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The Effect of Nutrition on Athletic Performance With a Focus on Rock Climbing

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Abstract
Rock climbing has steadily grown in popularity in recent years. In light of this recent growth, new climbers joining the sport and those who have been involved in the sport for years would benefit from knowing how nutrition affects their immediate or long term performance in the high-intensity sport. This review found that rock climbers engaged in intense training should aim to consume carbohydrates at 5-8 g/kg of body weight each day, while rock climbers who have a mild training regiment should consume carbohydrates at roughly 3-5 g/kg of body weight each day. Additionally, this review discovered that climbers should also aim to consume protein levels reaching up to 1.4-1.8 g/kg of body weight and fat levels of 30% of the climber's total daily caloric intake. This review furthermore ascertained that an addition of glycerol as well as creatine in the climber's diet is likely to serve ergogenic benefits in performance. Lastly, it is strongly recommended that rock climbers stay hydrated at all times.

I. Introduction

Having its first international competition in 1991, and being introduced into the Olympics at the Buenos Aires Youth Olympic Games in 2018 (Olympics, 1), rock climbing has steadily grown in popularity in recent years (Outdoor Foundation, 42). Due to this recent uprising, many elite and recreational rock climbers are seeking ways to maximize their performance in the high intensity sport.

SPORT	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	1-YR CHANGE	2-YR	5-YR AAG
Adventure Racing	698	809	1,005	1,214	1,202	1,618	2,095	2,368	2,864	2,999	2,529	2,215	2,143	1,966	1,826	-7.1%	-14.8%	-9.3%
Alpine Touring												998	1,122	1,126	1,100	-2.3%	-2.0%	
Aquatic Exercise	9,757	9,512	8,965	8,947	9,042	9,177	8,483	9,122	9,226	10,575	10,459	10,518	11,189	10,954	10,400	-5.1%	-7.1%	-0.3%
Archery	5,950	6,180	6,368	6,323	6,471	7,173	7,647	8,435	8,378	7,903	7,769	7,654	7,449	7,249	7,342	1.3%	-1.4%	-1.5%
Backpacking Overnight - More Than 1/4 Mile From Vehicle/Home	6,637	7,252	7,757	7,998	7,722	7,933	9,069	10,101	10,100	10,151	10,975	10,540	10,660	10,746	10,306	-4.1%	-3.3%	0.4%
Badminton	7,057	7,148	7,469	7,645	7,135	7,278	7,150	7,176	7,198	7,354	6,430	6,337	6,095	5,862	6,061	3.4%	-0.6%	-3.7%
Barre							2,901	3,200	3,583	3,329	3,436	3,532	3,665	3,579	3,659	2.2%	-0.2%	1.9%
Baseball	16,058	15,539	14,429	14,198	13,561	12,976	13,284	13,152	13,711	14,760	15,642	15,877	15,804	15,731	15,587	-0.9%	-1.4%	1.1%
Basketball	25,961	26,108	25,131	25,156	24,790	23,708	23,669	23,067	23,410	22,343	23,401	24,225	24,917	27,753	27,135	-2.2%	8.9%	4.1%
Bicycling (BMX)	1,887	1,896	1,858	2,090	1,958	1,861	2,168	2,350	2,690	3,104	3,413	3,439	3,648	3,880	3,861	-0.5%	5.8%	4.5%
Bicycling (Mountain/Non-Paved Surface)	6,892	7,242	7,367	7,152	6,989	7,265	8,542	8,044	8,316	8,615	8,609	8,690	8,622	8,998	8,693	-3.4%	0.8%	0.2%
Bicycling (Road/Paved Surface)	38,940	38,527	39,127	39,730	39,834	39,790	40,888	39,725	38,280	38,365	38,866	39,041	39,388	44,471	42,775	-3.8%	8.6%	2.3%
Birdwatching More Than 1/4 Mile From Home/ Vehicle	13,476	13,938	13,847	13,317	13,067	13,535	14,152	13,179	13,093	11,589	12,296	12,344	12,817	15,228	14,815	-2.7%	15.6%	5.3%
Boardsailing/Windsurfing	1,118	1,213	1,218	1,373	1,384	1,372	1,324	1,562	1,766	1,737	1,573	1,556	1,405	1,268	1,297	2.3%	-7.6%	-5.5%
Bodyweight Exercise & Bodyweight Accesso-ry-Assisted Training								22,390	22,146	25,110	24,454	24,183	23,504	22,845	22,629	-0.9%	-3.7%	-2.1%
Boot Camp Style Training					7,706	7,496	6,911	6,774	6,722	6,583	6,651	6,695	6,830	4,969	5,169	4.0%	-24.3%	-3.9%
Bowling	60,184	59,417	57,972	56,585	53,906	48,614	46,209	46,642	45,931	45,925	45,491	45,793	45,372	40,143	41,666	3.8%	-8.2%	-1.8%
Boxing for Competition				855	747	959	1,134	1,278	1,355	1,210	1,368	1,310	1,417	1,361	1,460	7.3%	3.1%	4.1%
Boxing for Fitness				4,788	4,631	4,832	5,251	5,113	5,419	5,175	5,157	5,166	5,198	5,230	5,237	0.1%	0.8%	0.2%
Camping	31,375	32,531	34,012	32,667	31,961	29,982	29,269	28,660	27,742	26,467	26,262	27,416	28,183	36,082	35,985	-0.3%	27.7%	6.8%
Camping (RV)	16,168	16,343	16,977	16,651	16,282	15,108	14,556	14,633	14,699	15,855	16,159	15,980	15,426	17,825	16,371	-8.2%	6.1%	0.9%
Canoeing	9,797	9,866	9,997	10,306	10,170	9,839	10,153	10,044	10,236	10,046	9,220	9,129	8,995	9,595	9,199	-4.1%	2.3%	-1.6%
Cardio Kickboxing	4,812	4,905	5,500	6,287	6,488	6,725	6,311	6,747	6,708	6,899	6,693	6,838	7,026	5,295	5,099	-3.7%	-27.4%	-5.3%
Cardio Tennis		830	1,004	1,340	1,293	1,442	1,539	1,617	1,821	2,125	2,223	2,499	2,501	2,503	2,608	4.2%	4.3%	4.3%
Cheerleading	3,279	3,192	3,070	3,134	3,049	3,244	3,235	3,456	3,608	4,029	3,816	3,841	3,752	3,308	3,465	4.8%	-7.6%	-2.8%
Climbing (Indoor)											5,045	5,112	5,309	5,535	5,684	2.7%	7.1%	
Climbing (Sport/Boulder)											2,103	2,184	2,183	2,290	2,301	0.5%	5.4%	
Climbing (Traditional/Ice/ Mountaineering)	2,062	2,175	2,062	2,017	1,904	2,189	2,319	2,457	2,571	2,790	2,527	2,541	2,400	2,456	2,374	-3.3%	-1.1%	-3.1%

Table 1. *(Outdoor Foundation, 42)*

Nutrition is known to have an immense impact on the performance of athletes in all sports; it is utilized to maximize athletic performance (Kerksick et al., 9). The impact of nutrition on sports performance has been well researched by scholars. Over 2000 research papers were published under the keywords "sports and nutrition" in 2017 (Kerksick et al., 1). **This literature review aims to discuss and explain the relationship and applications of nutrition on athletic performance, with a focus on bouldering, a specific kind of high intensity rock climbing.** By understanding this relationship, professional and recreational rock climbers will be able to enhance their performance in the sport.

II. Methodology

This study required a broad spectrum of literature survey to correlate the dietary requirements of athletes with the dietary requirements of rock climbers. The dietary requirement guidelines established by multiple research papers served as fodder for the larger deductions derived to understand the roles of the nutrients and the dietary requisites of rock climbers. Different categories of rock climbing may require different nutrient profiles as the endurance levels of every category varies moderately (Michael, 7). Hence, the strategy to fill the research lacunae included comparison of dietary requirements from multiple scientific literature with dietary requirement profiles of varied categories of rock climbing.

Furthermore, although numerous research papers were deducted for information, specific selection/exclusion criteria were put in place to ensure accurate and up to date information was included in this Literature Review. The first criteria restricts the use of research papers published before the year 2005, the second criteria ensures that the papers mentioned in this review already had sufficient citations from different scientific papers.

III. Literature Reviews

3.1 Carbohydrates

Of the major macronutrients in the human body, carbohydrates act as the substrate our body metabolizes to yield energy in the form of ATP (Mul et al., 1). Eukaryotic cells have evolved to utilize glucose in order to synthesize energy. Furthermore, glucose undergoes glycogenesis to be converted into glycogen, which will be shuttled as the storage form of carbohydrates within intra-muscular stores (Daghlas and Shamim, 1). These stores of glycogen are then put through a metabolic process, and once again turned into glucose when needed (Daghlas and Shamim, 1). This glucose is used in cellular respiration to synthesize ATP, the metabolite used to power muscle contractions (Musaiger and Samir, 5). Therefore, the goal of consuming carbohydrates in a sport-focused point of view could be put as attempting to replenish the intra-muscular stores of glycogen while in rest during training, or while resting in between training sessions (Burke et al., 1).

It is imperative to mention that carbohydrates can be split into two categories, high-glycemic and low-glycemic index carbohydrates. High-glycemic index carbohydrates (HGI) are present in foods which release glucose quickly into the bloodstream (Arvidsson-Lenner et al., 84-85), such as white bread and cornflakes (Arvidsson-Lenner, et al. 88). Low-glycemic index carbohydrates (LGI) are present in foods that release glucose slowly into the bloodstream, such as Yoghurt (Arvidsson-Lenner et al., 88). A study sampling 7 trained men aimed to find the difference between the effects of HGI and LGI carbohydrates. The researchers found the statistically significant result ($P<0.05$) that muscle glycogen concentrations increased 15%, 3 hours after HGI carbohydrates were consumed at 2.5 g/kg of body weight, while the same consumption of LGI carbohydrates had no effect on muscle glycogen concentrations (Wee et al., 707). For rock climbers, or athletes of any sport, this would suggest that intake of HGI carbohydrates a few hours before exercise may be beneficial to enhance performance through an increase in available muscle-glycogen stores.

One method by which athletes have attempted to enhance their intramuscular glycogen stores is through ingesting carbohydrates along with another substance. Examples such as caffeine (Pedersen et al., 10), and creatine loading (Robinson et al., 598) have been tested, although the safety and the effectiveness of supplementing carbohydrates with the previously mentioned examples is still debated. An undebated method to enhance glycogen storage is to consume carbohydrates in combination with protein (Burke et al., 18). Another sound method of increasing glycogen storage is carbohydrate loading: a meal-timing strategy by which an athlete undergoes high-volume training while consuming small amounts of carbohydrates, followed with a period of high consumption of carbohydrates at roughly 8-10 g/kg of body weight while simultaneously reducing training volume (Kerksick et al., 3). Although this strategy serves the interest of athletes wishing to engage in prolonged endurance competitions, the benefit of carbohydrate loading for athletes that participate in sports that require strength rather than endurance, such as rock climbing, is still to be studied extensively (Michalczyk et al., 1).

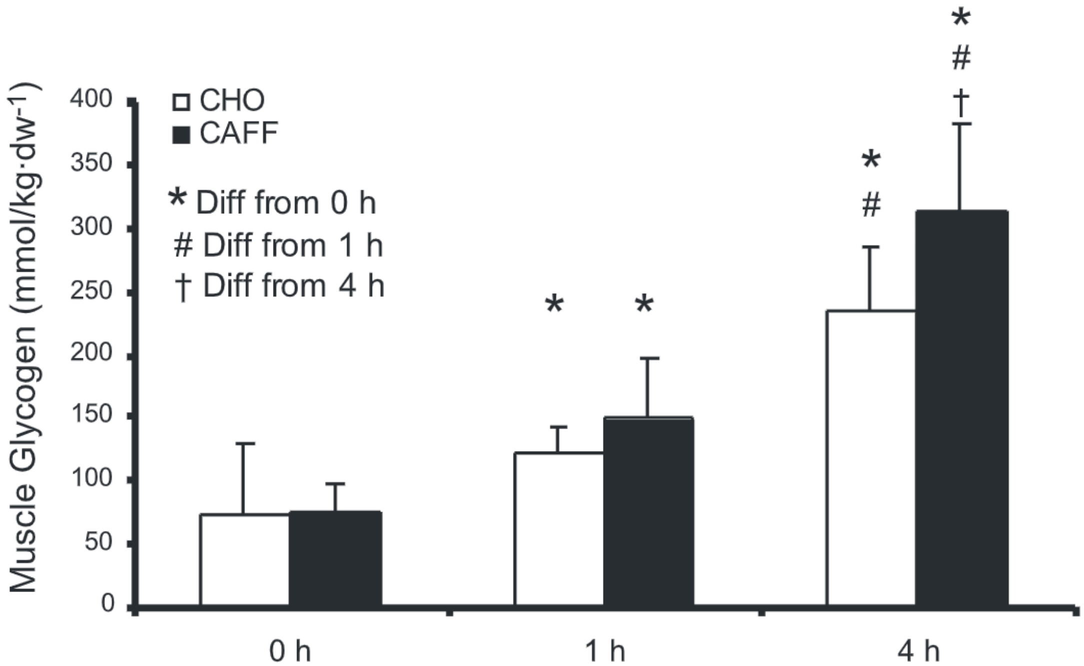

Fig. 1. *Skeletal muscle glycogen content immediately after exercise (0 h) andafter 1 h and 4 h of recovery following cycling to volitional fatigue [70%peak O2 uptake (V˙ O2peak)]. During recovery subjects consumed 1 g carbohy-drate/kg body mass (BM) (CHO) or 1 g carbohydrate/kg BM 8 mg caffeine/kg BM (Caff). *Significant difference vs. 0 h; #significant differencevs. 1 h; †significant difference, CHO vs. Caff 4 h (P 0.05). All values are means SD. (Pederson, 10)*

The amount of carbohydrate an athlete is recommended to consume daily is a function of their weekly training frequency, height, bodyweight, in addition to whether they are concurrently participating in a high-intensity anaerobic activity or sport (Kerksick et al., 11). Those participating in frequent, high intensity training such as 2 to 3 hours of intense exercise a day, 5-6 times a week should aim to consume carbohydrates at 5-8 g/kg of body weight each day (Kerksick et al., 11). Although for climbers with a lighter training schedule akin to the level of intensity of a general fitness program, it is recommended to consume carbohydrates at 3-5 g/kg of body weight each day (Kerksick et al., 11).

3.2 Carbohydrates

Proteins serve as the macronutrients the human body uses for skeletal muscle proliferation (Atherton and Smith, 1050). Although this is true through the process of myofibrillar protein synthesis (Atherton and Smith, 1050), protein serves additional purposes that may prove more benefits to rock climbing performance than increased muscle mass and strength. Mentioned previously in the carbohydrates section, consuming protein alongside carbohydrates enhances glycogen storage in intramuscular stores (Burke et al., 19).

To gauge an individual's appropriate protein intake, nitrogen balance is often used as the appropriate measuring method (Rand et al., 110). Due to the fact that protein is the only nitrogen-containing macronutrient, a comparison of nitrogen consumption to urinary excretion of nitrogen allows researchers to gauge whether an individual is meeting their protein needs. (Dickerson, 2). An insufficient protein intake leads to a negative nitrogen balance, a state in which there is a greater outflow than intake of nitrogen, leading to muscle atrophy, injuries, illness, and training intolerance (Kerksick et al., 11), creating unfavorable conditions for athletes such as rock climbers. However, several issues have been presented regarding the method of measuring an individual's nitrogen balance in order to gauge their appropriate protein intake (Campbell et al., 2). The technical issues associated with this method often understate the required amount of protein an athlete is recommended to consume (Campbell et al, 2). Therefore, any rock climber aiming to maximize their muscle protein synthesis should take this into account when reading about recommended daily doses of protein found through the method of nitrogen balance.

It is perhaps partially due to the technical shortcomings of the nitrogen balance measurement that over recent years, evidence for the recommended daily amount of protein for people in general has increased. In the 1980s, the RDA - recommended daily amount - of protein any adult above the age of 19 should be consuming was 0.75 g/kg of body weight (National, 66). However, evidence that has been gathered over the past decades suggests that adult athletes engaged in intensive training require higher protein levels reaching up to 1.4-1.8 g/kg of body weight (Kerksick et al., 11). The amount of protein an individual should be consuming however, also changes with age (Baum et al, 2). There is early evidence to show that due to a lower sensitivity to protein intake, it is recommended that the population of older individuals consume more protein relative to their body weight when compared to younger individuals (Baum et al., 6).

In 2022 the sales of whey and plant protein saw respective growths of 25% and 12% (Nutritional), an indicator that a growing population of people are turning to protein supplements in the form of powder or capsules to efficiently meet their protein intake goals. In order for athletes such as rock climbers to fully maximize the benefit of consuming this supplement, they first must understand that proteins are measured based on quality, depending on their source (Schaafsma, 988). The way this is measured is through "protein digestibility corrected amino acid score" abbreviated as PDCAA (Schaafsma, 989). The way protein quality is measured through this score is from 0 to 1, or 0 to 100 (FAO, 17), with a score of 1 or 100 meaning that the protein digested can provide all of the essential amino acids required in a diet (Schaafsma, 1). Proteins coming from sources such as tuna and minced beef have a PDCAA value of 1 or 100, while other protein sources such as raw black beans have a PDCAA value of 72 (Schaafsma, 991). Research has found that a greater PDCAA value may result in greater stimulation of muscle protein synthesis (Phillips and Loon, 33).

Lastly, technical details of processes such as protein signaling and gene transcription that lead to adaptations in the body after resistance training and protein ingestion will not be mentioned since it is not the focus of this paper, and will stray away from the topic of how rock climbers can enhance their performance through better awareness of their nutrition.

3.3 Fat

Lipids are the most energy dense out of all macronutrients, containing 9 kcal/gram, while other macronutrients such as carbohydrates and protein contain 4 kcal/gram (Espinosa-Salas and Gonzalez-Arias). Carbohydrates are known as a source of energy, and it is perhaps because of this, that a number of rock climbers may opt for a low fat, high carb diet. Such a diet's caloric intake could be composed of 15% fat, 65% carbohydrates, and 20% protein (Venkatraman et al., 389).

However, researchers have found low fat, high carb diets to be correlated with increases in inflammation and decreases in anti-inflammatory immune factors, depression of antioxidants, and adverse effects on blood lipoprotein ratios (Venkatraman et al., 389). These effects were only reversed when researchers increased subjects' total caloric intake and dietary fat composition to 35% (Venkatraman et al., 389). Furthermore, research has shown that increasing caloric intake of fat may lead to a higher V̇O2max (Venkatraman et al., 389) as well as testosterone level which is positively correlated with fat-free body mass (Ma et al., 1) and strength (Vingren et al., 1037). This increase in strength may be beneficial for rock climbers in the long term as it leads to a higher strength-to-mass ratio, which has been found to be correlated with higher levels of climbing (Ginszt et al., 1340). However, a chi-square analysis done in 2020 has shown that more advanced levels of climbing are correlated with a greater prevalence of eating disorders (Joubert et al., 1), perhaps due to the search for a higher strength-to-mass ratio.

	High-fat, low-fiber diet		Low-fat, high-fiber diet		High-fat diet − low-fat diet		
	Mean	95% CI	Mean	95% CI	Difference[1]	95% CI	P^2
SHBG (nmol/L)	19.2	16.9, 21.6	18.5	16.2, 21.2	1.2	−0.6, 2.9	0.33
Androgens							
Testosterone (nmol/L)							
Total	13.3	11.6, 15.3	11.8	10.1, 13.8	1.6	−0.2, 3.5	0.10
Free	0.31	0.26, 0.36	0.33	0.23, 0.28	0.03	−0.02, 0.08	0.27
Albumin-bound	4.4	3.8, 5.2	4.1	3.4, 4.9	0.4	−0.4, 1.1	0.37
SHBG-bound	8.2	7.0, 9.7	7.1	6.0, 8.5	1.2	0.1, 2.4	0.04
Dihydrotestosterone (nmol/L)	1.2	1.1, 1.4	1.1	0.9, 1.3	0.09	−0.04, 0.22	0.20
DHEAS (μmol/L)	9.3	8.2, 10.5	8.8	7.6, 10.1	0.4	−0.6, 1.4	0.10
Androstanediol glucuronide (nmol/L)	1.7	1.5, 1.9	1.7	1.5, 1.9	0.1	−0.1, 0.2	0.99
Estrogens							
Estrone (pmol/L)	154.1	140.3, 170.0	148.0	133.8, 164.7	4.8	−6.3, 16.0	0.28
Estradiol (pmol/L)							
Total	99.4	87.9, 112.6	104.6	90.9, 120.3	−6.8	−18.7, 5.0	0.31
Free	2.2	2.0, 2.5	2.4	2.1, 2.8	−0.3	−0.6, 0.1	0.15
Albumin-bound	32.9	28.8, 37.4	36.3	30.7, 42.7	−1.7	−6.1, 2.3	0.12
SHBG-bound	63.4	55.7, 72.2	64.9	56.5, 74.1	−2.9	−10.3, 4.4	0.46

[1] Mean differences of untransformed values after removal of outliers: total estradiol (n = 1), free estradiol (n = 1), albumin-bound estradiol (n = 3). DHEAS, dehydroepiandrosterone sulfate.

[2] P value for test of H_o: difference = 0 when using all observations based on a t test when differences were normally distributed (total, free, albumin-bound, and SHBG-bound testosterone; dihydrotestosterone; and SHBG-bound estradiol) and a Wilcoxon rank-sum test when differences were not normally distributed (SHBG, DHEAS, androstanediol glucuronide, estrone, and total, free, and albumin-bound estradiol).

Table 2. *(Dorgan, 853)*

A general recommendation of the amount of daily fat an athlete should be consuming is only slightly higher than an average person at around 30% of the athlete's total daily caloric intake (Kerksick et al., 13). This would serve them beneficially in the long term, with increasing testosterone levels that boost muscle growth/strength. Although if an athlete is attempting to find something that would immediately boost their performance before a competition, current literature suggests that consuming the necessary levels of fats would make a minimal difference.

3.3 Caffeine

An online survey conducted by the International Food Information Council, sampling 1000 adults ranging from 18-80 years of age in the United States found that 88% of their respondents consumed caffeine everyday (IFIC, 10). However, potential undercoverage or response bias may be present in this survey due to it being conducted online. In the same survey above, the IFIC found that nearly a third of Americans ingest caffeine due to its perceived energy boost (IFIC, 8). This notion is justified, as caffeine was found to enhance performance in several aerobic as well as anaerobic sports (Guest et al., 1).

A study sampling 37 resistance-trained men gave one group placebo pills and another group caffeine pills. The researchers of the study found statistically significant results ($P<0.05$), where the volunteers who were randomly assigned the caffeine pill were able to output more upper body power (Beck et al., 506). These results may be useful to rock climbers as the sport uses many muscles within the upper body.

However, results suggesting caffeine's ergogenic effect only emerged in trained individuals (Collomp et al., 439). A study sampling six untrained-individuals found that when participants consumed a pill containing caffeine at 5 mg/kg of body weight, there was no statistically significant increase in anaerobic capacity or power (Collomp et al., 439). These findings suggest that those seeking to enhance their rock climbing performance through the consumption of caffeine should be trained professionals, and not those who rock climb for recreational purposes. However, readers must keep in mind the fact that these suggestions are made on the basis of studies concentrated not specifically on rock climbing. To ascertain caffeine's effect on trained or untrained populations, experiments must be designed with rock climbers specifically as the population of interest.

The previous method by which caffeine possibly enhances rock climbing performance is through increasing muscular strength (Guest et al., 1). Another way caffeine may elevate performance is by helping rock climbers lose weight (Westertetp-Plantenga et al., 1195). Research has positively correlated the levels of caffeine with higher levels of satiety in women (Westertetp-Plantenga et al., 1195), and a meta-analysis of papers seeking to find caffeine's correlation with weight loss found that caffeine intake promotes weight reduction, BMI reduction, as well as fat reduction (Westerterp-Plantenga et al., 1995). Furthermore, a review done in 2023 found that elite level climbers tended to have lower levels of body mass and body fat (Ginszt et al., 1339), as well as higher strength-to-mass ratios (Ginszt et al., 1340). These relationships however, are only correlational, and not causal. Therefore, a decrease in body weight due to caffeine would both decrease body mass and increase a strength-to-mass ratio, thereby possibly, and not certainly, enhancing performance.

Lastly, caffeine consumption has been shown to possibly dehydrate the body through acute diuresis (Antonio et al., 192). For reasons covered in the next paragraph, this may be a fault in ingesting caffeine for the purpose of enhancing athletic performance.

3.5 Hydration

A meta-analysis conducted in 2015 found that dehydration, leading to hypohydration - a state in which body water is greater than 2%, occurring from possibly sweat loss, diuresis, or lack of fluid intake by a person (Sawka et al., 51) - leads to a negative impact on most kinds of athletic performance (Judge et al., 112). This includes a decrease in muscle strength by 5.51%, and a decrease in anaerobic power by 5.82.3% (Judge et al., 112).

Although these studies investigate hypohydration's effects on athletic performance, many fail to isolate confounding variables that may attenuate or exacerbate athletic performance, such as core body temperature (Judelsonet al., 1817). Even in a study that acknowledges this and reduces the presence of confounding variables, it still found that hypohydration consistently attenuated resistance exercise performance (Judelson et al., 1817). It is paramount that athletes who compete in aerobic sports are hydrated throughout their training, as a 2% reduction in body weight due to fluid loss already significantly impairs exercise performance (Kerksick et al., 19), a 4% reduction in body weight due to fluid loss can lead to headaches (Shaheenet al., 2), and an 8% reduction in body weight due to fluid loss can possibly lead to death (Shaheen et al., 2).

However, studies have found that even a critical level of hypohydration (3-5% loss of body weight) likely does not degrade anaerobic performance (American, 381). Suggesting that rock climbers may not be as affected from dehydration when compared to athletes competing in sports such as basketball or football. However, earlier it was mentioned that a meta analysis performed in 2015 found that a state of hypohydration decreased anaerobic power by 5.82.3% (Judge et al., 112), which do suggest rock climbing performance to be negatively impaired with dehydration. Equipped with this conflicting information, rock climbers nevertheless should stay hydrated during anaerobic training or competitions, as most would agree the possible consequences of death (Shaheen et al., 2) far outweigh the possible performance benefits of a higher strength-to-mass ratios (Ginszt et al., 1340).

A strategy that a recreational rock climber may use during training in order to maintain hydration is through ingesting sodium through glucose-electrolyte solution (Kerksick et al., 19). However, rock climbers that participate in the sport for competition and not recreational purposes may benefit more from the aforestated hydration strategy. Additionally, resources suggest a strategy to maintain body weight during exercise through fluid intake is implemented by ingesting " Ingesting 500 mL of water or sports drinks the night before a competition, another 500 mL upon waking and then an-other 400–600 mL of cool water or sports drink 20–30 min before the onset of exercise" (Kerksick et al., 19). This strategy should then be supplemented with routine ingestion of water during a competition such as 0.5-2 L of water every hour in order to maintain appropriate hydration status (Kerksick et al., 19).

3.6 Glycero

Companies such as Coca cola have long established that hydration plays an important role in the performance of athletes in various sports. This has possibly resulted in the creation of "sports drinks" containing glycerol that claim to "support effective hydration" (Coca-Cola).

A study investigating the effects glycerol had on the performance of anaerobic and aerobic exercises took 40 male volunteers who consumed glycerol at 1.2 g/kg of body weight for 20 days. Results confirmed that glycerol increased their performance in both aerobic and anaerobic exercises (Patlar et al., 69). A possible explanation for this is that glycerol can be turned into glucose via gluconeogenesis (Shah et al., 3), and oxidized into ATP(Adenosine triphosphate), which are the molecules that power muscle contraction (Musaiger and Miladi, 5). By increasing the amount of ATP that is readily available, this may improve athletic performance (Patlar et al., 77). Furthermore, glycerol may be used as a hyper hydrating agent, increasing the body's water volume, and increasing the body's duration of hydration by decreasing urinary volume (Patlar et al., 70).

Although the use of glycerol would be beneficial in both recreational and professional-level bouldering, its use was previously banned by the WADA (World Anti Doping Agency) starting 2010 (World, 5). This meant olympic level boulderers and those who competed in competitions provided by the IFSC, International Federation of Sport Climbing, were not able to take advantage of glycerol's benefits. Although, the reason for prohibiting glycerol was not for its performance enhancing properties, but because it can act as a masking agent (World, 5). However the ban on glycerol was lifted in 2018, as it was no longer included in their prohibited list of banned substances (World, 2), thus as of the publishing year of this literature review, glycerol is a legal substance to consume under WADA.

3.7 Creatine

An athlete's nutrition plan should focus on food and proper meals, although dietary supplements can prove to be useful and make small contributions to a nutrition plan. There is no explicit definition for what a dietary supplement is, but it can be described as "A food, food component, nutrient, or nonfood compound that is purposefully ingested in addition to the habitually-consumed diet with the aim of achieving a specific health and/or performance benefit" (Maughan et al., 105). These sought after benefits can include access to more convenient sources of energy, enhanced athletic performance, and shorter recovery periods.

Creatine is a non-protein amino acid found commonly in many foods such as red meats and seafoods (Kreider et al., 2). Within the human body, the majority of creatine is found within skeletal muscle, and some traces are found in the brain and testes (Kreider et al., 2). Creatine is one of the most popular among the dietary supplements on the market (Kreider et al., 1). This may be due to the fact that it is one of the most researched supplements available, with over 500 research papers published on its effects on muscle physiology and exercise capacity in various populations (Kreider, 89). This is likely due to the findings of creatine's performance enhancing properties (Kreider et al., 1).

Research has found that short term creatine supplementation, such as taking 20 grams a day for 5-7 days has been reported to improve maximal power/strength by 5-15% (Kreider, 89). Moreover, a number of studies have researched creatine's applications regarding its possible neuroprotective properties against diseases such as Parkinsons and Huntington's disease (Kreider et al., 1). Creatine may not only help the aging population fight against diseases, but may also improve cognitive function possibly due to an increase in brain creatine and phosphocreatine levels (Rawson and Andrew, 1349). Although this trend of cognitive improvement is mainly seen in the elderly population, these effects may not be present in younger populations, as a limited body of evidence suggests that creatine has no effect on the cognitive performance of young adults (Moriarty et al., 1). This means that for the older population of people who rock climb for recreational purposes, supplementing creatine may not only help with increasing their performance physically by enhancing maximal power and strength, but may also help by improving cognitive function, thereby improving the ability to solve bouldering "problems".

One of the many explanations as to why creatine may enhance high-intensity exercise performance is due to the fact that this kind of performance is partly powered by the creatine-phosphocreatine system (Sahlin, 168), as much of the anaerobic production of ATP is fuelled by PCr (phosphocreatine). "For example in a single 6-s sprint, glycogen degradation (glycogenolysis) contributes 50 % of the ATP production, whereas PCr contributes 48 % and the remaining 2 % is provided by the muscle's small store of ATP" (Williams and Ian, 14).

IV. Discussion

Rock climbing in all forms is a strength based sport, where bouldering is the discipline that seems to create the strongest climbers in terms of strength when compared to lead and speed climbing (Stien et al, 1). Major muscles that contribute to rock climbing movements include, but are not limited to, the digit flexors, shoulder adductors, elbow flexors, and lumbar flexors (Deyhle, 2006). These muscles play a critical role in actions such as gripping, and spine stabilization (Deyhle, 2007). This discussion iterates the role of the nutrients in promoting the human body to effectively enhance performance during a climb.

Muscle glycogen levels being a significant component in muscular activity plays a pivotal role in muscle activity for rock climbers (Mul et al., 1; Musaiger and Samir, 5). High Glycemic Index (HGI) foods were mentioned to have increased muscle glycogen concentrations by 15% post 3 hours of consumption, at 2.5 g/kg of bodyweight (Wee et al., 707). Though the same consumption of Low Glycemic Index (LGI) yielded no change in muscle glycogen concentrations (Wee et al., 707). This information prompts rock climbers of every category to consume HGI foods such as white bread and cornflakes (Arvidsson-Lenner, et al. 88) shortly before any competition or climbing session in order to enhance performance through an increase in available muscle-glycogen stores. Additionally, supplementing the consumption of HGI with caffeine may enhance the effectiveness of glycogen shuttling into intramuscular stores (Pedersen et al., 10). Speed climbers may be similar in strength to boulderers as elite speed climbers are characterized as having a "high anaerobic relative strength" (Hosseini and Wolf, 10), hence both might require similar levels of carbohydrate-loading through ingestion of HGI. Lead climbing is the longest in duration when compared to bouldering or speed climbing (Olympics), and therefore a comparatively higher level of HGI consumption than speed climbing and bouldering is likely to be required.

Proteins act as the building blocks for a rock climber's skeletal muscle (Atherton and Smith, 1050), which is the mechanism inside the body responsible for the rock climber's various actions of movement (Pham and Puckett). Papers often utilize the BUN (Blood Urea Nitrogen) levels in order to gauge the appropriate level of protein intake for an athlete (Rand et al., 110) . This method however, has been found to potentially understate the amount of protein necessary for optimized muscle growth for enhanced performance (Campbell et al, 2). Therefore, it is perhaps in the best interest of boulderers, speed climbers, and lead climbers alike to consume slightly more protein in their daily diet than the recommended 1.4-1.8 g/kg of bodyweight (Kerksick et al., 11). Another point of interest is in the existence of antinutrients such as tannins, lectins, and phytic acid. Foods such as kidney beans contain such antinutrients which decrease the bioavailability of certain nutrients, and minerals such as Iron and Zinc (Abera et al., 2). Thus, a rock climber of any category that aims to maximize their diet absorption of nutrients may consider avoiding consumption of foods with antinutrients. Furthermore, if an athlete is supplementing their diet with protein powder in order to meet a certain level of protein intake, they should consume a protein powder with a PDCAA, protein digestibility corrected amino acid score, of 1. A PDCAA of 1 means that the protein powder digested can provide every essential amino acid required in a diet (Schaafsma, 1), giving the rock climbers of every category a more complete diet. To that end, regular foods containing proteins have their own PDCAA scores, milk with a PDCAA of 1, beef at 0.92, and soy at 0.91 (Vilet et al., 3). A PDCAA score however, is not authoritative of what source protein is ingested from, as different factors such as preferred calorie to protein ratio and fat to protein ratio changes based on the rock climber.

Lipids are the most energy dense out of all the macronutrients (Espinosa-Salas and Gonzalez-Arias). It is perhaps for this reason that athletes in antigravitational sports such as rock climbing, where a higher strength-to-mass ratio is correlated with a greater performance (Ginszt et al., 1340), avoid this macronutrient in their diet. However, research has found that increased caloric intakes of fats led to higher VO2 max (Venkatraman et al., 389), testosterone levels (Dorgan, 853), and an increase of fat-free body mass (Ma et al., 1) and strength (Vingren et al., 1037). These results suggest that lead climbers are likely to benefit the most out of consuming more daily calories through fat intake when compared to boulderers or speed climbers, as stamina levels likely play a more pivotal role in athletic performance for lead climbers due to the fact that lead climbers climb for longer in duration (Stien et al., 2).

Due to the fact that caffeine is a commonly consumed substance (IFIC, 10), many of the performance benefits that can be taken advantage of from caffeine may already be in effect for all rock climbers across all categories. It was previously mentioned that caffeine consumption increased the maximum weight that participants were able to lift though chest and leg press (Beck et al., 506). Boulderers and speed climbers would therefore face the most benefit from caffeine, as these divisions of rock climbing require rapid and powerful movements through anaerobic strength (Hosseini and Wolf, 10; Stien et al, 1). These results of performance enhancement however, only emerged in trained individuals (Collomp et al., 439). This leads to the conclusion that rock climbers seeking to improve their performance in the sport by increasing upper and lower body strength through the ingestion of caffeine should be experienced individuals, and not novices who are beginning in the sport.

Water is essential to life (Dargaville and Hutmacher, 1). It is perhaps due to this that an 8% reduction in body weight due to fluid loss can possibly lead to death (Shaheen et al., 2). Furthermore, levels of hypohydration decreased anaerobic exercise performance (Judge et al., 112). Despite this though, a study found that a critical level of hypohydration - 3-5% loss of body weight - did not degrade anaerobic performance (American, 381). This study however, was done in 2007, while the study conducted by Judge et al. that concluded hypohydration to decrease anaerobic performance was conducted in 2021. Due to the fact that the study by Judge et al. was conducted more recently, it's likely that their results are more accurate. This data suggests that hypohydration in rock climbing will negatively affect performance in all categories of rock climbing: bouldering, speed climbing, and lead climbing. Regardless of research suggesting boulderers' athletic performance may not be considerably strained due to hypohydration, it is highly recommended that they still stay hydrated throughout their training sessions and competitions.

When glycerol is consumed into the human body, it can be turned into glucose via gluconeogenesis (Shah et al., 3), and oxidized into ATP, Adenosine triphosphate, which are the molecules that power muscle contraction (Musaiger and Miladi, 5). This increase in ATP supply within the body may have a relationship with the length of time as well as the maximal amount of force that skeletal muscle can produce (Patlar et al., 77). This reasoning may be the reason why a study found that glycerol consumption enhanced both aerobic and anaerobic performance in male volunteers. A rock climber from any one of the three olympic categories would likely benefit equally from glycerol's effects due to the fact that it enhances both aerobic and anaerobic movements (Patlar et al., 69). Furthermore, it is recommended that rock climbers who are involved in competitions consume glycerol as it is now a legal substance under the World Anti Doping Agency (World, 2).

Creatine is one of the most popular dietary supplements among athletes (Kreider et al., 1), perhaps due to its performance enhancing capabilities that have been well researched across more than 500 research papers (Kreider, 89). Ingestion of creatine at 20 grams a day for 5-7 days has been reported to improve maximal power/strength by 5-15% (Kreider, 89), moreover research has revealed that the supplement has neuroprotective properties against diseases such as parkinson's (Kreider et al., 1), in addition to increasing cognitive function within the human brain (Rawson and Andrew, 1349). This suggests that creatine may be the most effective when taken by elderly boulderers. Furthermore, based on the research acquired, it is in the best interest of rock climbers of all olympic categories, bouldering, speed and lead climbing, to consume creatine regularly as part of their daily diet.

A handful of the deductions made in this review were based on research papers studying the effects of varying nutritional elements in general anaerobic sports, but not research works specific to rock climbing. To fully understand and confirm the effects of differing nutritional elements on rock climbing, more research that specifically aims to uncover the connection between nutrition and rock climbing must be conducted in order to properly and responsibly conclude the research results to the rock climber's guild.

Furthermore, much of the information presented in this literature review was taken from the International Society of Sports Nutrition. If the reader wants a more in depth, comprehensive review of the nutrition needed not only for rock climbing, a high intensity sport, but for other sports, they should visit https://www.sportsnutritionsociety.org/ and read for themselves the relevant topics for the sports they want to improve in. Additionally, their sports nutrition 2022 review (Kerksick et al.) contains much information about many other dietary supplements that were not mentioned in this paper such as anabolic steroids, Isoflavones, Vanadium, ZMA, etc. Furthermore, many of the studies mentioned in this literature review were samples collected from males, and thus the results of the studies cited in this literature review may not be accurate when generalized to a population of female athletes. Therefore, for female rock climbers reading this paper in hope of enhancing their performance through nutrition, it is recommended they read "Nutritional Considerations for Female Rock Climbers"(Leslie-Wujastyk and Gibson-Smith) in order to better understand the nutritional needs of female rock climbers.

Research regarding how the duration between meals can affect sports performance is still vastly lacking. The single piece of information included in this literature review regarding meal timing was the inclusion of carbohydrate-loading. Furthermore, most of the information found was limited to how meal timing affected processes such as weight loss or muscle protein synthesis. This may help rock climbers improve their performance in the long term, but has minimal effects if an athlete is looking for something that can immediately boost their sports performance.

On the topic of weight loss in rock climbers, it is worth considering the sparsely previously mentioned tendencies of rock climbers in reaching a lower body weight to strength ratio. This is usually done by intentionally eating an inadequate amount of calories for better calisthenic ability. Due to this reality in the sport, many climbers develop eating disorders

In addition to experiments being concentrated to a certain population, a number of experiments cited within this literature review, such as (50, 53), had insufficient sample sizes, $n < 30$ when measuring a sample mean, for the results to be considered normal. Therefore, future experiments which sample means such as finding a subject's pre and post bench press after creatine supplementation should be conducted with more than 30 participants.

V. Conclusion

Strengths of this research paper include the fact that the discussion mentions all of the olympic categories of rock climbing, while many of the research papers cited in the previous literature review are limited only to one or two of the olympic categories in their discussion. Some weaknesses of this paper may be the inclusion of sources dating back more than 10 years.

Vast amounts of research must still be conducted in order for rock climbers to fully understand how nutrition may provide ergogenic effects to rock climbing performance. However, by gathering the closest information scientific literature offers regarding how nutrition may affect rock climbing performance, future researchers of the same topic will know what areas of research that tie in nutrition with rock climbing still need researching. Furthermore, rock climbers reading this literature review will be able to make rough guidelines surrounding their diet.

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