) have been found to increase blood lactate during exercise and negatively impact high-intensity exercise performance (Crowe et al., 2006), alongside reported side effects, such as jitters, which would be likely to impair bouldering performance. Due to the long half-life of caffeine (4–6 hr), consumption in the evening may affect the ability to sleep or reduce sleep quality, which can in turn negatively impact recovery. Athletes should be particularly cautious of this effect when competing in 2-day events.

Beetroot Juice. Beetroot juice is rich in dietary nitrate (NO^{3-}) which is rapidly digested in the stomach and small intestine, with plasma levels peaking ~1–2 hr after consumption (Jones, 2014). Following consumption, ~25% of dietary nitrate is secreted in saliva before being converted anaerobically to nitrite (NO^{2-}) by commensal bacteria in the mouth, followed by reduction to nitric oxide (NO) in the acidic environment of the stomach (Mensinga et al., 2003). This NO^{2-} to NO reduction is facilitated under conditions of low oxygen availability and low PH (Lundberg et al., 2011). During exercise, NO stimulates vasodilation and improves muscle contractility, enabling more precise local matching of blood flow to metabolic rate (Jones et al., 2016). NO has also been found to reduce the oxygen demand of exercising muscle, potentially due to improved phosphate/oxygen ratio of mitochondrial respiration (McDonough et al., 2005) and/or reduced ATP cost of force production (Bailey et al., 2010). Dietary nitrate supplementation could be a useful strategy for bouldering athletes as it has been found to enhance maximal power, contractile speed, and recovery time (Clifford et al., 2016; Rimer et al., 2016). Barnes (1980) demonstrated that forearm blood flow is completely occluded during sustained isometric contractions with a hand-grip force of 340 N, far below the maximal grip force reported by elite climbers which can exceed 750 N (Limonta et al., 2016). Higher oxygen demand relative to delivery during intense exercise increases the risk of hypoxia and acid-base disturbances, subsequently contributing to fatigue and impairing NOS activity (Wylie et al., 2013). This increases reliance on the nitrate-nitrite-nitric oxide pathway to maintain NO homeostasis and regulate blood flow. Improved muscle blood flow facilitates the clearance of waste metabolites during intermittent exercise and oxygen delivery to the muscle.

Beetroot juice is now commercially available in concentrated shot form, typically containing 400 mg of dietary nitrate per 70 ml shot. An effective approach could be one 400mg dose of nitrate daily, followed by another dose 2–3 hr before competition.

Conclusion

Bouldering is a complex sport, demanding high levels of strength and anaerobic conditioning, with emphasis on a lean and light physique. Despite the inclusion of bouldering in the Olympic program, very little is known about the nutritional requirements of the sport, and information regarding current nutritional practices relies on unpublished observations. Nutritionists working within bouldering should ensure training and competition performance is not compromised by weight loss goals. There should also be focus on educating athletes and coaches on poor nutritional practices and disordered eating, with a multidisciplinary approach to support high risk individuals.

Research is warranted in all fundamental areas of nutrition for bouldering and these are summarized in Table 3.

Table 2 Summary of Suggested Supplementation

Erogenic Aid	Mechanism of action	Application to Bouldering	Dosing Strategy
Creatine	↑Muscle creatine levels by ~20–50% ↑ Rate of phosphocreatine resynthesis	↑ Grip endurance & power ↑ Muscular strength & power ↑ Forearm blood flow & relaxation velocity	Loading phase: 20 g/d for 5 days Maintenance phase: 3–5 g/d ↑ Muscle uptake with CHO coingestion
b-Alanine	↑ Carnosine levels up to 80% ↑ Intracellular buffering capacity ↑ Ca^{2+} sensitivity in muscle contractile components	↓ Rate of fatigue during longer problems ↑ Tolerance to high volume training	Loading phase: 4–6 g/d for 4–10 weeks Maintenance phase: 1.2 g/d
Caffeine	↑ Stimulation of the sympathetic nervous system	↓ RPE and maintain mental alertness during prolonged training ↑ Cognitive focus at competition	1–3 mg/kg 30–60 min before exercising
Beetroot Juice	↑ Production of NO ↑ Contractile function in type II muscle ↑ Muscle oxygenation in type II muscle	↑ Maximal muscle speed & power ↑ Tolerance during repeated supramaximal efforts	400 mg/d nitrate; equivalent to 70 ml concentrate shot Additional 400 mg dose 2–3 hr before competition

Table 3 Summary of Future Nutrition-Related Studies Required in Bouldering

Future studies required on bouldering
• Assessment of body composition and morphology of elite boulderers in relation to performance.
• Sweat rates and electrolyte losses during training and competition across a spectrum of environmental conditions
• The energy requirements of bouldering during training and competition.
• Current nutritional practices of boulderers, with markers of health and performance.
• Use of supplements and ergogenic aids by boulderers
• Perceptions of weight loss and weight loss practices of boulderers
• How does the culture of climbing influence the eating behaviours of athletes? – e.g. vegetarianism
• Nutritional considerations for the Olympic climbing event.
• The effect of nutritional ergogenic aids such as creatine, beta-alanine, caffeine, carbohydrate, nitrates on bouldering performance.

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