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SMITH, Edward, STOREY, Ryan and RANCHORDAS, Mayur
<<http://orcid.org/0000-0001-7995-9115>>

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Published version

SMITH, Edward, STOREY, Ryan and RANCHORDAS, Mayur (2017). Nutritional considerations for bouldering. *International Journal of Sport Nutrition & Exercise Metabolism*, 27 (4), 314-324.

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Nutritional Considerations for Bouldering

Edward J. Smith¹, Ryan Storey², and Mayur K. Ranchordas³

1 - BUPA Wellness, 3 Sandygate Park, Sheffield, S10 2LQ

2 - Sheffield City Council, Sheffield

3 - Sheffield Hallam University, Academy of Sport & Physical Activity, Collegiate Crescent Campus,
Sheffield, UK, S10 2BP

Running Head: Nutrition for Bouldering

Word Count: 4991 **Reference Count:** 75

Address for Correspondence:

Dr Mayur K Ranchordas

Sheffield Hallam University

A220 Collegiate Hall

Collegiate Crescent Campus

Sheffield

S10 2BP

Phone: 07917402562

E-mail: m.ranchordas@shu.ac.uk

21 **Abstract**

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

39

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

41 Introduction

42 Rock climbing was once a fringe activity pursued by outdoorsmen; however, it is now an
43 established sport with growing international recognition and has been selected to feature at the
44 Tokyo 2020 Olympic Games. It is estimated that 25 million people climb regularly, with athletes from
45 52 countries representing 5 continents competing in 2014 (IFSC, 2016). Bouldering, once primarily
46 used as a training method, is now a well-established discipline of rock climbing with specialist
47 training facilities and competitions. Unlike other forms of climbing, bouldering is performed rope-
48 less with spotters and crash mats for protection, and indoor walls typically do not exceed 4 metres in
49 height. Bouldering routes, or “problems”, feature a short sequence of unique and powerful moves
50 that often require the athlete to support the full body mass on small parts of the fingers or toes.
51 Difficulty or grading is manipulated using factors such as steepness and varying the size, shape, and
52 positioning of the holds. The physical demands include high levels of specific isometric and dynamic
53 strength, and a physique specifically developed to optimise power, whilst limiting the load on the
54 extremities. Although no studies have assessed energy needs in boulderers, the metabolic demands
55 are likely to differ depending on the training goal and duration, with sessions lasting several hours.
56 Governed by the International Federation of Sport Climbing (IFSC), bouldering competitions are held
57 up to International level, with annual World Cup competitions featuring 6-8 events and single event
58 World Championships every other year. Competitions generally consist of 3 rounds (qualifying, semi-
59 finals & finals), with a maximum of 2 rounds per day, each with 4-5 problems to be attempted. Each
60 problem is comprised of 4-8 handholds and multiple attempts are allowed within a 4-5 minute
61 period. A successful ascent typically requires around 40 seconds to complete (White & Olsen, 2010)
62 and 4-5 minutes of rest are allowed between each boulder; with the exception of finals, where there
63 may be up to 30 minutes between attempts.

64 Despite the development of bouldering into an elite sport, there have been no studies to
65 date investigating the nutritional demands, and consequently, there is no consensus on

66 requirements. Therefore, athletes often base their nutritional strategies on habits of experienced or
67 successful athletes in the sport. However, research has shown inadequate energy availability,
68 unbalanced food quality, and poor nutrient timing in the diets of elite climbers (Zapf et al., 2001).
69 Consequently, this paper aims to explore the physiological demands of bouldering, the nutritional
70 considerations to maximise performance, and directions for future research.

71

72 **Method**

73 Articles were retrieved in accordance with an extensive search in several databases including
74 MEDLINE (1966-2016); SPORTDiscus (1966-2016); PubMed (1966–2016) and Google Scholar (1980–
75 2015). The following search terms were used in various combinations: "recovery," "nutrition,"
76 "diet," "food," "climbing," "bouldering," "grip strength," "hydration," "supplements," "ergogenic
77 aids," "glycogen re-synthesis," "refuelling," "repair," "adaptation". Articles were selected based on
78 their relevance and application to climbing and bouldering. References cited in the retrieved articles
79 were also considered.

80

81 **Physiological Demands of Bouldering**

82 *Energy Systems*

83 Due to lack of scientific interest in the area, key training and physiological qualities required
84 to produce an elite bouldering athlete remain inadequately defined. Due to the high-intensity and
85 short duration nature of bouldering, there is an assumed predominant reliance on the anaerobic
86 energy systems to perform. The rapid, high force contractions used in bouldering might initially rely
87 on alactic metabolism for adenosine triphosphate (ATP) production; however, after just 10 seconds
88 of repeated maximal isometric contractions, the yield of ATP from phosphocreatine (PCr) hydrolysis
89 is reduced by more than 50% (Hultman et al., 1991). Successful ascents in elite competitive

90 bouldering last an average of 40 seconds (White & Olsen, 2010), with rarely an opportunity to rest or
91 allow adequate recovery in between holds. Therefore, there is likely to be an increased contribution
92 from the lactic acid system to maintain power output, resulting in increased blood lactate
93 concentration. Capillary blood lactate samples collected directly after two elite level national
94 bouldering competition performances report mean peak levels from 6.2 ± 0.9 – 6.9 ± 1.2 mmol/L (La
95 Torre et al., 2009). Similarly, in the longer duration discipline of sport climbing, mean blood lactate
96 concentrations have been reported between 4.5-6.8 mmol/L post-climb (Watts, 2004).

97

98 *Climbing Specific Strength*

99 The upward propulsion during climbing typically relies on the ability to sustain powerful,
100 intermittent forearm muscle contractions with a substantial, yet less intense, contribution of the
101 lower limbs (Sheel et al., 2003). In modern sport climbing, one of the main limiting factors to
102 performance is the anaerobic strength endurance of the forearm flexor muscles responsible for grip
103 (Schöffl et al., 2006). The intermittent isometric contractions in these muscles that occur during
104 bouldering may occlude blood flow to the active musculature leading to a disproportionate rise in
105 heart rate in comparison with oxygen consumption, as demonstrated in sport climbing (Sheel et al.,
106 2003). This effect is greater with increasing levels of climbing difficulty, where there is an increased
107 reliance on anaerobic metabolism. Conversely, Ferguson and Brown (1997) found an enhanced
108 vasodilatory capacity in the forearms of trained rock climbers attenuating this mechanism. During a
109 simulated bouldering competition, heart rate was recorded in the range of 70-85% HR_{max} for 25.9%
110 of the time and between 86-100% HR_{max} for 12% of the time in elite subjects, indicating significant
111 engagement of the cardiovascular system (La Torre et al., 2009).

112 Due to the large demand placed on the hands and forearm flexors of climbers, handgrip
113 strength in relation to body mass has been consistently reported to be significantly greater in
114 comparison to non-climbers (Watts, 2004). Finger flexor strength data collected from highly trained

115 male boulderers is consistent with these findings, achieving the highest recorded values (494 ± 64 vs.
116 383 ± 79 N, $p = 0.001$) of any climbing specific study to date (Macdonald & Callender, 2011). Fanchini
117 et al. (2013) found that isometric maximal voluntary contraction force (MVC) and rate of force
118 development (RFD) were significantly greater in competitive male boulderers compared to lead
119 climbers in crimp and open-crimp positions; similar findings were later reported by Laffaye et al.
120 (2015). It was reported that the largest discriminatory outcome between the two groups was the
121 RFD, which may reflect a unique requirement in bouldering, as high levels of rapid force generation
122 is required by the finger flexors to stabilise the body following dynamic movements (Watts, 2004).
123 Furthermore, the specific strength of the finger and hand bones are closely correlated with climbing
124 styles that emphasise athletic difficulty, with the highest levels observed in sport climbing and
125 bouldering (Sylvester et al., 2010); emphasising the effect of the high mechanical load on the hands
126 of boulderers. Handgrip strength has been shown to decline with increasing levels of blood lactate
127 (Watts et al., 1996), which may provide a useful marker of climbing fatigue.

128

129 *Aerobic Capacity*

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

134 There is currently no research outlining the aerobic capacity of boulderers, although studies
135 that have examined sport climbers have reported values averaging between 52-55 ml/kg/min for
136 maximum oxygen uptake (Watts, 2004). However, these studies have measured this using protocols
137 that utilise the lower body on cycle ergometers or treadmills which is clearly a limitation as it lacks
138 specificity to climbing. More recently, researchers have acknowledged that these methods neglect
139 the use of upper-body musculature predominantly responsible for climbing performance and have

140 developed an incremental maximal upper-body ergometer test (UBT) to evaluate climbers' aerobic
141 fitness and sport-specific work capacity, performed on a vertically mounted rowing ergometer
142 (Michailov et al., 2015). While studying sport climbers, Michailov et al. (2015) found UBT aerobic and
143 work capacity results were strongly correlated to climbing-performance variables and reflected
144 sport-specific fatigue, whereas treadmill results were not. Positive effects of non-specific, aerobic
145 based endurance training have been demonstrated to promote recovery in the forearms following
146 anaerobic strength endurance tests (Schöffl et al., 2006), although it would seem more appropriate
147 for climbing athletes to choose a form of exercise that will enhance upper body aerobic capacity to
148 gain the most benefit.

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

153

154 **Optimal Physique**

155 *Anthropometric Characteristics*

156 Anthropometric data obtained from the studies investigating the related discipline of sport
157 climbing suggest that the athletic profile optimal for performance is a positive ape index, low body
158 mass, small stature, and low body fat (Mermier et al., 2000; Watts, 2004; Giles et al., 2006; Laffaye et
159 al., 2015). However, there are significant differences between the two styles of climbing so
160 differences in the athletic profile are to be expected. Sport climbing involves increased ascent
161 duration of 2 to 7 minutes and a route length up to 18 metres. White and Olsen (2010) suggested
162 that the strength requirements of bouldering are greater than sport climbing due to the shorter
163 duration, greater number of attempts at each problem, and the lower time spent in a static position

164 (25% vs 38%). Due to the strength nature of bouldering, it could be assumed that boulderers are
165 required to be more muscular than other climbing athletes; however, a very high lean mass could
166 have a detrimental effect on performance as excessive muscular hypertrophy will increase total
167 body mass beyond the potential relative strength capacity of the finger flexors. With consideration
168 to this issue, it has been suggested that boulderers should train to promote muscle hypertrophy with
169 focus on the specific muscle groups most responsible for successful climbing motion (Michailov et
170 al., 2009) including the finger flexors, elbow flexors, and shoulder adductors. It should also be noted
171 that well-developed core and scapulohumeral muscles are likely to provide benefit through
172 increased stability.

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

183

184 *Issues Determining a Link between Physique & Performance*

185 Based on the data currently available, the characteristics of elite boulderers are similar to
186 that of elite sport climbers (Mermier et al., 2000). Although it is clear that boulderers exhibit a low
187 percentage of body fat, there has been no positive or negative influence identified on performance
188 (Michailov et al., 2009). Anecdotally, it is a commonly held belief in the climbing community that a

189 reduction in body fat is beneficial, based on the theory that excess fat provides additional resistance
190 during upward progression and reduces power to weight ratio. Due to the unique demands of each
191 bouldering problem or competition, performance is very difficult to determine. The specific
192 strengths of each athlete will differ and successful completion of a problem is dependent on a
193 variety of physiological, psychological and skill based attributes which are impossible to isolate from
194 one another.

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

203

204 **Nutritional Strategies to Promote Optimal Performance and Recovery**

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

207

208 *Carbohydrate Intake*

209 The recently updated position paper on Nutrition and Athletic Performance, recommends
210 carbohydrate intakes for athletes ranging from 3 to 12 g/kg/day (Thomas et al., 2016). However, a
211 carbohydrate intake of ~5 g/kg body weight/day is sufficient to maintain glycogen stores during
212 other sports featuring similar elements of repetitive high-intensity bouts of exercise and resistance

213 training (Tipton et al., 2007). It is important to tailor carbohydrate intake in line with training
214 periodisation and daily energy goals.

215 Carbohydrate consumed 1-4 hours before training enhances skeletal muscle carbohydrate
216 oxidation and glycogen resynthesis, particularly important in the morning after an overnight fast
217 (Thomas et al., 2016). In sports such as bouldering, where carbohydrate depletion is not a primary
218 concern, the pre-training meal need not be carbohydrate focussed and an intake of 1 g/kg of body
219 weight prior to exercise should be sufficient (Maughan & Burke, 2012). The use of carbohydrate
220 loading is not necessary for high-intensity, short duration events such as bouldering and may have
221 an adverse effect on performance due to the associated weight gain.

222

223 *Protein Intake and Timing*

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

228 It has been established that muscle protein synthesis is maximally stimulated during exercise
229 recovery by ingesting ~20 g of high quality protein (Macnaughton & Witard, 2014), or more
230 specifically, 0.25 g/kg lean mass (Moore et al., 2015). Rates of protein turnover can be enhanced for
231 24-48 hours following a single bout of resistance type exercise (Miller et al., 2005); therefore,
232 protein intake throughout this period may have a greater impact on skeletal muscle remodelling
233 than pre-/post exercise feedings alone. There is also a greater stimulation of muscle protein
234 synthesis throughout the day when the pattern of protein feeding is consistent (0.25-0.3 g/kg in 3-4
235 hour intervals) and when protein is consumed immediately after exercise (Mamerow et al., 2014).
236 During periods of maintaining strength rather than hypertrophy or heavy training, lower protein
237 intakes of 1.4 g/kg/day (Thomas et al., 2016) may be adequate divided into ~20 g servings

238 throughout the day (Areta et al., 2013). **Bouldering athletes looking at maximizing strength gains**
239 **and/or hypertrophy may benefit from the consideration of the type of protein and timing. Not all**
240 **protein sources are the same, and it has been established that whey protein has a higher leucine**
241 **content and greater absorption properties in comparison to soy protein (Tang et al. 2009), thus**
242 **considered a better quality of protein for enhancing gains in strength and hypertrophy. It should be**
243 **noted that whilst whey protein is easily found in everyday dairy foods, whey protein shakes have**
244 **become a popular choice for post-exercise recovery (Maughan & Burke, 2012) mainly because of**
245 **convenience. Moreover, there is some evidence that consuming a dose of 40 g of slow releasing**
246 **casein derived protein immediately before bedtime can lead to greater overnight muscle protein**
247 **synthesis (Res et al., 2012). Casein makes up ~80% of the protein found in milk, however, a casein**
248 supplement might be more appropriate to achieve a large dose whilst avoiding excessive energy
249 intake for athletes following an energy controlled diet.

250

251 *Hydration*

252 The hydration strategy of any athlete is dependent on the intensity and duration of exercise,
253 the individuals' sweat rate, sodium loss, and opportunities to consume fluids during training or
254 competition. Considering that bouldering is not a continuous activity as it comprises multiple rest
255 opportunities, the loss of fluid through exercise is likely to be low. Nevertheless, in hotter and humid
256 climates (i.e. World cup events in hotter climates) where sweat rates and electrolyte losses will be
257 greater, boulderers should place a greater focus on replacing fluid and electrolytes. Dehydration in
258 athletes concerned with anaerobic performance should not exceed 3-4% of bodyweight, marginally
259 higher than the critical limit for endurance athletes (2%) (Kraft et al., 2012). During hotter climates,
260 boulderers should be wary of hypohydration as this exacerbates environmental heat stress by
261 decreasing plasma volume and impairing thermoregulation, resulting in elevated core temperature
262 and premature fatigue (Nybo et al., 2014). The addition of ~20-30 meq/L sodium and ~2-5 meq/L

263 potassium to beverages can replace associated losses through sweat, promote maintenance of
264 plasma volume, and enhance absorption of glucose and fluids in the intestines (Baker & Jeukendrup,
265 2014). First morning body weight measurement is a simple and effective method of monitoring
266 hydration status, typically varying by <1% and providing a stable marker of hydration status over
267 longer periods of time (1-2 weeks) involving daily exercise and heat stress (Cheuvront et al., 2004).
268 Studies are needed to accurately assess sweat rates and sweat sodium losses in boulderers in
269 training and competition across a spectrum of climates.

270

271 *Poor Dietary Practices and Implications*

272 The issue of excessively low body weight in climbing is becoming recognised amongst
273 governing bodies. In 2009, the Austrian Climbing Association introduced body mass index (BMI)
274 restrictions, with a requirement of a BMI >17 for females and >18 for males to compete (Austria
275 Climbing, 2016). The IFSC have also expressed concern towards weight loss in climbing athletes,
276 implementing BMI screening and imposing disqualification to athletes who refuse to submit in-
277 competition measurements (IFSC, 2016).

278 Anecdotally, one of the most common dietary practices is chronic calorie restriction,
279 typically by reducing carbohydrate intake to very low levels irrespective of training volume or
280 intensity and some boulderers are known to utilise this strategy in order to achieve or maintain a
281 light mass and lean physique in an attempt to improve performance and reduce load on the
282 extremities. This may be an effective, albeit sub-optimal, solution to acute weight management;
283 however, it is likely to have negative consequences when used for prolonged periods and could be
284 considered a disordered eating behaviour. Zapf et al. (2001) reported that 40% of elite climbers had
285 energy intakes <2500 kcal/day, despite training over 2 hours daily. More recently, the term 'Relative
286 Energy Deficiency in Sport' (RED-S) is a syndrome that refers to various health complications such as
287 impaired physiological function in: metabolic rate; menstrual function; bone; health; immunity,

288 protein synthesis; and cardiovascular health amongst other issues all caused by relative energy
289 deficiency (Mountjoy et al., 2014). RED-S details the complex issue of relative energy deficiency
290 which can affect both men and women. When energy availability falls below 30 kcal/kg fat-free
291 mass/d, fat and lean tissue will be metabolised by the body to create fuel, resulting in the loss of
292 strength and endurance, subsequently compromising performance and negating the benefits of
293 training (Mountjoy et al., 2014). Other negative consequences include a significant increase in
294 markers of exercise induced stress (Gleeson et al., 1998), a suppression of Type 1 immunity against
295 intracellular pathogens like viruses (Loucks et al., 2011), and therefore, an increased susceptibility to
296 infection. Female athletes are especially at risk, as low energy availability (with or without
297 disordered eating) can severely impact menstrual function and bone mineral density. Early
298 intervention is essential to prevent the development of serious health consequences including
299 clinical eating disorders, amenorrhoea and osteoporosis (Mountjoy et al., 2014).

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

313 requirement is high and compromises the ability to perform at a high intensity (Stellingwerff et al.,
314 2006).

315 *Safe Long-Term Weight-Loss Strategies*

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

324

325 *Vegetarian and Vegan Considerations*

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

334 At present, there is limited research regarding long-term vegetarianism among athletic
335 populations and the potential impact on athletic performance. However, there is some evidence to
336 suggest that vegetarianism can be a dietary predictor for an increased risk of stress fractures due to

337 low bone density (Wentz et al., 2012). This is particularly important in high impact sports such as
338 bouldering, where joint and bone stress is high and falls are common. Considering the potential
339 issues surrounding vegetarian practice, athletes may benefit from specialist dietary assessment and
340 education to ensure their food intake is nutritionally complete to support health and performance
341 (Thomas et al., 2016).

342

343 **Supplements Which May Promote Optimal Bouldering Performance**

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

347

348 *Creatine*

349 Supplementing with creatine monohydrate can increase muscle creatine levels by ~20-
350 50%, with muscle uptake optimised when co-ingested with carbohydrate (Rawson et al., 2004).
351 The higher availability of creatine in the muscle has been shown to increase the rate of
352 phosphocreatine re-synthesis, increasing the energy directly available for high intensity exercise
353 (Greenhaff et al., 1994) leading to significant increases in strength and power (Okudan &
354 Gokbel, 2005).

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

361 rate and window for re-oxygenation in the working muscles (Arciero et al., 2001, Jäger et al.,
362 2008).

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

369

370 *Beta-Alanine*

371 Supplementation with β -alanine has been shown to increase carnosine (a naturally occurring
372 dipeptide formed from β -Alanine and L-Histidine) levels by up to 80% after 10 weeks of use (Hill et
373 al., 2007). An elevated level of carnosine is thought to improve short-duration, high-intensity bouts
374 of exercise by acting as an intracellular buffer, helping to maintain acid-base homeostasis. The
375 accumulation of H^+ in skeletal muscle has been found to inhibit glycolysis (Trivedi & Daniforth, 1966),
376 and disrupt PCr resynthesis (Harris et al., 1976) and contractile functioning (Fabiato and Fabiato,
377 1978), which is likely to have a negative effect on bouldering performance during longer problem
378 attempts.

379 To replicate the increase in intracellular carnosine concentration reported in the literature, 4
380 - 10 weeks of beta-alanine supplementation (4-6 g/day) is recommended (Hill et al., 2007), while 1.2
381 g/day appears to maintain elevated muscle carnosine levels (Stegen et al., 2014). Athletes may
382 decide to divide this into several smaller doses to minimise the likelihood of paraesthesia, a common
383 side effect.

384

385 *Caffeine*

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

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

404

405 *Beetroot Juice*

406 Beetroot juice is rich in dietary nitrate (NO_3^-) which is rapidly digested in the stomach and
407 small intestine, with plasma levels peaking ~1-2 hours after consumption (Jones, 2014). Following
408 consumption, ~25% of dietary nitrate is secreted in saliva before being converted anaerobically to

409 nitrite (NO^{2-}) by commensal bacteria in the mouth, followed by reduction to nitric oxide (NO) in the
410 acidic environment of the stomach (Mensinga et al., 2003). This NO^{2-} to NO reduction is facilitated
411 under conditions of low oxygen availability and low PH (Lundberg et al., 2011). During exercise, NO
412 stimulates vasodilation and improves muscle contractility, enabling more precise local matching of
413 blood flow to metabolic rate (Jones et al., 2016). NO has also been found to reduce the oxygen
414 demand of exercising muscle, potentially due to improved phosphate/oxygen ratio of mitochondrial
415 respiration (McDonough et al., 2005) and/or reduced ATP cost of force production (Bailey et al.
416 2010). Dietary nitrate supplementation could be a useful strategy for bouldering athletes as it has
417 been found to enhance maximal power, contractile speed, and recovery time (Clifford et al., 2016;
418 Rimer et al., 2016). Barnes (1980) demonstrated that forearm blood flow is completely occluded
419 during sustained isometric contractions with a hand-grip force of 340 N, far below the maximal grip
420 force reported by elite climbers which can exceed 750 N (Limonta et al., 2016). Higher oxygen
421 demand relative to delivery during intense exercise increases the risk of hypoxia and acid-base
422 disturbances, subsequently contributing to fatigue and impairing NOS activity (Wylie et al., 2013).
423 This increases reliance on the nitrate-nitrite-nitric oxide pathway to maintain NO homeostasis and
424 regulate blood flow. Improved muscle blood flow facilitates the clearance of waste metabolites
425 during intermittent exercise and oxygen delivery to the muscle.

426 Beetroot juice is now commercially available in concentrated shot form, typically containing
427 400 mg of dietary nitrate per 70 ml shot. An effective approach could be one 400mg dose of nitrate
428 daily, followed by another dose 2-3 hours before competition.

429

430 **Conclusion**

431 Bouldering is complex sport, demanding high levels of strength and anaerobic conditioning,
432 with emphasis on a lean and light physique. Despite the inclusion of bouldering in the Olympic
433 programme, very little is known about the nutritional requirements of the sport, and information

434 regarding current nutritional practices relies on unpublished observations. Nutritionists working
435 within bouldering should ensure training and competition performance is not compromised by
436 weight loss goals. There should also be focus on educating athletes and coaches on poor nutritional
437 practices and disordered eating, with a multidisciplinary approach to support high risk individuals.

438 Research is warranted in all fundamental areas of nutrition for bouldering and these are
439 summarised in table 3.

440

441 **Word Count: 4991**

442

443 **Acknowledgements:** The authors would like to thank the bouldering community in Sheffield for their
444 insights and ideas.

445

446 **Author Contributions:** The review was designed by EJS; manuscript preparation was undertaken by
447 EJS, RS and MKR. All authors approved the final version of the paper.

448

449 **Conflict of Interest:** There were no conflicts of interest in the conception of this review or
450 production of the manuscript.

451

452 **Funding:** No funding was received.

453

454 **References:**

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671

Table 1: Anthropometric characteristics of boulderers

	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)
Authors											
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)	≥ 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		

Table 2: Summary of suggested supplementation

Erogenic Aid	Mechanism of action	Application to Bouldering	Dosing Strategy
Creatine	<ul style="list-style-type: none"> ↑ Muscle creatine levels by ~20-50% ↑ Rate of phosphocreatine re-synthesis 	<ul style="list-style-type: none"> ↑ Grip endurance & power ↑ Muscular strength & power ↑ Forearm blood flow & relaxation velocity 	<ul style="list-style-type: none"> Loading phase: 20 g/d for 5 days Maintenance phase: 3 - 5 g/d ↑ Muscle uptake with CHO co-ingestion
β-Alanine	<ul style="list-style-type: none"> ↑ Carnosine levels up to 80% ↑ Intracellular buffering capacity ↑ Ca²⁺ sensitivity in muscle contractile components 	<ul style="list-style-type: none"> ↓ Rate of fatigue during longer problems ↑ Tolerance to high volume training 	<ul style="list-style-type: none"> Loading phase: 4 - 6 g/d for 4 - 10 weeks Maintenance phase: 1.2 g/d
Caffeine	<ul style="list-style-type: none"> ↑ Stimulation of the sympathetic nervous system 	<ul style="list-style-type: none"> ↓ RPE and maintain mental alertness during prolonged training ↑ Cognitive focus at competition 	<ul style="list-style-type: none"> 1 - 3 g/kg 30 - 60 minutes before exercising
Beetroot Juice	<ul style="list-style-type: none"> ↑ Production of NO ↑ Contractile function in type II muscle ↑ Muscle oxygenation in type II muscle 	<ul style="list-style-type: none"> ↑ Maximal muscle speed & power ↑ Tolerance during repeated supramaximal efforts 	<ul style="list-style-type: none"> 400 mg/d nitrate; equivalent to 70 ml concentrate shot Additional 400 mg dose 2-3 hours 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.
-