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Helen O'Connor [a]; Tim Olds [b]; Ronald J. Maughan [c]
[a] Exercise and Sport Science, University of Sydney, Lidcombe, NSW, Australia
[b] Centre for Applied Anthropometry, University of South Australia, Adelaide, SA, Australia
[c] School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK

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Physique and performance for track and field events

HELEN O'CONNOR[1], TIM OLDS[2], & RONALD J. MAUGHAN[3]

[1]*Exercise and Sport Science, University of Sydney, Lidcombe, NSW, Australia,* [2]*Centre for Applied Anthropometry, University of South Australia, Adelaide, SA, Australia, and* [3]*School of Sport and Exercise Sciences, Loughborough University, Loughborough, UK*

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Abstract

Evidence of the importance of physique in the athletics disciplines is supported by the persistence of certain characteristics over long periods, despite marked secular changes in the source population. These characteristics may also result in physiological benefits such as effective thermoregulation or a greater power-to-weight ratio. Coaches and athletes are often convinced of weight or fat loss benefits based on personal or anecdotal experience, intuition, and "trained eye" observation of successful competitors. This may entice athletes into adopting unbalanced, erratic or highly restrictive eating patterns that increase the risk for nutrient deficiencies, and disordered eating. Despite heavy training loads and often extreme diets, some athletes fall short of their physique goals as ultimately phenotype is under genetic control. Professionals assisting athletes with physique management need to be highly skilled in anthropometry and require a thorough understanding of sports-specific nutrition requirements. Careful assessment of the risks and benefits of various approaches to weight and fat loss is required before they are recommended to athletes.

Keywords: *Anthropometry, morphological optimization*

Introduction

Athletics incorporates a range of sporting disciplines and specific physique or morphological features play a major, arguably critical role in competition success. The body mass of winners in the Boston marathon, the world's oldest existing annual race, has not varied over many decades, suggesting this characteristic remains important. However, in the case of the high jump, the move from a straddle to the "Fosbury flop" technique in the late 1960s resulted in a substantial ($\sim$10 cm) increase in the height of male competitors over two Olympiads. Despite a lack of empirical evidence for the influence of physique on performance in some disciplines, coaches and athletes are often convinced of benefits based on personal experience, intuition, and "trained eye" observation of successful competitors. In their pursuit to emulate champions, some athletes increase their risk for inadequate or inappropriate dietary intake and disordered eating, particularly when physique ideals are at the more extreme, low end for body weight and fat. Attaining ideals may be challenging, as genetic characteristics are largely responsible for phenotype. In this review, we discuss the relative importance of physique for elite performance in athletics. In addition, strategies used to achieve loss of weight and body fat will be evaluated.

Morphological optimization

Many factors contribute to athletic success, including skill, the right affective and cognitive psychological characteristics, and powerful and capacious energy-production systems. One major factor for success is body size and shape, or morphology (e.g. Claessens, Hlatky, Lefevre, & Holdhaus, 1994). The importance of morphology is obvious even to casual observers, who notice that sprinters tend to be muscular, marathoners small and lean, and throwers very large with high levels of adiposity. A guiding concept here is morphological optimization, the notion of an ideal body morphology, or narrow range of morphologies, most likely to be associated with success in various disciplines (Norton, Olds, Olive, & Craig, 1996). We note that 400-m and 800-m runners tend to be relatively tall, male marathoners usually weigh about 60 kg, and shot putters are unlikely to have body mass indexes less than

Correspondence: H. O'Connor, Exercise and Sport Science, University of Sydney, PO Box 170, Lidcombe, NSW 1825, Australia.
E-mail: h.oconnor@fhs.usyd.edu.au

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30 kg · m^{-2}. There are some exceptions, but they are very rare among the most successful performers.

The importance of morphological optimization varies from sport to sport. Successful soccer players come in a wide range of sizes and shapes. Indeed, the coefficients of variation in height and mass in elite male soccer players (4% and 10% respectively) are not very different from those in the general population of young males (4% and 13%). Successful sprinters, on the other hand, tend to be more homogeneous (coefficients of variation of 2% for height and 9% for mass).

The relative importance of morphological optimization can be quantified using three types of comparisons:

- comparisons between the morphological characteristics of the athletic population and those of the "source" population from which they are drawn (e.g. healthy young males);
- comparisons between the characteristics of athletes of different competitive standards ("best vs. rest" analyses; international vs. state level performers); and
- comparisons across time, charting secular changes in morphological characteristics, against the backdrop of population changes.

Athletes vs. source population

In many cases, athletes are clearly different from the source population. They are smaller (jockeys), leaner (distance runners), more muscular (powerlifters), fatter (sumo wrestlers), taller (basketballers), or have longer legs (high jumpers). The morphological characteristics of athletes can differ from the source population either by having different mean values, different distributional characteristics, or both. Figure 1 shows the bivariate height–mass distribution for elite marathoners and the source population. The mean height and mass of marathoners are well below population means. The coefficients of variation for height are similar, but the masses of marathoners are much less scattered. The relatively small overlap between the density ellipses suggests that height and mass are important correlates of success in marathon running.

Gradients across competitive levels – best vs. the rest

We would expect success-critical morphological characteristics to show gradients across competitive levels, with more extreme values (and/or more homogeneity) among elite athletes. The mass of male 5000-m and 10,000-m runners, for example, varies with competitive standard. The mean mass of international runners is 61.7 kg; that of Australian state-level runners is 65.2 kg, and that of club runners is 67.1 kg (unpublished data). It is likely that a very low body mass is important for distance running success. This, of course, is achieved in part by body fat content, but this is perhaps not the only reason for low body mass.

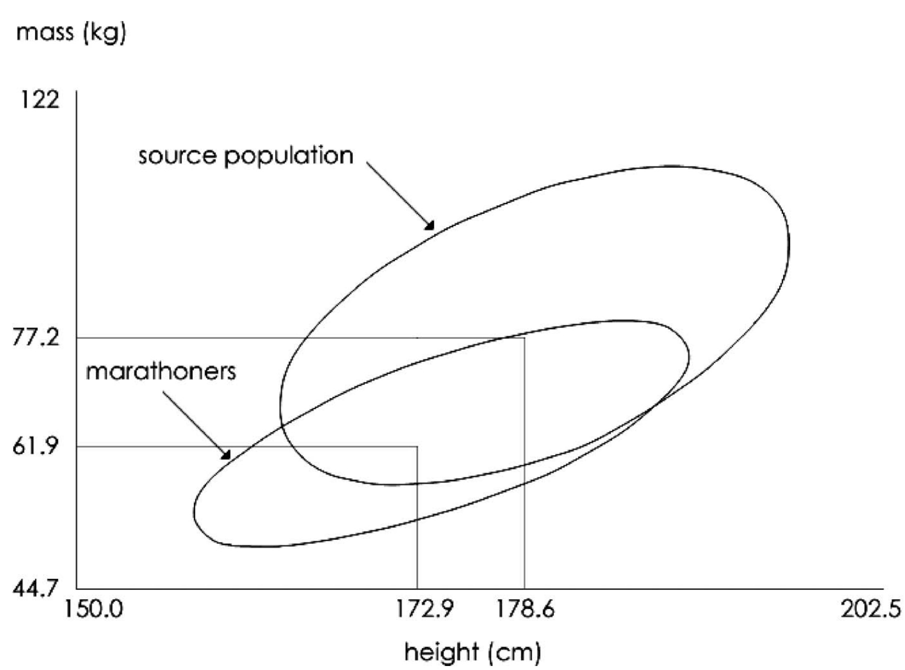

Figure 1. Bivariate distributions of height (cm) and mass (kg) for elite marathoners and the source population. The ellipses are 90% density ellipses for both marathoners and the source population. Mass values are plotted on a log scale.

Secular trends

Sport is Darwinian in nature. Over time, the morphologically fittest are selected and the others disappear. We would therefore expect to see time trends in success-critical morphological characteristics. Figure 2 shows data on throwers from various Olympic Games between 1928 and 1992, as well as some measurements taken on elite non-Olympic performers. In these years, mass increased at a rate of 3 – 7 kg per decade – or three to seven times the rate of increase in the source population (Norton & Olds, 2001). This disproportionate rate of increase suggests that mass is a major success-critical factor in throwing events. The existence of secular trends in athlete morphologies underscores the importance of using up-to-date reference data.

Time trends do not always reveal "open-ended optimization", where athletic characteristics become more and more extreme. Sometimes we see an "absolute optimization", where athlete morphologies do not change in spite of background changes in the source population. Over the last 100 years, for example, the body mass index (BMI) of elite marathoners has hardly changed (at about 21 $kg \cdot m^{-2}$), in spite of marked increases in the source population (Norton *et al.*, 1996). Absolute optimization probably reflects a balance between differential effects of morphology on supply and demand factors in the event. In the case of the marathon, smaller body mass is probably associated with better heat exchange and less susceptibility to injury, but may reduce the benefit of elastic return when running.

Like natural selection, athletic selection can take unexpected turns as the competitive environment changes. The introduction of the "Fosbury flop" led to an increase in height of nationally competitive high jumpers from 183.9 to 194.7 cm in only 8 eight years (Stepnicka, 1986). The introduction of a modified javelin after Hohn's record-shattering throw in 1984 resulted in a new definition of "morphological fitness" for javelin throwers. The optimal release angle of the javelin increased because the centre of mass of the javelin was shifted back towards the tail. This placed javelin throwers on a different part of their force – velocity curves.

Selection and adaptation

Morphological optimization occurs through two mechanisms: selection and adaptation. Selection is a Darwinian process whereby "naturally occurring" optimal (and hence successful) morphologies are selected for. Adaptation refers to the physique-modelling effects of training, diet, supplementation and, occasionally, more radical interventions such as

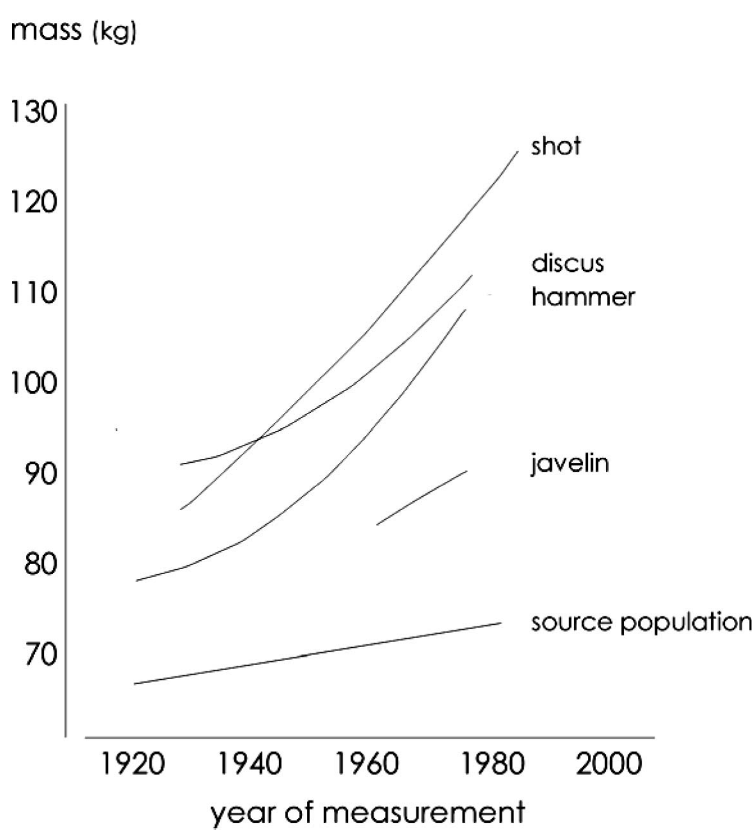

Figure 2. Secular trends in the mass of international throwers between 1920 and 1992.

drugs and surgery. The use of anabolic steroids, for example, may increase fat-free mass by up to 15% in training bodybuilders (Norton & Olds, 2001). The relative mix of selection and adaptation depends largely on the plasticity of the morphological characteristic in question. Fat mass and fat-free mass, for example, are relatively plastic, while bony dimensions are not. Consequently, adaptation will be more important for the former, and less so for the latter.

Morphology and performance

So far, we have looked only at empirical evidence of a connection between morphology and success, without considering mechanisms. Mechanisms can be explored from the point of view of biomechanics, physics, physiology, and the allometric relationships between morphology and performance. In many cases, the relationships between morphology and performance are complex, and affect energy supply and demand in different and often contradictory ways.

Consider the case of a middle-distance runner who weighs 70 kg and is 1.75 m tall. He has a maximal oxygen uptake ($\dot{V}O_{2max}$) of 75 $ml \cdot kg^{-1} \cdot min^{-1}$. What will be the effect of him putting on 2 kg of fat? The overall effect depends on the impact of that extra mass on demand-side and supply-side variables, and on the relative contribution of each to the overall performance. On the demand-side, air resistance will increase by about 1.2%, but will account for less than 5% of the overall power requirement. Kinetic energy will also increase by 2.9%, but over 1500 m this will account for only a small portion (<0.5%) of the total energy requirement. Mass-specific anaerobic capacity will decrease linearly as body mass increases. The metabolic cost of horizontal forward motion will in principle increase *pari passu* with mass (2.9%). In reality, heavier body mass is associated with improved efficiency, perhaps due to improved return of elastic energy via the stretch–shortening cycle (Bergh, Sjödin, Forsberg, & Svedenhag, 1991). The reduction in oxygen cost might be as great as 2.5%. Mathematical modelling (e.g. Péronnet & Thibault, 1989) suggests that in this case, the nett effect might be an increase of about 1.8% in performance time.

Despite the complexities of modelling, some morphological factors have consistently been associated with success, and have plausible mechanistic explanations. Some examples are offered below.

Heat exchange

Heat exchange becomes increasingly important as running distance increases – up to a point only, and the highest body temperatures are typically recorded in events lasting about 30–60 min. The two main morphological factors affecting heat exchange are subcutaneous body fat and the body surface area (BSA):mass ratio. The former acts as a barrier to heat loss; the latter is an index of the ratio of potential for heat production to potential for heat loss. In hot weather, when ambient temperature exceeds skin temperature, a high surface area will increase radiant heat gain from the environment. Figure 3 shows the relationship between endomorphy (a measure of

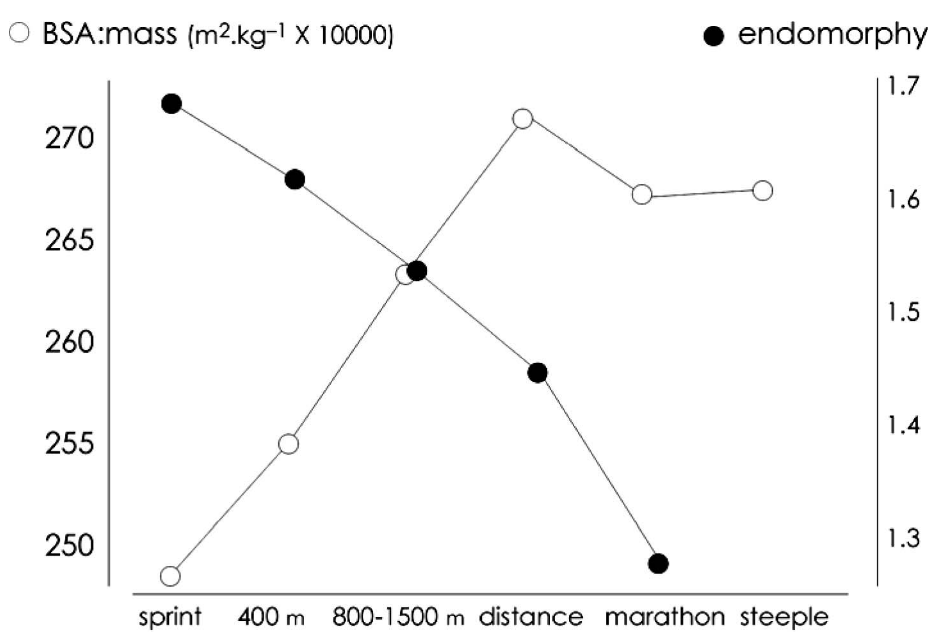

Figure 3. Relationship between endomorphy (right ordinate, solid symbols) and BSA:mass ratio (left ordinate, open symbols) and track events of increasing distance.

fatness based on skinfolds) and BSA:mass ratio in international runners over various distances. There is a strong log-linear relationship between distance and heat-exchange characteristics, with endomorphy decreasing and the BSA:mass ratio increasing as event distance increases. In other words, heat exchange characteristics improve with run distance. In throwing events, endomorphy can be quite high (2.9 vs. 1.3 for marathoners), and the BSA:mass ratio very low (0.0205 $m^2 \cdot kg^{-1}$ for shot putters vs. 0.0267 $m^2 \cdot kg^{-1}$ for marathoners). Intermediate values are found in multi-event disciplines.

Height and mass

Figure 4 shows the relationship between height and mass in track runners. Height and mass peak for runners over 400 m. The smallest athletes are those at the extremes of running distances. Sprinters (<100 m) tend to be short. These relativities, which have held for over 100 years, are probably due to a variety of biophysical factors. In short sprint events, the acceleration phase is relatively important (Radford, 1990). Shorter legs will generally have a lower moment of inertia, and hence require less energy to accelerate. Furthermore, small body size minimizes the power required to impart kinetic energy to the body, and to overcome air resistance, both of which are quantitatively more important over short distances. In long-distance events, small body size may optimize heat loss and minimize injury.

Height is clearly critical in jumping and throwing events. A greater release height is clearly advantageous, and high jump performance is facilitated by a higher centre of gravity. Khosla and McBroom (1988) found that a female athlete would be 191 times more likely to make it to an Olympic final if she were $\geq$1.81 m tall than if she were $\leq$1.51 m tall.

Skeletal ratios

Significant differences in skeletal ratios are found between different types of athletes, even when differences in absolute body size are taken into account. Marathoners tend to have a high skelic index (ratio of total leg length to sitting height) – that is, relatively longer legs. Distance runners also have a higher crural index (ratio of lower leg length to upper leg length). Longer legs reduce stride rate, and relatively shorter thighs mean that the resistance arm on the upper leg is shorter. The muscle mass of the thigh is moved closer to the axis of rotation of the leg, reducing the energy cost of locomotion.

Anthropometric profiling for performance

The extent and nature of anthropometric profiling depends on the primary purpose of the

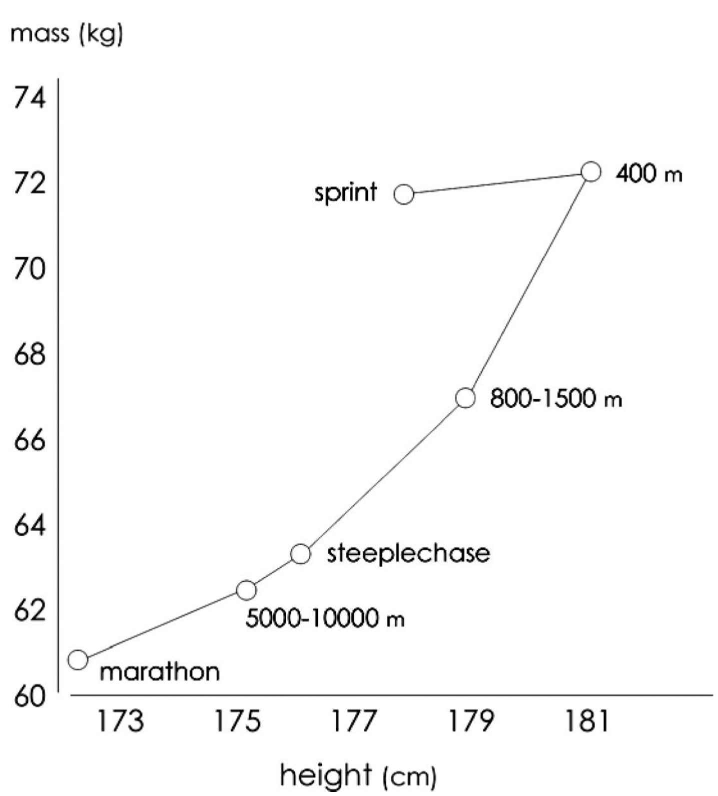

Figure 4. Relationship between mean height and mass in international track athletes, 1960–2005.

measurement. Talent identification, or directing athletes to morphologically appropriate events, depends largely on identifying relatively unalterable characteristics (at least in maturity), and comparing them with reference data. Reference data should be as recent as possible. Accuracy and validity are therefore critical. Profiling should include bony lengths and breadths.

For monitoring morphological adaptation, the focus should be on plastic characteristics, such as muscle mass and fat mass. The emphasis is on serial measurements, and hence reliability is critical. Skinfolds provide a good index of fatness, and skinfold-corrected girths a simple estimate of muscle mass. Routine profiling should be frequent (months or weeks), and should include skinfolds and girths. Little is gained by attempting to convert skinfolds to percentage body fat using one or more of the several hundred regression equations available. The profiling system recommended by the International Society for the Advancement of Kinanthropometry (ISAK; Marfell-Jones, Olds, Stewart, & Carter, 2006) is now widely used around the world, and is backed up by an accreditation system demanding rigorous demonstration of accuracy and precision in measurement. "Gold standard" methods of assessing fat and fat-free mass (hydrodensitometry, DEXA) are expensive, invasive, and complex, and offer little information that simple skinfolding cannot provide. Bioelectrical impedance analysis is too sensitive to hydration status and to other factors to be used for routine profiling.

"Virtual anthropometry" using three-dimensional whole-body scanners (Olds, Ross, Blanchonette, & Stratton, 2007) offers a non-invasive anthropometric assessment that allows new possibilities for quantifying important morphological characteristics such as body surface area, projected frontal area, and limb volumes. Whole-body scanning offers promise in assessing differences in the distribution of mass over the body. The world's first sports anthropometric survey using three-dimensional scanning took place in March 2007 at the Australian National Rowing Championships.

Challenges for achieving optimal weight and fat loss

Genetic factors

An individual's phenotype (shape, weight, and body composition) is determined by the interaction between genetic and environmental factors. Estimates of the heritability of body weight and composition from epidemiological studies vary but are typically in the order of 25–40% and possibly up to 70% in some environments (Bouchard, 1994). Several genetic polymorphisms are associated with human fatness and obesity (reviewed in Paracchini, Pedotti, & Taioli, 2005); these increase the susceptibility for body fat gain but not necessarily its expression. Successful participation in some disciplines of athletics require either extreme leanness (e.g. running, jumping, walking) or high muscularity (e.g. sprint, throwing events), so it is not surprising that athletes with a less suitable genetic predisposition struggle to attain their physique goals, despite rigorous diet and training regimens.

Gender and pubertal influences

Males are leaner than females and this distinction becomes increasingly evident throughout puberty (reviewed in Meyer, O'Connor, & Shireffs, 2007). A normal increase in fat at this time may have a devastating impact on female athlete body image (Robinson & Ferraro, 2004). This may be accentuated when tight, revealing sports attire is worn and the media decide to comment critically on physique changes (Hodgkinson, 2007). Diet or training may be used to reverse weight or fat gains associated with normal pubertal development. This increases the risk for inadequate nutrient intake and disordered eating.

Training, appetite, and adequacy of energy intake

Training may alter appetite and many studies have demonstrated that matching of energy intake to expenditure is not precise in humans. Partial, complete, and even over-compensation of the energy expended during exercise has been observed and may be influenced by numerous factors, including the intensity, duration, and mode of exercise (reviewed King, Burley & Blundell, 1994). Gender might also be influential but the literature is conflicting (Pomerleau, Imbeault, Parker, & Doucet, 2004; Westerterp, Meijer, Janssem, Saris, & ten Hoor, 1992). An abrupt reduction or cessation of training has been associated with fat gain in distance runners (McConell *et al.*, 1993), and one study of female swimmers equated the gain almost exactly to the reduction of training energy expenditure (Almeras, Lemieux, Bouchard, & Tremblay, 1997). Similarly, after a 20% increase in energy expenditure over 40 weeks of marathon training, no increase in appetite was observed (Westerterp, Verboeket-Van de Venne, Meijer, & ten Hoor, 1991; Westerterp *et al.*, 1992), suggesting that – like exercise reduction or cessation – appetite may not be spontaneously adjusted with training load.

Although limited research exists, there is evidence of a greater reduction in appetite after exercise of high intensity and long duration ($\sim$60 min) than exercise of low intensity and short duration (reviewed King, Tremblay, & Blundell, 1997). This energy imbalance has been reported in elite Kenyan endurance runners using the doubly labelled water technique where heavy training loads resulted in a mean deficit in energy intake of 13% each day over 7 days (range −24% to +9%). This was almost entirely accounted for by under-eating (mean deficit of 9%; range −55 to +39%) in some of the runners as opposed to significant under-reporting of intake (Fudge *et al.*, 2006). Matching energy intake to requirements may be even more difficult for athletes on a day-to-day basis given that training programmes are periodized and highly varied over a week or block of weeks.

Although not observed in the study of Kenyan runners, under-reporting of food intake has been observed in athletes from a range of sports and frequently in female endurance runners (reviewed Manore & Thompson, 2006). A mismatch of energy intake and expenditure is often attributed to under-reporting, and clinical experience suggests this is certainly the case for many athletes, but chronic inadequate energy intake with or without weight loss, or so-called "decreased energy availability", has more recently been described and attributed as the primary cause of amenorrhoea and bone mineral loss in otherwise healthy female athletes (reviewed in Manore, Kam, & Loucks, 2007). Previous studies could have misclassified some athletes as under-reporters when they may have been chronically energy deficient. If energy availability falls to critically low levels, suggested to be $125\ \text{kJ} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ ($30\ \text{kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$), fat-free mass, reproductive and bone turnover will be disrupted in female athletes.

Determining whether an athlete is under-reporting or truly energy deficient is complex. Under-reporting may be more likely in individuals who have higher energy intakes, more food to report, or variable eating and exercise patterns (Barnard, Tapsell, Davies, Brenninger, & Storlien, 2002). Biochemical markers including unexplained low blood glucose or the presence of urinary ketones (particularly urinary aceto-acetate) may suggest energy deficiency (Loucks, 2004). Surface anthropometry is also helpful, as this can be used to track and assess the appropriateness of lean and fat mass changes over time. Evidence of fatigue, declining performance, and in females menstrual irregularity suggest investigation of energy deficiency is warranted (Manore *et al.*, 2007). Due to the error (Pederson & Gore, 1996) and potentially confrontational nature of anthropometry in weight-/fat-sensitive athletes, a high degree of technical and counselling expertise is required for this to be both safe and useful (Kerr & Ackland, 2006). Although coaches are often concerned that monitoring body composition in this group will make them more weight focused (Jeffrey, 2007), failure to do so may result in ongoing and undetected energy deficiency.

Strategies to reduce weight and body fat

Energy vs. fat reduction and energy density

Ad libitum reduction in fat intake results in a modest decrease in both energy intake and weight/fat loss in obese individuals (Astrup, Grunwald, Melanson, Saris, & Hill, 2000). Although not well studied in elite athletes, this approach will typically result in a satisfactory result for those who have high energy expenditures and modest reduction goals. Athletes and coaches who desire more extreme losses may become frustrated with the *ad libitum* low fat approach, as it may not deliver the reduction required. However, where possible this method should be favoured because it is less restrictive, avoids jeopardizing carbohydrate intake, and is less likely to result in binge eating (Astrup *et al.*, 2000). A recent, large cohort study of women also found this approach to be supportive of spontaneous weight loss over a period of 7 years when compared with a normal fat control diet (Howard *et al.*, 2006).

When planned energy restriction is required, careful consideration and diet design are necessary to optimize nutrient density and prevent insufficient energy availability. The least energy restriction that will achieve desired results is recommended and a good starting point may be an energy deficit of 2100 kJ (500 kcal) from theoretical requirements (American College of Sports Medicine, 2001). Weight cycling often observed in "making weight" sports (e.g. boxing, lightweight rowing) may also occur in association with erratic dieting in track and field athletes. Long-term outcomes from weight cycling remain controversial but recent evidence from former elite athletes suggests this may increase the risk of weight gain and obesity in later life (Saarni, Rissanen, Sarna, Koskenvuo, & Kaprio, 2006).

Designing a diet with lower energy density (less energy per gram of food) is also recommended, as many lines of evidence suggest that energy-dense diets promote "passive over-consumption" (reviewed Blundell, 2004). In an elegant series of studies, the initial relative over-consumption demonstrated in individuals fed 40% and 60% versus 20% fat diets in a 24-h calorimeter was found to be associated with energy density rather than percentage fat (Prentice & Poppitt, 1996). Redesign of the study diets to make energy density identical resulted in abolition of energy over-consumption observed with the higher fat diets (Stubbs, Harbron, Murgatroyd, & Prentice, 1995a; Stubbs, Ritz, Coward, & Prentice, 1995b). Energy-dense sports products (e.g. sports drinks, bars, gels) are popular with athletes during and around training. These products, although convenient and compact, may need to be carefully incorporated into a tight energy budget. In this situation, planning pre- and post-training nutritional support to occur around meals may be helpful so that nutrient and recovery needs can be managed with usual rather than supplemental intake.

Reduced carbohydrate diets

Despite the global popularity and financial success of reduced carbohydrate diets – for example, The Zone (Sears, 1995) and Dr. Atkins' diet (Atkins, 1992) – research on the mechanisms of action, long-term safety, and efficacy have been lacking (reviewed in Noble & Kushner, 2006). These diets have the potential to induce faster weight loss in athletes than in sedentary individuals because, with heavy physical activity, glycogen stores will be rapidly depleted and amino acids used to derive glucose, theoretically inducing a loss of lean mass. Unfortunately, this has not been assessed in athletes, but contrary to concerns, several studies report preservation of lean tissue, at least in obese individuals (Layman *et al.*, 2003).

Most studies on the Atkins diet have shown faster initial weight loss in obese individuals compared with a diet higher in carbohydrate; however, by 12 months, weight loss has not been significantly greater (Foster *et al.*, 2003; Stern *et al.*, 2004), except in one recent study (Gardner *et al.*, 2007). Greater weight loss with Atkins has been related to satiety and decreased energy intake (Skov, Toubro, Rønn, Holm, & Astrup, 1999), thermogenesis (Nair, Halliday, & Garrow, 1983), energy expenditure (Dauncey & Bingham, 1983), reduction in glycaemic load (Ebbeling, Leidig, Sinclair, Hangen, & Ludwig, 2003), and even diet simplicity/monotony (Foster *et al.*, 2003). As the degree of ketosis has not been associated with extent of weight loss, it is considered unlikely that this is a key factor (Foster *et al.*, 2003). Strict adherence to the Zone diet results in a typical energy intake of 4200–8400 $\text{kJ} \cdot \text{day}^{-1}$ (1000–2000 $\text{kcal} \cdot \text{day}^{-1}$), which is low for athletes (reviewed by Cheuvront, 1999, 2003).

Rapid and early weight or fat loss is often greeted with enthusiasm by athletes and coaches and may result in short-term improvements in performance, as a reduction in mass may outweigh the effect of depletion of glycogen and lean mass. Over time, performance would be expected to decline as inadequate carbohydrate and lean mass/strength loss overwhelm initial benefits. In practice, athletes following these diets rarely implement the guidelines exactly; rather, they adopt certain aspects such as a higher protein or a reduced rather than low carbohydrate intake (Burke, 2007). Athlete claims for success need to be considered within this context. In fact, athletes recommended to eat a "high carbohydrate diet" may benefit from a reduction if they have misinterpreted advice to eat an unlimited rather than appropriate amount of carbohydrate for their individual needs. Most studies suggest adherence to reduced carbohydrate diets is difficult in the long term and there is evidence of a significant rebound weight gain by 12 months (Foster *et al.*, 2003). The National Weight Loss Registry in the USA also supports the suggestion that these diets are not the most successful in the long term (Hill, Wyatt, & Phelan, 2005).

Studies evaluating the benefit of the Zone diet in athletes have not demonstrated greater weight loss or performance benefits (Bosse *et al.*, 2004; Jarvis, McNaughton, Seddon, & Thompson, 2002). No study has evaluated the Atkins diet in this population. In the short term, the induction diet side-effects of Atkins, including headaches, fatigue, and nausea (Van Itallie, 1980), are unlikely to promote high-quality training sessions. There is also insufficient evidence to support long-term safety (Noble & Kushner, 2006). Ketosis is potentially harmful with possible long-term sequelae, including hyperlipidaemia, impaired neutrophil function, optic neuropathy and osteoporosis, as well as alternations in cognitive function (Denke, 2001). The risk of nutritional inadequacy (Williams & Williams, 2003), disordered eating, and energy insufficiency is also a concern. Short-tem improvement in cardiovascular risk factors reported in obese individuals may be primarily due to weight loss (Foster *et al.*, 2003), and a recent longer term (12 year) follow-up study reported increased total and cardiovascular risk mortality with lower carbohydrate diets (Lagiou *et al.*, 2007). Risk of decreased immunocompetence is also a concern (Nimmo & Ekblom, 2007).

Manipulation of the glycaemic index and increased dietary fibre

There is evidence that both supports (McMillan-Price & Brand-Miller, 2006) and questions (Sloth & Astrup, 2006) the benefit of low glycaemic index (GI) diets for weight loss. Unlike restricting carbohydrate, reducing the glycaemic index is not associated with negative health consequences, although the influence of this strategy on glycogen storage and performance in the longer term in athletes has not been evaluated. Diets that are low GI (McMillan-Price & Brand-Miller, 2006) and high fibre (reviewed in Astrup, 2006) improve satiety and this may be particularly helpful for "hungry" athletes or those needing to restrict energy intake over longer periods.

Role of dairy intake

Epidemiological and clinical trial evidence supports a positive role for dairy foods on weight/fat loss (reviewed in Zemel, 2004). Potentially to their detriment, athletes aspiring to lose weight or fat often avoid or reduce dairy products (Barr, 1987). The benefits of dairy appear to be greater than with calcium supplementation alone, so the active component(s) of dairy are greater than calcium in isolation (Zemel, 2004) but are not well understood. Several hypotheses exploring possible biological mechanisms for the observed weight or fat loss benefit are available. These include increased satiety (Lorenzen, Molgaard, Michaelsen, & Astrup, 2006) as well as the role of intracellular calcium, calcitrophic hormones, and 1,25-dihydroxyvitamin D in the regulation of adipocyte lipid metabolism and triglyceride storage (reviewed in Zemel, 2004). Support has also emerged for a gastrointestinal mechanism whereby dairy calcium increases faecal fat excretion, presumably via formation of insoluble fatty acid soaps or by binding bile acids that impair micelle formation. A recent study (Lorenzen *et al.*, 2006) demonstrated that daily faecal fat excretion increased 2.5-fold ($\sim$14 g fat excreted and a loss of 350 kJ) when on a higher calcium, dairy-based diet. These effects, while useful, fail to explain the magnitude of weight or fat loss reported in many studies.

Popular, very low-energy diets and weight loss centres

Most popular diets lack scientific support (Williams & Williams, 2003) and are designed for overweight/sedentary individuals, not athletes with higher energy and nutrient needs. Very low-energy diets (4200 $kJ \cdot day^{-1}$ or 1000 $kcal \cdot day^{-1}$) are associated with significant negative side-effects, including nausea, headaches, hypotension, glycogen depletion, loss of lean mass, dehydration, and electrolyte imbalance (Brodoff & Hendler, 1992). These diets would be dangerous for athletes. Although some commercial weight-loss programmes (e.g. Weight Watchers™, Jenny Craig™) offer sound approaches for weight management, they are not designed for athletes, and if used an accredited programme with the capacity to cater for specific athlete needs is required.

Training strategies for weight and fat loss

Training modifications to assist athletes to promote or enhance weight or fat loss are important for optimizing successful physique management. Specific strategies are beyond the scope of this review but have been detailed elsewhere (American College of Sports Medicine, 2001; O'Connor & Caterson, 2006).

Adjunctive agents

Dietary supplements

Supplements including L-carnitine, chromium picolinate, and hydroxy-methylbutyrate have been touted to assist with weight management but strong evidence of clinically meaningful benefits is lacking (reviewed Burke *et al.*, 2006). The efficacy of other over-the-counter supplements touted to assist weight loss has been reviewed elsewhere (Dwyer, Allison, & Coates, 2005; Egger, Cameron-Smith, & Stanton, 1999; St-Onge, 2005).

Pharmacological agents

Pharmacological agents may be used to regulate or reduce weight but most are not permitted by sports drug agencies. These agents are designed to treat obese individuals, not healthy athletes who are not overweight by health standards. Even if permitted by sports drug agencies, their use in athletics must be questioned on health and ethical grounds and for these reasons the use of pharmacological agents for physique management in this context is not recommended (O'Connor & Caterson, 2006).

Conclusions

Physique or morphological characteristics play one of the most critical roles in competition success in athletics. The relative importance of these characteristics depends on the demands of the sport. Unlike height, which is a static, "non-plastic" characteristic, body weight and fat can be significantly manipulated by diet and training. Unfortunately, attempts to modify weight and body fat are not without risk and due to genetic limitations may not be easy to achieve. Anthropometric measurement appears to be the most appropriate method for physique assessment in athletes, but skilled anthropometrists are needed to ensure precise measurement and insightful interpretation of results. If weight or fat loss is to be recommended, then support from a professional with a thorough understanding of the nutritional demands of the sport, and a high level of expertise in nutrition, dietetics, and dietary counselling is required.

Summary of recommendations regarding physique for track and field athletes

Consensus for:

BODY COMPOSITION ASSESSMENT AND MONITORING

- Substantial evidence exists to support the role of optimizing physique for athletics disciplines. While some anthropometric characteristics are not modifiable (e.g. bone lengths), other success-critical characteristics can be modified by diet and training. In particular, success in many athletic disciplines is unlikely outside of a relatively narrow range of body masses and body fat percentages.
- Regular (e.g. monthly) surface anthropometry is recommended as the most practical and safe method to assess and track changes in body composition for athletics disciplines. Other methods are generally either too invasive, expensive or not valid for use with athletics.
- Practitioners measuring and interpreting anthropometric measurements need to have rigorous and appropriate training (e.g. as per ISAK recommendations) to ensure they are capable of taking accurate and precise measurements, and in making assessments and interpreting change within the context of their own error.
- Anthropometrists need to be sensitive to the potential psychological impact of body composition assessment. Measures need to be performed in private and always reported to the athlete in the context of maintaining both health and optimizing performance. So as not to mislead athletes about real changes, data should be reported as a value plus a confidence interval, rather than as a single value.
- Measures should remain confidential and not be displayed publicly or discussed with others without the athlete's consent.
- Coaches may have concerns about anthropometric measurement in weight-/fat-sensitive disciplines and prefer to use "trained eye" observations. However, many examples exist of serious weight loss and eating disorders bring missed using this approach. An athlete's response to anthropometric measurement may also help to indicate underlying body image and eating issues.
- Reference data should be event-specific and up-to-date (preferably no more than 10 to at most 20 years old). Coaches should be aware that there are often physique gradients across competitive standards.

DIETARY INTERVENTION FOR WEIGHT AND FAT LOSS IN ATHLETICS

- Professionals who provide dietary advice to assist physique management need to have a comprehensive understanding of the benefits and risks of manipulating physique, a thorough understanding of the nutritional demands of the sport, and a high level of expertise in nutrition, dietetics, and dietary counselling.
- Dieting to manipulate physique represents a potentially serious risk to the athlete's physical health and psychological well-being. The recommendation to manipulate physique needs to be made after careful consideration of the risks and potential benefits to the individual.
- Assessing under-reporting of energy intake in athletes is challenging. Intakes that do not appear plausible may indicate under-reporting or energy deficiency, and athletes with any of the following – fatigue, decreased performance, inadequate nutrient intake, menstrual irregularity – should be assessed for energy deficiency.
- Athletes may benefit from planning and "periodizing" dietary intake to match training demands, as natural appetite cues may not be adequate or sensitive enough to guide intake.
- Athletes need to be assisted to understand their own specific energy and carbohydrate needs, as advice to eat a "high", unlimited carbohydrate diet may result in over-consumption.
- Optimizing nutrient density will help to promote adequate nutrient intake when the energy budget of the athlete is restricted.
- Athletes seeking to reduce weight or fat are recommended to do so gradually using modest energy and fat restriction to ensure carbohydrate and nutrient needs are satisfied. Deficits of 2100 $kJ \cdot day^{-1}$ (500 $kcal \cdot day^{-1}$) from theoretical needs are suggested as a good starting point. Energy availability must not fall below 125 $kJ \cdot kg^{-1} \cdot day^{-1}$ or 30 $kcal \cdot kg^{-1} \cdot day^{-1}$ fat-free mass.
- No dietary supplement at this time is recognized as providing significant, effective support to enhance weight or fat loss in athletes.

Consensus against:

- Athletes are warned against adopting "fad", unsubstantiated diets for weight loss, or weight cycling approaches. These may result in inadequate energy and nutrient intake, and be detrimental to physical and mental health and to athletic performance.

- Athletes should not be directed to lose weight or fat without health professional support.
- Low carbohydrate diets ($<5\ g \cdot kg^{-1} \cdot day^{-1}$) and pharmaceutical agents for weight/fat loss are not recommended.

Issues that are equivocal:

- Adequate dairy intake may assist with weight or fat loss but further research is required to determine the benefits of this strategy, particularly in athletes.
- Low GI diets may improve satiety and weight loss but may potentially reduce glycogen storage and recovery. Further research is required to assess the benefit of the glycaemic index for weight management and in the everyday eating of the athlete.

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