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Article *in* Journal of Sports Sciences · June 2011

DOI: 10.1080/02640414.2011.574722 · Source: PubMed

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Journal of Sports Sciences, 2011; 1–11, i*First* article

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Nutrition guidelines for strength sports: Sprinting, weightlifting, throwing events, and bodybuilding

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(Accepted 21 March 2011)

Abstract

Strength and power athletes are primarily interested in enhancing power relative to body weight and thus almost all undertake some form of resistance training. While athletes may periodically attempt to promote skeletal muscle hypertrophy, key nutritional issues are broader than those pertinent to hypertrophy and include an appreciation of the sports supplement industry, the strategic timing of nutrient intake to maximize fuelling and recovery objectives, plus achievement of pre-competition body mass requirements. Total energy and macronutrient intakes of strength-power athletes are generally high but intakes tend to be unremarkable when expressed relative to body mass. Greater insight into optimization of dietary intake to achieve nutrition-related goals would be achieved from assessment of nutrient distribution over the day, especially intake before, during, and after exercise. This information is not readily available on strength-power athletes and research is warranted. There is a general void of scientific investigation relating specifically to this unique group of athletes. Until this is resolved, sports nutrition recommendations for strength-power athletes should be directed at the individual athlete, focusing on their specific nutrition-related goals, with an emphasis on the nutritional support of training.

Keywords: *Strength, power, athlete, diet*

Introduction

The ability to generate explosive muscle power and strength is critical to success in Olympic weightlifting and powerlifting, as well as throwing events, including javelin, discus, shot put and hammer, plus sprints (100–200 m) in track and field. Consequently, athletes competing in these events will typically incorporate some form of generic resistance exercise into their overall training programme despite sport-specific training varying markedly.

Athletics competitors participating in throwing events typically undertake periodized training programmes that aim to develop maximum strength and power of the major muscle groups using a range of modalities such as plyometric exercises, sprinting, power lifts, Olympic lifts and weighted throwing drills to complement technical throwing training. Periodization of resistance training typically involves a transition from high-volume, high-force, low-velocity movements requiring less coordination characteristic of traditional powerlifting (Hoffman, Cooper, Wendell, & Kang, 2004) to more explosive, lower-force, low-repetition training using Olympic lifts in preparation for competition (Judge, Moreau, & Burke, 2003). The focus on explosive Olympic lifts over more traditional strength-based lifting results in more favourable power and strength gains (Hoffman et al., 2004), derived primarily from neural rather than skeletal muscle hypertrophy adaptations (Folland & Williams, 2007).

Consequently, this style of training enhances traits important to athletic development and is common among other explosive athletics disciplines like sprinting and jumping events (Lambert & Flynn, 2002), and is increasingly being incorporated into the training practices of powerlifters (Swinton, Lloyd, Agouris, & Stewart, 2009).

Unlike other sports that use resistance exercise to complement sport-specific training, powerlifting, Olympic lifting, and bodybuilding use resistance training as a primary mode of training. While Olympic and powerlifting athletes are primarily concerned with enhancing power and strength respectively, bodybuilding training primarily aims

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ISSN 0264-0414 print/ISSN 1466-447X online © 2011 Taylor & Francis
DOI: 10.1080/02640414.2011.574722

to induce skeletal muscle hypertrophy. Consequently, the training programmes of bodybuilders are unique, typically of greater volume than those of other athletes, using higher repetition ranges with multiple sets per muscle group and little rest between sets (Lambert & Flynn, 2002).

Given the disparity between sport-specific training programmes of strength-power athletes and their subsequent metabolic implications, this paper will focus on the nutritional implications of resistance training among strength-power athletes. The sport of bodybuilding will also be addressed given the focus on resistance exercise in overall training programme prescription.

Training nutrition

Nutrition plays an important role in three aspects of training nutrition for strength-power athletes: fuelling of sport-specific and strength training, recovery from this training, and the promotion of training adaptations, including skeletal muscle hypertrophy. Resistance exercise requires a high rate of energy supply, derived from both the phosphagen energy systems and glycogenolysis (Lambert & Flynn, 2002; Tesch, Colliander, & Kaiser, 1986), the contribution being dependent upon the relative power output, the work-to-rest ratio, and muscle blood flow (Tesch et al., 1986). The source of fatigue during resistance exercise is likely multi-factorial, including neuromuscular (Hakkinen, 1993) and peripheral metabolic factors such as a decline in intramuscular pH (MacDougall et al., 1999), the latter being somewhat dependent on the intensity and volume of training undertaken as well as the time point within a resistance training session. Metabolic fatigue during the earlier part of a workout may be due at least partially to reductions in phosphagen energy system stores and mild acidosis, while subsequent fatigue may result more from acidosis and impaired energy production from glycogenolysis (MacDougall et al., 1999).

A summary of the reported dietary intake of adult strength-power athletes in training is presented in Tables I and II. Investigations including athletes acknowledging the use of anabolic steroids have been omitted as steroid use has been shown to influence dietary practices (Kleiner, Calabrese, Fiedler, Naito, & Skibinski, 1989). Investigations focusing on the pre-competition dietary practices of bodybuilders have also been omitted due to the range of novel interventions undertaken acutely before competition to maximize muscularity, including adjustments in sodium, fluid, and carbohydrate intake (Kleiner, Bazzarre, & Litchford, 1990; Walberg-Rankin, Edmonds, & Gwazdauskas, 1993).

Given the extreme muscularity of these individuals and the association between muscle mass and total energy expenditure (Schulz & Schoeller, 1994), it is not surprising that these athletes have generous energy intakes. However, when expressed relative to body mass the energy intakes of strength-power athletes are generally unremarkable relative to those reported for athletes in other sports (Burke et al., 2003) but lower than current strength athlete guidelines of ~ 185–$210\ \text{kJ} \cdot \text{kg}^{-1}$ body mass (Manore, Barr, & Butterfield, 2000). This likely reflects the fact that taller and/or more muscular individuals have lower resting and total energy requirements relative to body mass (Heymsfield et al., 2009). Thus, consideration may need to be given to the allometric scaling of traditional sports nutrition guidelines for macronutrients among larger athletes to reflect their lower relative energy requirements. Consideration should also be given to the distribution of nutrient intake, with a paucity of information available on daily distribution of nutrient intake (Burke et al., 2003; van Erp-Baart, Saris, Binkhorst, Vos, & Elvers, 1989), making it difficult to infer compliance with guidelines relating to key periods of nutrient intake, specifically before, during, and after exercise.

Carbohydrate

A single resistance training session can result in reductions in muscle glycogen stores of as much as 24–40% (Koopman et al., 2006; MacDougall et al., 1999; Pascoe, Costill, Fink, Robergs, & Zachwieja, 1993; Tesch et al., 1986), the amount of depletion depending on the duration, intensity, and overall work accomplished during the session. Higher-repetition, moderate-load training characteristic of programming prescribed to promote skeletal muscle hypertrophy results in the greatest reductions in muscle glycogen stores (Pascoe et al., 1993), an effect most pronounced in type II fibres (Koopman et al., 2006). Reductions in muscle glycogen stores have been associated with performance impairment in both isokinetic torque (Jacobs, Kaiser, & Tesch, 1981) and isoinertial resistance training capacity (Leveritt & Abernethy, 1999), although this effect is not always evident (Mitchell, DiLauro, Pizza, & Cavender, 1997) and possibly dependent on the method used to induce a state of glycogen depletion. Nonetheless, it is conceivable that impaired training or competition performance could occur in any session or event that relied on rapid and repeated glycogen breakdown.

Given that resistance training is merely one component of the overall training programme of sprints and throwing event athletes, and that the skeletal muscle damage that accompanies resistance training (Gibala et al., 2000) impairs muscle glycogen resynthesis (Zehnder, Muelli, Buchli, Kuehne, & Boutellier, 2004), it would seem pertinent to

Table I. Reported dietary intake of energy and macronutrients among adult male strength and power athletes during training (unless otherwise stated) since 1980.

Sport	Population	Body mass (kg)	Energy		Carbohydrate		Protein		Fat		Survey method	Reference
			MJ	$kJ \cdot kg^{-1}$	g	$g \cdot kg^{-1}$	g	$g \cdot kg^{-1}$	g	% E		
Throwing	Elite ($n=6$)	109	22.4 ± 2.9	205 ± 25	450 ± 52	4.1 ± 0.5	265 ± 44	2.4 ± 0.4	277 ± 97	47 ± 16	3–5 day weighed diary	Chen et al. (1989)
	National level ($n=20$)	96	14.6 ± 3.3	152 ± 36	375	3.9	160	1.7 ± 0.9	158	41 ± 5	7 day diary	Faber et al. (1990)
	National team ($n=2$)	104	15.0 ± 2.8	145 ± 20	429 ± 81	4.1 ± 0.6	134 ± 2	1.3 ± 0.1	119 ± 8	30 ± 4	3 day diary	Sugiura et al. (1999)
Sprinting	National level ($n=10$)	67	11.1 ± 1.5	167 ± 33	340 ± 57	5.1 ± 1.0	102 ± 20	1.5 ± 0.4	90 ± 16	30 ± 3	3 day diary	Sugiura et al. (1999)
Weightlifting	Elite ($n=10$)	80	19.2 ± 2.5	238 ± 25	431 ± 96	5.4 ± 1.2	257 ± 47	3.2 ± 0.6	205 ± 33	40 ± 7	3–5 day weighed diary	Chen et al. (1989)
	International ($n=7$)	76	12.8	167	320	4.2	97	1.3	134	39	4–7 day diary	van Erp-Baart et al. (1989)
	National and collegiate ($n=28$)		15.2 ± 3.9		392		161		160	39 ± 6	3 day diary	Grandjean (1989)
	National team ($n=15$)	95	31.4	330	764	8	295	3.1	380	45	3 day semi-weighed diary	Heinemann & Zerbes (1989)
	National level ($n=19$)	84	15.2 ± 5.0	181 ± 50	399 ± 143	4.8	156 ± 42	1.9 ± 0.6	155 ± 62	39 ± 4	7 day diary	Burke et al. (1991)
Bodybuilding	Competitive ($n=76$)	82	15.0 ± 4.2	183	320 ± 132	3.9	200 ± 79	2.4	157 ± 50	39	7 day diary	Faber et al. (1986)
	Elite ($n=6$)	80	20.1 ± 0.2	251	592	7.4 ± 0.3	224	2.7 ± 0.1	174	32	7 day diary	Tarnopolsky et al. (1988)
	International ($n=8$)	87	13.7	157	424	4.9	201	2.5	118	32	4–7 day diary	van Erp-Baart et al. (1989)
	Competitive ($n=7$)											
	Training	91	15.0 ± 4.9	165	457 ± 148	5	215 ± 59	2.4	110 ± 71	26 ± 12	3 day diary	Heyward et al. (1989)
	Competition	86	9.8 ± 1.1	113	365 ± 76	4.2	163 ± 59	1.9	32 ± 18	13 ± 8		
	Competitive ($n=20$)	77	15.4 ± 4.4	200	532	6.9	165	2.1	120	29 ± 7	4 day diary	Giada et al. (1996)
	International ($n=7$)	85	12.4 ± 1.5	145	369 ± 70	4.3	144 ± 41	1.7	95 ± 12	28	4 day diary	Maestu et al. (2010)

Table II. Reported dietary intake of energy and macronutrients among adult female strength and power athletes during training (unless otherwise stated) since 1980.

Sport	Population	Body mass (kg)	Energy		Carbohydrate		Protein		Fat		Survey method	Reference
			MJ	kJ · kg^{-1}	g	g · kg^{-1}	g	g · kg^{-1}	g	% E		
Throwing	Elite ($n = 6$)	84	18.6 ± 3.1	222 ± 38	386 ± 57	4.6 ± 0.7	208 ± 28	2.5 ± 0.3	230 ± 14	47 ± 21	3–5 day weighed diary	Chen et al. (1989)
	National level ($n = 10$)	83	9.3 ± 2.0	112 ± 28	269	3.2	94	1.1 ± 0.3	95	38 ± 6	7 day diary	Faber et al. (1990)
	National team ($n = 8$)	67	11.0 ± 2.4	167 ± 39	336 ± 68	5.1 ± 1.1	93 ± 23	1.4 ± 0.4	94 ± 24	32 ± 3	3 day diary	Sugiura et al. (1999)
Sprinting	National level ($n = 11$)	54	10.0 ± 2.2	191 ± 46	305 ± 79	5.8 ± 1.6	89 ± 25	1.7 ± 0.5	86 ± 17	33 ± 4	3 day diary	Sugiura et al. (1999)
Bodybuilding	International ($n = 4$)	56	6.2	110	196	3.5	112	2.0	47	28	4–7 day diary	van Erp-Baart et al. (1989)
	Competitive ($n = 12$)	58	6.8 ± 2.3	118	208 ± 60	3.6	102 ± 30	1.8	42 ± 30	21 ± 9	3 day diary	Heyward et al. (1989)
	Training	52	6.1 ± 2.7	117	261 ± 112	5.0	77 ± 57	1.5	15 ± 7	10 ± 3		
	Competition											
	Collegiate ($n = 4$)	58	9.1 ± 3.6	156	290 ± 124	5.0	99 ± 44	1.7	69 ± 44	28.1	3 day diary	Lamar-Hildebrand et al. (1989)

encourage strength-trained athletes to maintain a moderate carbohydrate intake. Guidelines proposing an intake within the range of 6 g · kg^{-1} body mass for male strength athletes (Lambert & Flynn, 2002) and possibly less for females (Volek, Forsythe, & Kraemer, 2006) have been advocated. Dietary survey literature relating to strength athletes suggests lifters and throwers typically report carbohydrate intakes of 3–5 g · kg^{-1} body mass, while bodybuilders maintain daily intakes equivalent to 4–7 g · kg^{-1} body mass, independent of gender (Tables I and II). While this may appear low relative to endurance athletes (Burke, Cox, Culmmings, & Desbrow, 2001), conclusive evidence of benefit from maintaining a habitual high carbohydrate intake among strength athletes remains to be confirmed. Given the lower relative energy expenditure of larger athletes and their requirements for other nutrients, plus the impact of adjusting carbohydrate on total energy intake, recommendations for carbohydrate intake at strategic times, including before, during and after exercise, may be more applicable for the strength athlete, ensuring carbohydrate availability is optimized at critical time points. Thus we would consider a range of daily carbohydrate intakes between 4 and 7 g · kg^{-1} body mass as reasonable for these athletes depending on their phase of training.

Protein

Strength-trained athletes have advocated high protein diets for many years. While debate continues on the need for additional protein among resistance-trained individuals, general guidelines now recommend athletes undertaking strength training ingest approximately twice current recommendations for protein of their sedentary counterparts or as much as 1.6–1.7 g protein · kg^{-1} · day^{-1} (Phillips, 2004). Given the relatively wide distribution of protein in the meal plan and increased energy intake of athletes, it should not be surprising to learn that the majority of strength-trained athletes easily achieve these increased protein needs (Tables I and II). Exceeding the upper range of protein intake guidelines offers no further benefit and simply promotes increased amino acid catabolism and protein oxidation (Moore et al., 2009). Furthermore, there is evidence that an intense period of resistance training reduces protein turnover and improves net protein retention, thus reducing relative dietary protein requirements of experienced resistance-trained athletes (Hartman, Moore, & Phillips, 2006).

Simply contrasting an athlete's current daily protein intake against guidelines does not address if protein intake has been optimized to promote gains in muscle mass or optimize repair of damaged tissues. Rather, consideration should be given to other dietary factors, including total energy intake (Calloway & Spector, 1954), the daily distribution of protein intake, especially as it relates to training, and the source of dietary protein (Tang & Phillips, 2009). While there is very little information available on the eating patterns of strength athletes, available literature suggests the majority of daily protein intake is ingested at main meals, with little consideration for between-meal intake, presumably inclusive of pre- and post-training snacks (Burke et al., 2003). Thus, rather than focusing on total daily intake, athletes are encouraged to consume rapidly digested protein meals/snacks in close proximity to their exercise bout, especially during and after exercise (Phillips & Van Loon, 2011). Less is known about the impact of protein distribution in the meal plan outside of the acute period before and/or after exercise (<3 h). There is some evidence to suggest that protein breakdown may be less with a wider distribution of daily protein intake compared with an acute daily bolus of protein (Arnal et al., 2000). However, given that muscle protein synthesis becomes refractory to persistent aminoacidemia (Bohe, Low, Wolfe, & Rennie, 2001), Moore and colleagues (2009) suggest the ingestion of 20 g of high biological value protein (8–10 g essential amino acids) no more than 5–6 times daily may result in maximal stimulation of muscle protein synthesis.

Fat

The dietary fat intake of strength-power athletes reported in Tables I and II is generally higher than that recommended for healthy individuals (Zello, 2006), and often derived from sources rich in saturated fat (Chen et al., 1989; Faber, Benade, & van Eck, 1986; Faber, Spinnler-Benade, & Daubitzer, 1990; Giada et al., 1996), presumably from an emphasis on animal foods in the pursuit of a higher protein intake (Chen et al., 1989). While the acute health implications of such dietary practices on blood lipid profiles is not immediately evident (Faber et al., 1986, 1990; Giada et al., 1996), it may explain in part the lower dietary carbohydrate intakes reported among strength-power athletes. Given that isoenergetic substitution of fat for carbohydrate has a favourable effect on nitrogen balance (Richardson, Wayler, Scrimshaw, & Young, 1979), it is tempting to advocate a reduction in dietary fat intake, especially for those individuals exceeding current guidelines for fat intake. However, consideration must be given to the practical implication of substituting a high-energy density macronutrient with a lower energy macronutrient and the impact this may have on energy balance, especially among strength-power athletes with very high energy needs. Conversely, there may be situations in which a higher intake of foods rich in unsaturated fats may be advocated for strength-power athletes struggling to achieve energy needs because of an emphasis on the selection of lower energy density foods in the meal plan.

Pre-exercise and during exercise

Athletes are encouraged to pay particular attention to dietary intake in the hours before exercise, based on the assumption that pre-exercise nutritional strategies can influence exercise performance. While this is a widely accepted practice before endurance exercise to enhance work capacity (Hargreaves, Hawley, & Jeukendrup, 2004), evidence is also emerging for a beneficial role of acute carbohydrate ingestion prior to strength training. For example, Lambert and colleagues (Lambert, Flynn, Boone, Michaud, & Rodriguez-Zayas, 1991) reported that supplemental carbohydrate ingestion before and during resistance exercise ($1\ \text{g} \cdot \text{kg}^{-1}$ before, $0.5\ \text{g} \cdot \text{kg}^{-1}$ during) increased total work capacity, a response that has been replicated elsewhere (Haff et al., 1999, 2001). However, not all investigations show benefit with acute carbohydrate ingestion (Haff et al., 2000; Kulik et al., 2008); we propose that the ergogenic potential for carbohydrate ingestion is most likely to be observed when undertaking resistance training of long duration and high volume. At present, a specific recommendation for an optimum rate or timing of carbohydrate ingestion for strength-power athletes before and during any given training session cannot be determined. As with all athletes, strength-power athletes should be encouraged to initiate training in a euhydrated state given that even moderate hypohydration can impair resistance-training work capacity (Kraft et al., 2010).

Recently, there has been interest in the co-ingestion of carbohydrate and essential amino acids both before and during resistance exercise, presumably to increase substrate availability and thus exercise performance, promote a more anabolic hormonal environment (Bird, Tarpenning, & Marino, 2006a, 2006b), stimulate muscle protein synthesis (Tipton et al., 2001), and/or reduce indices of muscle damage and soreness (Bird et al., 2006b; Saunders, Kane, & Todd, 2004). While initial research had suggested a greater muscle protein synthetic response to resistance training when nutritional support was provided before compared with after resistance exercise (Tipton et al., 2001), this has not been replicated elsewhere (Fujita et al., 2009; Tipton et al., 2007). Consequently, current guidelines advocate protein ingestion at a time that coincides with maximal stimulation of muscle protein synthesis, which is after exercise (Burd, Tang, Moore, & Phillips, 2009).

Recovery

Given that resistance training typically forms only one component of an athlete's training schedule, recovery strategies shown to enhance restoration of muscle glycogen stores such as post-exercise carbohydrate ingestion should be routinely implemented following resistance training. General sports nutrition guidelines advocate the ingestion of carbohydrate at a rate of 1.0–1.2 $g \cdot kg^{-1}$ body mass in the immediate post-exercise period (Burke, Kiens, & Ivy, 2004). However, this has no influence on muscle protein metabolism (Koopman et al., 2007). In contrast, post-exercise dietary protein ingestion results in an exacerbated elevation in muscle protein synthesis with a concomitant minor suppression in muscle protein breakdown, resulting in a positive net protein balance (Phillips, Tang, & Moore, 2009). The ingestion of $\sim$20 g of high biological value protein after resistance exercise appears to be sufficient to maximally stimulate muscle protein synthesis, with amounts in excess of this merely promoting protein oxidation (Moore et al., 2009). Thus the combined ingestion of carbohydrate and protein acutely following resistance training results in more favourable recovery outcomes, including restoration of muscle glycogen stores and muscle protein metabolism, than the ingestion of either nutrient alone (Miller, Tipton, Chinkes, Wolf, & Wolfe, 2003). Post-exercise protein ingestion also lowers carbohydrate intake requirements in the acute recovery period, with an energy-matched intake of $0.8 \text{ g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ carbohydrate plus $0.4 \text{ g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ protein resulting in similar muscle glycogen resynthesis over 5 h as $1.2 \text{ g} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$ carbohydrate alone following intermittent exercise (van Loon, Saris, Kruijshoop, & Wagenmakers, 2000), with a similar response evident following resistance exercise (Roy & Tarnopolsky, 1998). Preliminary evidence also suggests the post-exercise co-ingestion of carbohydrate and protein may reduce muscle damage often seen in strength-trained athletes (Cockburn, Stevenson, Hayes, Robson-Ansley, & Howatson, 2010); whether such a change has a functional benefit is unclear.

The muscle soreness common among strength-power athletes following heavy eccentric loading or novel training sessions is associated with adverse athletic outcomes (Cheung, Hume, & Maxwell, 2003). A number of nutrition interventions have been trialled to minimize the soreness, including fish oils (Lenn et al., 2002), branched-chain amino acids (Jackman, Witard, Jeukendrup, & Tipton, 2010; Matsumoto et al., 2009; Sharp & Pearson, 2010; Shimomura et al., 2010), and protease supplements (Beck et al., 2007; Buford et al., 2009; Miller, Bailey, Barnes, Derr, & Hall, 2004). While there is some evidence of reduced soreness as a result of consumption of branched-chain amino acid and protease supplementation, it may be premature to recommend these as strategies to overcome muscle soreness.

Supplementation practices

Supplement use is reported to be higher among athletes than their sedentary counterparts, with particularly high rates of supplement use among weightlifters and bodybuilders (Sobal & Marquart, 1994). The high prevalence of supplement use among bodybuilders (Brill & Keane, 1994), Olympic weightlifters (Burke, Gollan, & Read, 1991), track and field athletes (Froiland, Koszewski, Hingst, & Kopecky, 2004; Nieper, 2005; Ronsen, Sundgot-Borgen, & Maehlum, 1999), and those who frequent commercial gymnasia (Morrison, Gizis, & Shorter, 2004; Sheppard, Raichada, Kouri, Stenson-Bar-Maor, & Branch, 2000) is not unexpected, given the range of products targeted at this market (Grunewald & Bailey, 1993; Philen, Ortiz, Auerbach, & Falk, 1992). While multi-vitamin and mineral supplements are very popular among all athletes, other products such as protein powders and specific amino acid supplements, caffeine, and creatine monohydrate are also frequently used by strength-trained athletes (Brill & Keane, 1994; Goston & Correia, 2010; Morrison et al., 2004; Nieper, 2005; Sheppard et al., 2000).

Recognizing the nutritional value of food sources of protein and essential amino acids, creatine monohydrate is the only supplement that has been reported to enhance skeletal muscle hypertrophy and functional capacity in response to resistance training (Hespel & Derave, 2007). However, liquid meal supplements rich in carbohydrate and protein may be valuable in the post-exercise period to boost total energy and specific nutrient intake at a time when the appetite is often suppressed (Cribb & Hayes, 2006). There is also evidence of enhanced muscular strength with acute caffeine ingestion (Warren, Park, Maresca, McKibans, & Millard-Stafford, 2010). An excellent review of issues relating to supplement use by athletes is presented elsewhere (Maughan, Greenhaff, & Hespel, 2011).

Strength-trained athletes continue to seek supplement information from readily accessible sources including magazines, fellow athletes, and coaches (Froiland et al., 2004; Nieper, 2005; Sheppard et al., 2000). Consequently, the accuracy of information provided may vary, leaving the athlete vulnerable to inappropriate and/or ineffective supplementation protocols. The presence of muscle dysmorphia, a body dysmorphic disorder characterized by a pre-occupation with a sense of inadequate muscularity common among bodybuilders, may also influence supplementation practices and lead to anabolic steroid use (Hildebrandt, Schlundt, Langenbucher, & Chung, 2006).

Competition

Competition demands of strength sports are typically characterized by explosive single efforts where athletes are typically given a designated number of opportunities to produce a maximal performance, with significant recovery between each effort. Consequently, muscle energy reserves are unlikely to be challenged, even in the face of challenging environmental conditions of competitions like the summer Olympic Games (Peiser & Reilly, 2004). Consequently, nutrition priorities remain with more general goals like optimizing gastrointestinal tract comfort and preventing weight gain during the competition taper.

Olympic weightlifting, powerlifting, and bodybuilding are unique among strength-power sports in that competition is undertaken via weight categories or, on occasion, by height class in bodybuilding. As such, these athletes are vulnerable to the acute weight loss practices common to other weight category sports such as acute food/fluid restriction, resulting in a state of glycogen depletion and hypohydration (Kiningham & Gorenflo, 2001). While performance is typically compromised in sports requiring a significant contribution from aerobic and/or anaerobic energy metabolism, activities demanding high power output and absolute strength are less likely to be influenced by acute weight loss (Fogelholm, 1994). Furthermore, the weigh-in is typically undertaken 2 h before a weightlifting competition, affording athletes an opportunity to recover, at least partially, from any acute weight loss strategies undertaken prior to competition. The body mass management guidelines for wrestlers issued by the American College of Sports Medicine (ACSM) would appear applicable to Olympic weightlifters also (Oppliger, Case, Horswill, Landry, & Shelter, 1996).

Given the association between lower body fat percentages and competitive success, bodybuilders typically adjust their training and diet several weeks out from competition in an attempt to decrease body fat while maintaining/increasing muscle mass. While a compromise in muscle mass has been observed when attempting to achieve the extremely low body fat percentages desired for competition (Heyward, Sandoval, & Colville, 1989; Withers et al., 1997), this is not always the case (Bamman, Hunter, Newton, Roney, & Khaled, 1993; Maestu, Eliakim, Jurimae, Valter, & Jurimae, 2010; van der Ploeg et al., 2001). The performance implications of any skeletal muscle loss are unknown given the subjective nature of bodybuilding competition. Among female bodybuilders such dietary restrictions are often associated with compromised micronutrient intake (Heyward et al., 1989; Lamar-Hildebrand, Saldanha, & Endres, 1989) and menstrual dysfunction (Walberg & Johnston, 1991), presumably because energy availability falls below the threshold of $\sim$30 kcal · kg^{-1} fat free mass · day^{-1} required to maintain normal endocrine regulation of the menstrual cycle (Loucks, Kiens, & Wright, 2011).

If catabolism of muscle protein is experienced by an Olympic weightlifter or powerlifter as they attempt to "make weight" for competition, a compromise in force-generating capacity (Bamman et al., 1993), and thus weightlifting performance, is at least theoretically possible. To avoid this situation, consideration should be given to the amount of weight loss required and thus the specified weight category as well as nutritional strategies proven to assist with maintenance of lean body mass during weight loss, such as a relative increase in dietary protein intake (Mettler, Mitchell, & Tipton, 2010). Allocating sufficient time to achieve the specified weight-category limit without severe energy restriction will also be critical with possible consideration given to the strategic use of acute weight-loss strategies in the final 24–48 h before weigh-in. This may include the use of low-residue, low-volume meal plans as well as moderation of fluid intake, which in combination can induce a 2–3% body mass loss without promoting the health risks associated with other acute weight-loss strategies. However, as with any pre-competition strategy, this approach should be trialled in training with the support of suitably qualified sports science and/or sports medicine professionals to assess both tolerance and the amount of weight loss achieved. An excellent review of issues relating to body mass management of elite athletes is presented elsewhere (Sundgot-Borgen & Garthe, 2011).

Physique

Within the lifting events, physique traits influence performance in several ways. While the expression of strength has a significant neural component, lifting performance is closely associated with skeletal muscle mass (Brechue & Abe, 2002). Excluding the open weight category, weightlifters also tend to have low body fat, enhancing development of strength per unit body mass (Keogh, Hume, Pearson, & Mellow, 2007). Successful weightlifters also have a higher sitting height to stature ratio with shorter limbs, creating a biomechanical advantage (Keogh, Hume, Pearson, & Mellow, 2009). An association between physique traits and competitive success in the Olympic throwing events has been recognized for some time, with successful athletes being heavier and taller than their counterparts (Khosla, 1968) and growing in size at a rate well in excess of population secular trends (Norton & Olds, 2001). In contrast to other strength sports, bodybuilding is unique in that competitive success is judged purely on the basis of the size, symmetry, and definition of musculature. Not surprisingly, bodybuilders are the most muscular of all the strength athletes (Huygens et al., 2002). Successful bodybuilders have lower body fat, yet are taller and heavier with wider skeletal proportions, especially the ratio of biacromial to bi-iliocristal breadths (Fry, Ryan, Schwab, Powell, & Kraemer, 1991).

While it is reasonable to presume that the nutritional focus of strength-power athletes remains with skeletal muscle hypertrophy throughout the year, in reality this is rarely the case, except perhaps during the "off-season" for bodybuilders or specified times of the annual macrocycle of other strength-power athletes. Furthermore, significant changes in body mass among bodybuilders, Olympic weightlifters, and powerlifters will likely influence the weight category they compete in and those they compete against. Thus the intention to promote skeletal muscle hypertrophy must be given serious consideration by athletes and their coaches before being implemented.

Conclusions

Nutrition plays a number of important roles for athletes competing in sports where the expression of explosive power and strength are critical to competitive success. While total energy intake of strength-power athletes tends to be greater than that of endurance-focused athletes, intake relative to body mass is often unremarkable, with less known about distribution of nutrient intake over the day. Strength-power athletes will benefit from a greater focus on the strategic timing of nutrient intake before, during, and after exercise to assist them in optimizing resistance training work capacity, recovery, and body composition. Strength and power athletes create unique challenges for the nutrition service provider given their reliance on readily accessible sources of information, susceptibility to sports supplement marketing, potentially distorted body image and challenges associated with achieving a specified weight category in some sports, plus the general void of scientific investigation in recent years relating specifically to this unique group of athletes.

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