CURRENT OPINION

Sports Med 2001; 31 (11): 763-783
0112-1642/01/0011-0763/$22.00/0

Morphological Evolution of Athletes Over the 20th Century

Causes and Consequences

Kevin Norton and *Tim Olds*

School of Physical Education, Exercise and Sport Studies, University of South Australia, Underdale, South Australia, Australia

Abstract

Over the course of the past century it has become increasingly difficult to find athletes of the size and shape required to compete successfully at the highest level. Sport is Darwinian in that only the 'fittest' reach the highest level of participation. Not every physical characteristic could be expected to play a role in this selection process, but two that are important and for which substantial data assemblies exist, are height and mass. Measurements of elite athlete sizes were obtained from a variety of sources as far back as records allowed. We charted the shift in these anthropometric characteristics of elite sportspeople over time, against a backdrop of secular changes in the general population. Athletes in many sports have been getting taller and more massive over time; the rates of rise outstripping those of the secular trend. In open-ended sports, more massive players have an advantage. Larger players average longer careers and obtain greater financial rewards. In some sports it is equally difficult to find athletes small enough to compete. In contrast, there are sports that demand a narrow range of morphological characteristics. In these sports the size of the most successful athletes over the century has remained constant, despite the drift in the population characteristics from which they are drawn. A number of social factors both drive and are driven by the search for athletes of increasingly rare morphology. These include globalisation and international recruitment, greater financial and social incentives, and the use of special training methods and artificial growth stimuli. In many sports the demand for a specific range in body size reinforces the need to adopt questionable and illegal behaviours to reach the required size and shape to compete at the top level. Future scenarios also include 'gene-farming' through assortative mating and athlete gamete banks.

'Twenty years ago we never felt we'd have this many big people who could run this fast. It wasn't much further back that 250 lb was big for a lineman. Now it's not big enough to play. With advances in nutrition, weights, kinesiology and development techniques at an early age, we could see the day when 300 lb may be the minimum and 350 lb may be the standard.'

Bill Tobin
Indianapolis Colts General Manager, 1994.[1]

In 1998 all inside linemen in the National Football League (NFL) averaged 303.3 ± 17lb (135.4 ± 7.7kg), n = 463, and the starting players were significantly heavier averaging 309.7 ± 15.3lb (140.1 ± 6.9kg), n = 203 [based on data from NFL].[2]

There is a current hypothesis that suggests an 'expanding universe' of athletic bodies. This hypothesis argues that characteristic morphologies in different sports are diverging and many are moving away from the midpoints of the general population. The ideal athletic type proposed over a century ago[3] is being replaced by radically different, highly specialised and increasingly divergent body types. Furthermore, the rate of change is greater the further the sporting bodies are away from the population mean. The hypothesis is based on the notion that each sport, event and even position within a sport demands its own unique set of physical and physiological attributes for success at the highest level. Undoubtedly, this set of attributes includes other variables such as motivation and skill level. However, many of these are difficult to measure and we are not able to go back through time to quantify these assets in yesterday's athletes. Therefore, this article is limited to a review of athlete morphology and how this has become increasingly optimised within and across sports over the past century.

Sport is Darwinian, in that only the 'fittest' reach the highest level of participation. Not every physical characteristic could be expected to play a role in this selection process, and some which are likely to play a role are difficult or impossible to measure. Two that are clearly important, which can be easily measured, and for which substantial data assemblies are available, are height and mass.

In this review, we will focus on the evolution of height, mass and body mass index (BMI; kg/m^2) in elite sports individuals. Specifically, we will chart the shift in the anthropometric characteristics of elite sports people over time, against a backdrop of secular changes in the general population.

Sport fulfils a very different social role today than even 50 years ago. 50 years ago, sport was largely participatory, regionally-based, generalised and semi-professional. Today, it is largely spectatorial, global, specialised and highly paid. Modern athletes are not only talented performers but cult figures admired like movie stars and rock singers. Indeed, sometimes it is a prerequisite for recruitment that athletes have media presence, make a specified number of media appearances, or undergo classes in delivering presentations.[4] What has caused this revolution in the place of sport in society, and where will it lead? In this article, we address a specific factor associated with this broad question: how do changes in the size and shape of athletes relate to the shift in sporting culture, both as a cause and consequence?

Over the course of this century, it has become increasingly difficult to find athletes of the size and shape required to compete at the highest level. We suggest a number of social factors which both drive and are driven by the search for athletes of increasingly rare morphology. These include globalisation and international recruitment, greater financial and social incentives and rewards, and the use of special training methods and artificial growth stimuli. We also discuss future scenarios, such as the possibility of 'gene-farming' through assortative mating and gamete banks.

1. The Concept of the Overlap Zone (OZ)

1.1 Quantifying Differences Between Athletic and Nonathletic Populations

Two distributions can differ from each other if the mean of one is dislocated relative to the other, and/or if the variability of one is markedly different from the other. If we are dealing with a single characteristic, it is relatively easy to calculate the probability of someone from a given population falling within another population (e.g. the probability of a young adult male being tall enough to be a basketballer).[5] It is more complex when we are dealing with 2 or more related characteristics, such as height and mass. In the following sections we outline a method for calculating the overlap between 2 bivariate distributions (e.g. the probability of a young adult male having the required height and mass to be a successful footballer). We refer to the probability of an individual from one population falling within another population as the 'overlap' between the 2 populations. The overlap can best be visualised as the degree of superimposition of the frequency distributions of the 2 populations, and can be quantified in a statistic we call the overlap zone (OZ).

1.2 The Univariate OZ

When dealing with a single characteristic (univariate distributions), the OZ is represented graphically by the coincidence of two 2-dimensional frequency polygons as shown in figure 1.

The first panel of figure 1 shows the distribution of heights in the general population (Australian males, 18 to 29 years),[6] and the distribution of reported heights of soccer players.[7,8] Because the means are not greatly different (178.6 *vs* 178.3cm), and the standard deviation (SD) of the sporting population (6.4cm) is not greatly different from the SD of the general population (7.1cm), there is a considerable overlap. The second panel shows the distribution of heights in the general population and the distribution of reported heights of pursuit cyclists.[8-10] The sporting subpopulation here has a similar mean height (179.3cm) to that of the general population, but a much smaller SD (3.5cm). Therefore, the overlap is somewhat less. The third panel shows the distribution of heights of Australian Football League (AFL) players (AFL records, 1994),[5] with a mean height of 185.4cm; much taller than the general population. However, the SDs of the 2 populations are similar (7.1cm for the general population, and 6.9cm for the AFL players). Finally, the fourth panel shows the height of discus throwers.[11] The mean height (189.9cm) is much greater than that of the general population, and the SD (2.5cm) is much smaller. The overlap is therefore very small.

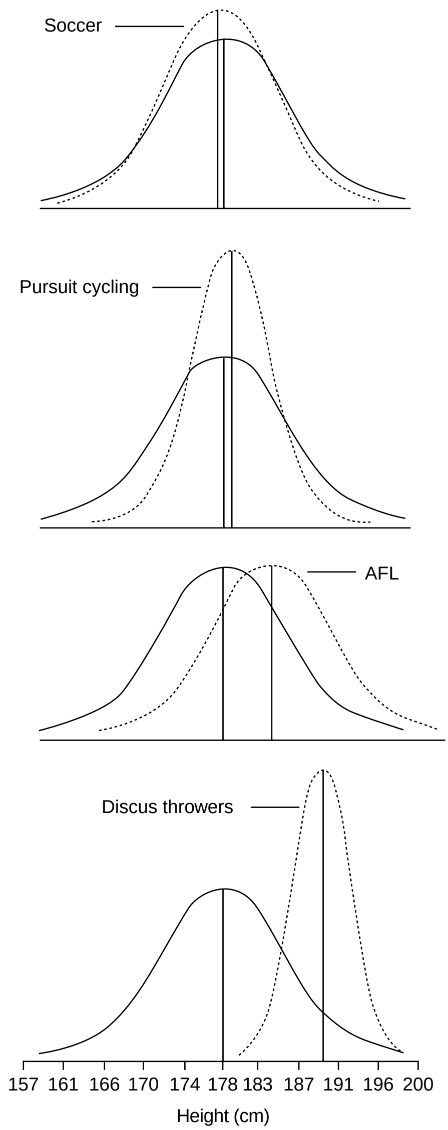

Fig. 1. Univariate overlap zone distributions for height for potential and sporting populations. The sports are for male athletes and were derived as described in the text (from Norton et al.[5] with permission). **AFL** = Australian Football League.

1.3 The Bivariate Overlap Zone (BOZ)

When we are dealing with 2 related characteristics (bivariate distributions), the OZ is represented graphically as the overlap of 2 'density ellipses'. For example, let us imagine now that we are dealing with the distribution of height (the X variable) and mass (the Y variable) in 2 populations. One population consists of young adult males. We will call this population the reference population, and will designate it by the subscript 'Ref'. The other population consists of a sample of sports individuals, the sporting population, which we will designate by the subscript 's'. We want to know the probability of someone randomly chosen from the reference population falling within the sporting population.

The first step is to generate a large number of height-mass datapoints from the reference population. If we have access to a very large random dataset, we can avoid the need to generate datapoints, but this is rarely the case. To generate 'pseudodata' from the reference population, we need to know the mean and SD of the X and Y variables within that population (X_{Ref} and sX_{Ref}; Y_{Ref} and sY_{Ref}), the equation of the line of best fit relating X to Y (of the form $Y' = bX + a$), and the standard error of estimate of that line of best fit (SEE_{Ref}). Once we have these statistics, we generate a large number of X values using a normal random number generator. For each X value, we calculate the corresponding Y value using the equation of the line of best fit, introducing randomness by using SEE_{Ref} as the error term.

We now have a large number of XY datapoints from the reference population. We next calculate the probability of each generated XY point falling within the sporting population. This is done using a statistic which follows a χ^2 distribution:[12]

$$\chi^2 = 1/(1 - r_s{}^2)[(X - X_s)^2/sX_s{}^2 - 2r_s(X - X_s)(Y - Y_s)/(sX_s\, sY_s) + (Y - Y_s)^2/sY_s{}^2]$$

where X and Y are the values of any XY datapoint from the reference population, r_s is the correlation between the X and Y characteristics in the sporting population; X_s is the sample mean of the X variable in the sporting population; sX_s is the estimated standard deviation of the X variable in the sporting population; Y_s is the sample mean of the Y variable in the sporting population; and sY_s is the estimated standard deviation of the Y variable in the sporting population. The statistics for the sporting population are usually gathered from published literature.

Once we have the χ^2 value associated with each XY datapoint, we can calculate the associated probability (using 2 d*f*) from tables or from algorithms. We then average the probabilities over the number of datapoints generated, and the result is a global figure we will call the bivariate overlap zone (BOZ). If the reference and sporting populations have the same means and standard deviations for both X and Y variables, and the same XY correlations, BOZ will be very close to 0.5. As the differences between the means and standard deviations increase, BOZ will approach 0. BOZ will approach 1 as the SD of the X and Y variables of the sporting population approach infinity. In this case, the sporting population is infinitely extensive and any datapoint from the reference population will fall arbitrarily close to the sporting mean. However, because sporting populations are usually subsets of the reference population, and elite athletes within sports tend to resemble one another, their standard deviations are usually smaller than those of the reference population.

1.4 Recreating Skewed Distributions

This procedure assumes that both populations are 'bivariate normal' with respect to X and Y, however, this is not always the case. While height is usually normally distributed, mass shows a strong positive skew (a skew which is increasing over time in both the general population and in open-ended sporting subsets). Therefore, we have transformed the masses by taking logs, so that they appear normally distributed, and so that the relationship between mass and height variables is well represented by a straight line. Similar 'normalising' procedures should be carried out with other anthropometric variables such as BMI and sum of skinfolds.

1.5 An Example of the BOZ Technique

Figure 2 is a graphical representation of this procedure using subsets of the population that most people are familiar with. In the top panel the swarm of individual points are the generated XY datapoints from the reference population of 18- to 34-year-old US females.[14] The ellipse is the 90% density ellipse for the 'sporting' population – in this case a group of 11 regionally-based catwalk models.[13] The BOZ is 0.076 indicating that about 8% of the reference population have the 'right' height-mass combination. In the middle panel, the individual points represent the reference population of 18- to 34-year-old US females and the ellipse is the 90% density ellipse for a group of 70 highly paid international models. The BOZ is 0.045 or less than 5%

of the population. The bottom panel shows the ellipse for 11 ‘supermodels’ with an average income of over $US5 million per year (1999 value).[16] The BOZ for this group is 0.005 or less than 1% of the population have the matching body size of the supermodels.

By ‘90% density ellipses’ we mean that 90% of all models will fall within the bounds of this ellipse. The closer each XY datapoint (representing someone from the general population) is to the centre of the ellipse, the more likely she is to belong to the model population. Although the ellipses are represented as 2-dimensional figures, the density of the points they contain increases as one moves towards the centre and decreases as one moves towards the boundaries. This figure shows that as one moves from catwalk models, international models and then further to supermodels, the overlap with the general population becomes smaller and smaller, no doubt reflecting the differences in salary and prestige between the groups. Simply put, there are very few young women in the general population with the height-mass location required to be an international model and less again in the supermodel ‘catchment’ zone. This is an example of the use of BOZ to contrast groups of differing ‘ability’. However, the BOZ technique can also be used to assess differences in ‘selection pressure’ between sports and various positions in sports, male and female sports, and to assess changes over time. Only a few examples are presented here using professional sports and/or Olympic athletes.

1.6 Secular Trends

Changes in the body size of athletes need to be considered in the context of a backdrop of on-going evolution of body dimensions within the population. For the past century throughout much of the world, humans have been increasing in size over successive generations. This secular trend may be caused by a number of things including better nutrition, heterosis between previously geographically diverse populations, mass immunisation, the end of the industrial revolution and urbanisation.[17]

The use of the BOZ technique to track selection changes over time needs to take into consideration these secular changes of the reference population from which the athletes are drawn. In Australia, for example, recent work suggests that children and adolescents have been increasing in stature (for about the past 150 years) at about 1.2cm per decade for females and 1.3cm per decade for males,[18] but adult rates are unknown. Recent estimates for US adults indicate a lower value at about 0.4cm per decade.[14,19-21]

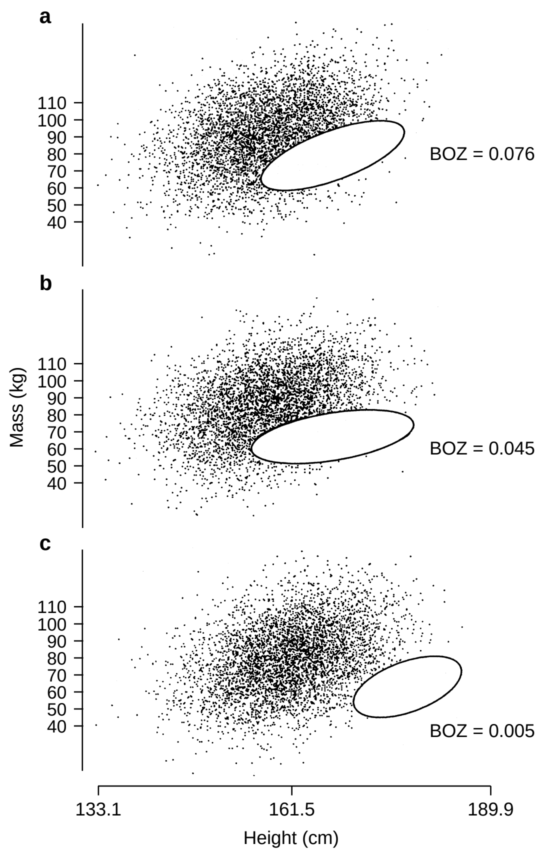

Fig. 2. Bivariate overlap zone (BOZ) simulation for catwalk models, international models and supermodels: (**a**) the 90% overlap between a group of 11 ‘regional’ catwalk models[13] and the population of 18- to 34-year-old US females;[14] (**b**) the 90% overlap between a group of 70 international models[15] and the population of 18- to 34-year-old US females; (**c**) the 90% overlap between a group of 11 supermodels[16] and the population of 18- to 34-year-old US females.

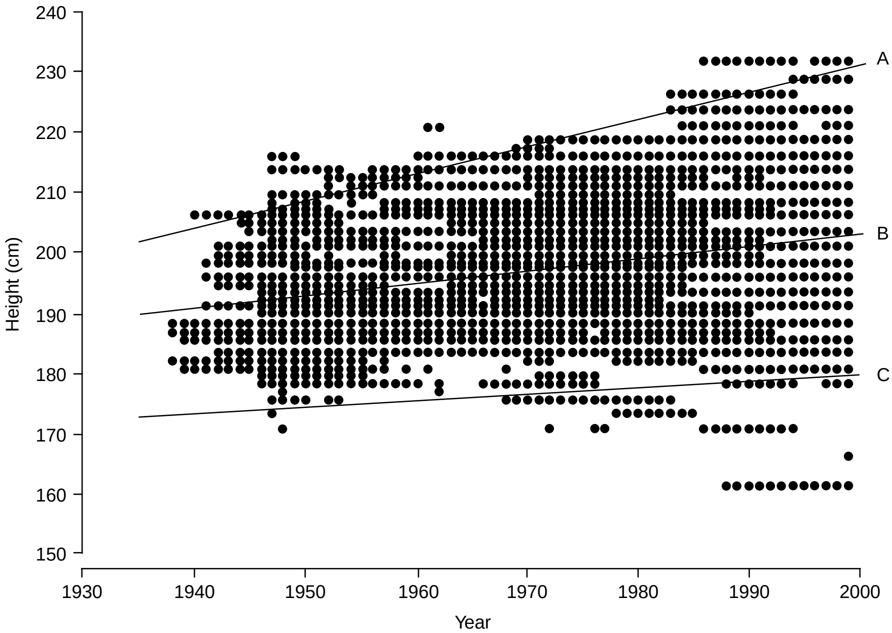

Fig. 3. The change in height over time for all National Basketball Association players. Line **A** shows the regression for the 3 tallest players each year, y = 0.483x + 182.6 where y is height in centimetres and x is the year. Line **B** shows the line of best fit for all players, y = 0.193x + 183.1; and line **C** represents the US general population secular trend for young adult males, y = 0.042x + 93.0.

Athletes in many sports (although not all, despite the secular trend) have been getting taller and more massive over time.[5] Importantly, however, often the rate of rise in height or mass outstrips the rate of rise which is attributable to the secular trend. Athletes are often getting bigger at a faster rate than that predicted by the secular trend alone. This is particularly true in sports which are 'open-ended', that is, the bigger the player the better (see Norton et al.[5] for discussion). A good example is the height of the National Basketball Association (NBA) players. Figure 3 shows that the rate of increase in height for all players is over 4 times the secular trend. This increases to over 10 times the rate for the tallest basketball players.

1.7 The 'Expanding Universe' of Athletic Bodies

We reviewed data on height and mass for athletes competing at the highest level (professional sports, world championships and Olympic games) in 22 sports over the past 100 years. Not all sports were represented throughout the entire century and the individual numbers within each sport ranged as listed: AFL 674; boxing 83; cycling – road 706; cycling – track 388; diving 180; gymnastics 366; high jump 162; jockey (horse racing) 1169; long jump 259; NBA 3370; NFL 18 517; rowing (heavy weight) 1167; rugby union 1372; running – 400m 465; running – 800/1500m 590; running – distance 654; running – marathon 668; running – sprint 968; shot put 133; swimming 1397; throwing (non-shot) 336; volleyball 398; waterpolo 532.

Data were assembled from over 100 sources (a full list of the references and sources of information are available from the authors). These data were collated from more than 100 reports published in peer-reviewed journals or presented at international conferences, Olympic summaries, from unpublished data provided by anthropometrists around the world [most were accredited by the International Society for the Advancement of Kinanthropometry (ISAK)], by workers at national sports institutes, websites, published in sports magazines, compendia or in event programmes, or communicated personally to the authors. The data were used to compare year of competition against indices of body size (height, mass and BMI). Linear regression was used to determine the rate of change of the variables for each sport over the century.

Figures 4 and 5 illustrate the relationships between rates of change in body size since 1970 across 22 sports. These relationships are highly significant and tell us that the rate of change of body size is proportional to how much the characteristic body size deviates from the population average. Those athletes who are bigger than the general population are becoming bigger at a greater rate. Athletes located close to the average of the population have changed very little. In athletes smaller than the source population mean, the rate of decrease in size is proportional to how much smaller they are than the population as a whole. The small remain small or get smaller, while the big get bigger.

Figure 6 illustrates the morphological evolution within a sport across the past century. In this example we have used running events from 100m to the marathon to show the pattern of divergent BMIs. The specialist nature of these events and the fact there is an optimal body type for each event drives the evolution towards that body shape. Despite the expanding nature of the BMIs, there is a relatively smaller expansion in height and the relationships among these groups have remained unchanged.

Thus, we have presented data showing that elite athletes have been evolving over the past century. This has been happening in consistent ways among and within sports such that clear patterns can be demonstrated and quantified. Each sport demands a particular set of attributes, including body composition and proportions. These body characteristics relate very closely to optimal biomechanics (e.g. torque-angle and force-velocity relationships), bio-

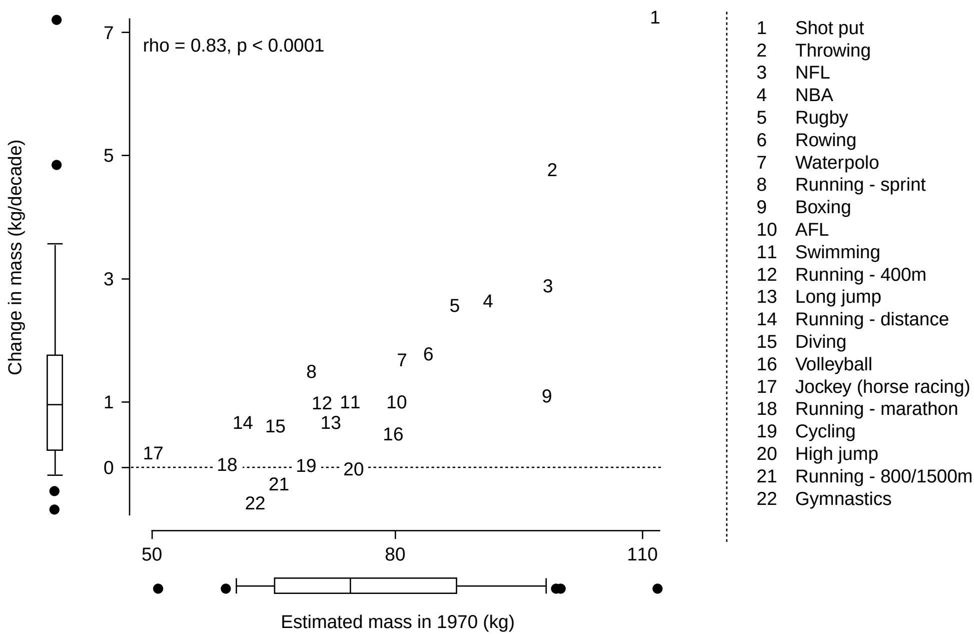

Fig. 4. Relationship between the rate of change of mass (kg/decade) and estimated average mass in 1970 in 22 sports. The box plots at the bottom and sides of the graph show the percentile distribution of the x and y variables. **AFL** = Australian Football League; **NBA** = National Basketball Association; **NFL** = National Football League; **rho** = correlation coefficient.

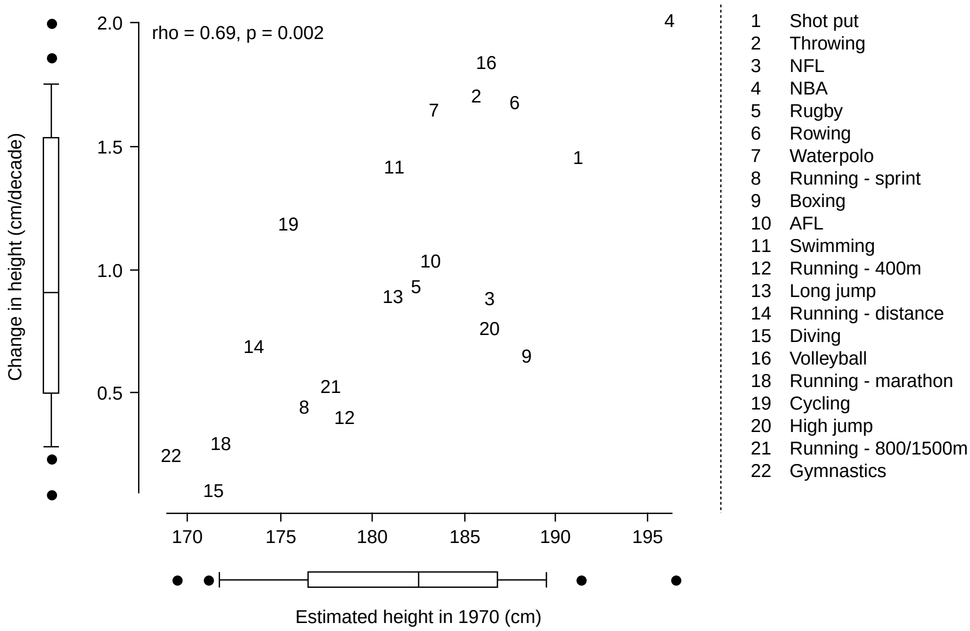

Fig. 5. Relationship between the rate of change of height (cm/decade) and estimated average height in 1970 in 21 sports (no data were available on the height of jockeys; listing number 17). The box plots at the bottom and sides of the graph show the percentile distribution of the x and y variables. **AFL** = Australian Football League; **NBA** = National Basketball Association; **NFL** = National Football League; **rho** = correlation coefficient.

physics (surface area-to-mass ratios) and physiology (energy release). The 'mix' of attributes is specific to particular environments, rules and technologies. Small changes in the competition conditions such as rule changes, temperature or altitude, and equipment use can modify the combination of ideal attributes.[5] In general, however, there is a 'Darwinian' selection pressure that directs the perfect body form in any event. Other less natural forces also drive and are driven by this evolution, and these are discussed in the following sections.

1.8 The BOZ for the National Football League and National Basketball Association

Figure 7 illustrates the change in the BOZ for inside linemen from 1920 to 1999, split into decade slices. The statistics have been calculated using 2618 players who have played in the NFL during the past century. The figure shows both the shift in the distribution of the general population of 20- to 29-year-old US males (as individuals get bigger across the decades) as well as the evolution of the linemen size. In the 1920s these players averaged about 180.9 ± 6.2cm and 89.8 ± 8.8kg. In the 1990s, these figures were 193.2 ± 4.2cm and 137.2 ± 7.8kg. The corresponding BOZs were 0.149 and 0.001, resulting from the dramatic change in player size over the century. The net result is a decrease in the 'availability' of these players. There is now only about 1 chance in a thousand of finding adult males with the required player size for the inside linemen positions. The ellipses show the 67% OZ for each time period. The BOZ data for each time slice are also shown. The figure illustrates the evolution of the selection pressure for linemen that is now at an extremely low probability.

Figure 8 illustrates the change in the BOZ for all NBA players (n = 3370) over the time period 1940 to 1999, relative to the general population of 20- to 29-year-old US males. There has been drift of the density ellipses away from the general population reflecting a deceased probability of finding individuals with the necessary height and mass combination. There appears to be a levelling of the NBA BOZ at about 5%. The small upswing in more recent times probably reflects the specialised nature of some of the positions in the game which allows for a larger range of body sizes, for example there are current players ranging in height from 161.5 to 231cm (5 foot 3 inches to 7 foot 7 inches).

2. Does Player Size Make a Difference?

When the heights and masses of all the retired NBA players are regressed against the number of playing years (career length) the relationships are significant ($p < 0.0001$) and positive. The regressions indicate that every 33kg increment in player mass equates to, on average, an extra year in career length. Similarly, for each 23cm increase in height the playing career increases by 1 year. Given the extraordinary player payments per season (the mean was approaching $US1 million per year in 1993 – see section 4.1) and that the average NBA career length is relatively short at 4.3 ± 3.8 years (calculated from data in Sachare[22]), then size is an important component of player success. Indeed, on average, for every 1.0cm (0.4 inch) in height or 1.3kg (3.0lb) in mass this equates to about $US43 000 (adjusted to 1993 values) in additional player payments over their career.

In the NFL, an increment of 51kg in mass or 17cm in height is associated with an additional playing year. The average NFL playing career is 4.7 ± 3.4 years. Increments of ≈1.0cm in height or 3kg (6.6lb) in mass equate to about $US45 000 (adjusted to 1993 values) in additional player payments over their career.

We calculated z-scores for mass and height of the 300 all-time greatest players[23] relative to others

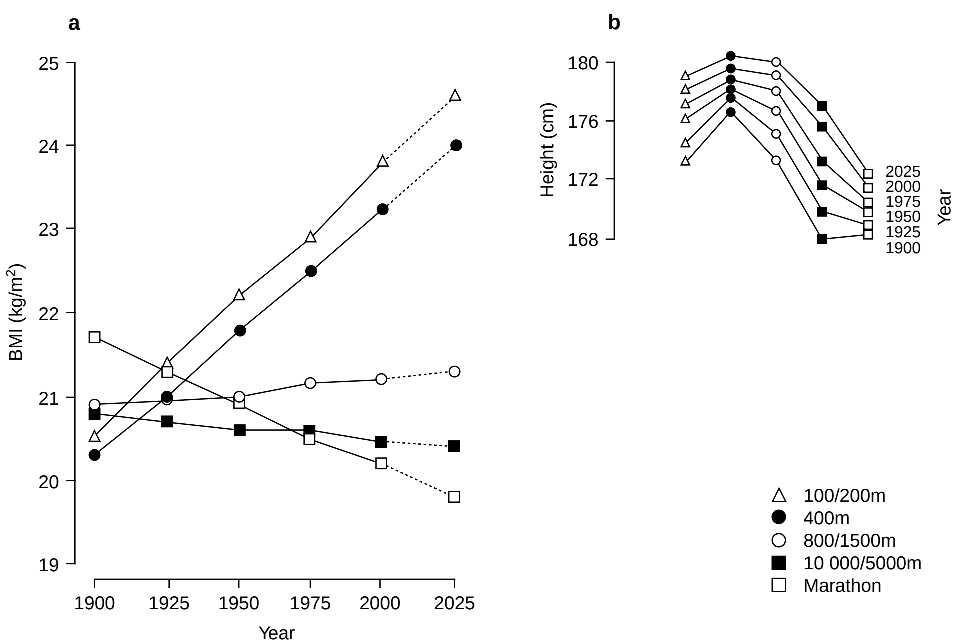

Fig. 6. (**a**) Trends in body mass index (BMI) [kg/m^2] for runners with event distances from 100 to 200m to the marathon between 1900 and extrapolated to 2025. The rate of change of BMI decreases as event distance increases. Datapoints outside the regression range are joined by dotted lines. (**b**) Heights of runners with event distances from 100 to 200m to the marathon between 1900 and extrapolated to 2025.

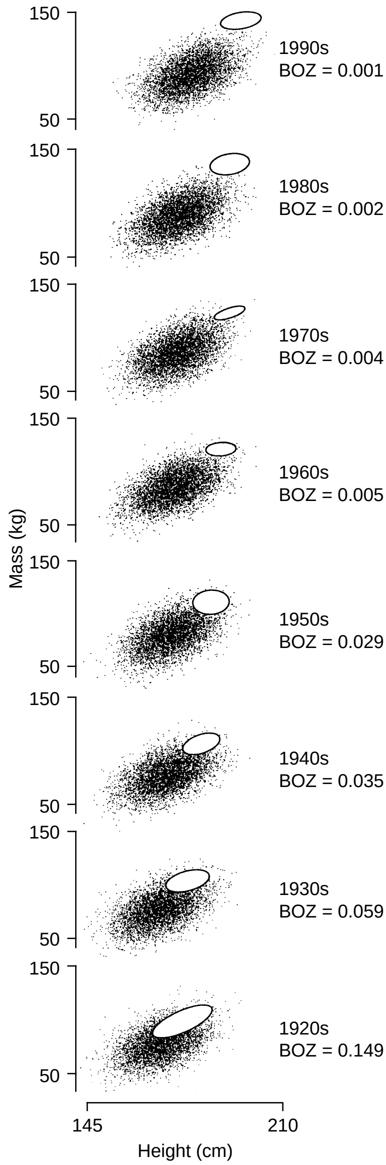

Fig. 7. The bivariate overlap zone (BOZ) for the National Football League inside linemen for the period 1920 to 1999. The general populations shown were recreated using data from Hatherway and Foard,[19] the National Health and Nutrition Examination Survey (NHANES) I,[20] II[21] and III.[14] Of note are both the secular changes in the reference population (the rightward drift in the swarm of points represents the reference population) and the growing drift of the footballers away from the background populations.

in their respective cohorts. Inside linemen selected as all-time greats across the years had an average z-score of 0.78 for mass and 0.80 for height. Quarterbacks averaged z-scores of 0.20 and 0.69, wide receivers 0.03 and 0.33, and running backs 1.18 and –0.63 for mass and height, respectively. With the exception of height for the running backs, there was a clear pattern of career success and above average size. The all-time great running backs had an average BMI z-score of 0.56. Finally, as indicated in the introduction, starting linemen in the NFL are significantly more massive compared with second-string players. In most positions in open-ended sports such as American football and basketball the pattern is clear. Larger players have an advantage and it is easy to see how this drives the evolution of player size in these sports.

3. International Recruitment

Despite an increasing world population, players of the required and desirable size have become harder and harder to locate. In response to this, various strategies have emerged to widen the net and to make sure that less potential players slip through. One of these strategies is increased globalisation and international recruitment in sport. Examples of the global market for athletes are found in the US national basketball leagues [NBA and Women's National Basketball Association (WNBA)]. Within these North American competitions, players come from countries such as Australia, Croatia, Germany, Lithuania, the Netherlands, Nigeria, Romania, Serbia, Sudan, Venezuela and Zaire, to name a few. The 29 team player lists for the 1998 to 1999 NBA season were used to calculate the player sizes. The heights and masses for the 516 US-born NBA players averaged 200.3 ± 9.3cm and 99.0 ± 13.2kg, respectively, whereas the 24 international recruits were significantly taller, 211.1 ± 8.4cm ($p < 0.0001$) and heavier, 110.6 ± 10.2kg ($p < 0.0001$).

This shows that selective recruitment of the most difficult to obtain players (the very biggest) has led to a search beyond the boundaries of the US population to include almost all countries of the world. The fact that one of the world's tallest peo-

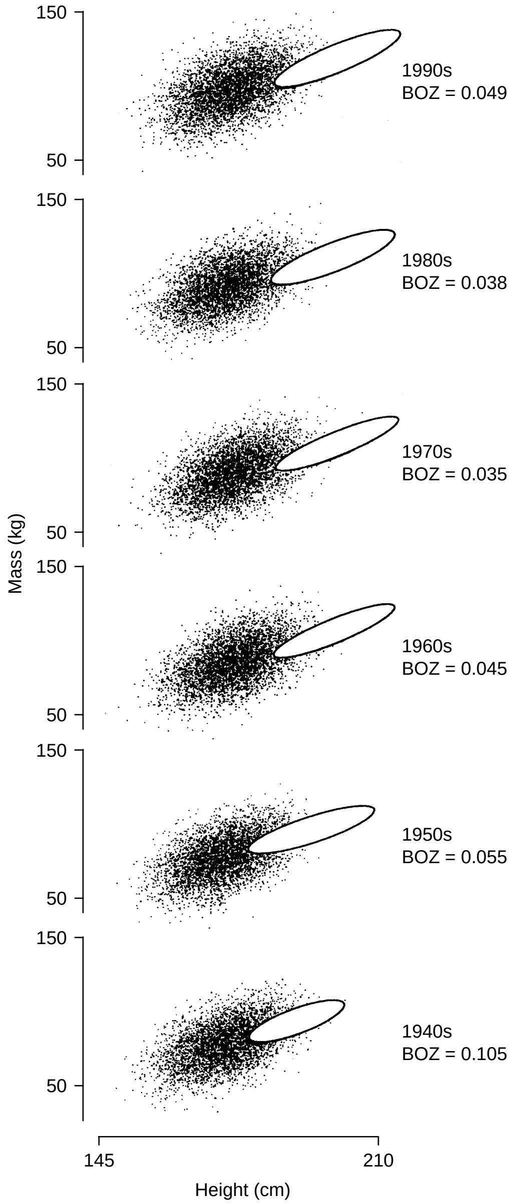

Fig. 8. Bivariate overlap zone (BOZ) for the National Basketball Association players from the 1940s through to the 1990s. The general populations shown were recreated using data from Hatherway and Foard,[19] the National Health and Nutrition Examination Survey (NHANES) I,[20] II[21] and III.[14] Of note are both the secular changes in the reference population (the rightward drift in the swarm of points represents the reference population) and the growing drift of the basketballers away from the background populations.

ple (reputedly 240cm), a North Korean who also happens to play basketball, is not playing in the NBA is a political decision (he was refused a US entry visa by the US department of Immigration) and not a selection decision. There are now 2 'permanently' placed teams in Canada and the NBA games are televised to 195 countries, reinforcing the global nature and 'catchment' of this competition.[24]

Figure 9 illustrates the differences in the BOZ for the US-born versus foreign-born NBA players. The differences reflect the requirement for team scouts to search the world for the rarer players (the tallest and largest) who have an obvious advantage in the sport of basketball.

A pattern emerges when the percentage of NBA players over 213cm (7 feet) is plotted for each year. Figure 10 shows the percentage rose sharply at about the same time that player salaries accelerated. During this time the NBA searched globally for the tallest players. The percentage appears to be levelling off during the past decade probably as a result of the world's tallest players having already been recruited.

The WNBA player lists detail the size of 120 players for the 1998 to 1999 season. The heights and masses for the 94 US-born WNBA players averaged 181.6 ± 8.3cm and 73.5 ± 10.0kg, respectively, whereas the 26 international recruits were significantly taller, 188.4 ± 11.8cm ($p < 0.0005$) and heavier, 78.3 ± 12.2kg ($p < 0.0001$). In fact, 9 of the 12 tallest players were international recruits from 8 different countries.[25] Given that it is only early in the history of this competition one would expect a rapid evolution of the physical size of these athletes as the recruitment process and talent migration intensifies.

The reference populations for these major North American sports has increased along with economic and media 'globalisation'. Another example can be found in the foreign contribution to the National Collegiate Athletic Association (NCAA) male track and field championships which increased from 28.1 to 34.2% in the decade 1977 to 1986.[26]

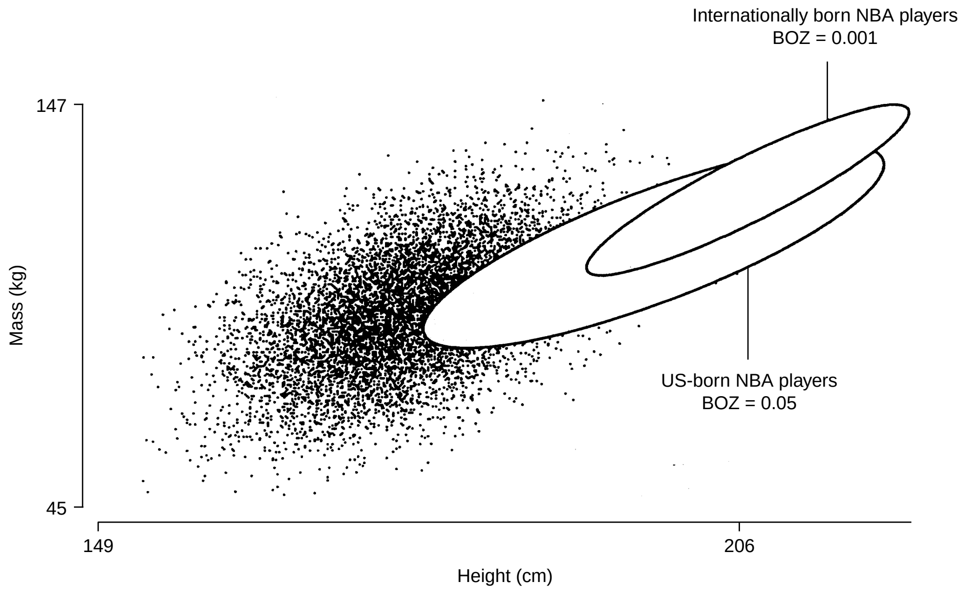

Fig. 9. The bivariate overlap zone (BOZ) for the US-born National Basketball Association (NBA) players versus the internationally born players. The BOZ scores are 0.05 for US players, indicating about 5% of the population of young adult males have the appropriate size for NBA selection. The international players are taller and heavier and are therefore 'rarer' with a BOZ of less than 0.001 or about one in a thousand have the necessary height-mass combination to play NBA. Data for the 1998/1999 season were used.[2]

4. Exploiting Existing Reference Populations and Financial Incentives

4.1 Player Salaries

One way of better exploiting existing reference populations is to recruit a greater percentage of those people who have appropriate body size and shape. This may involve player drift from one sport to another, often as children and adolescents but not always. One aspect of this involves the sports profile, a result of many things including, for example, international competition, sporting heroes and inclusion in the Olympics. Another component is the offer of greater financial incentives. A review of player salaries in the 4 major US male sports over the last several decades illustrates the recent acceleration in player payments.

Figure 11 shows the evolution of mean player salaries in American football, basketball, baseball, ice hockey and Australian football. Individual data are not available and so mean values have been calculated. Since it was not possible to obtain historical data, mean salaries are expressed as multiples of median male income in the respective years. Although this tends to exaggerate the mean salaries by positive skewness in player payments, it nonetheless shows a significant trend in player payments in general over time. More recent individual data for US hockey and baseball league players shown in this figure (for the 1999/2000 season)[29-31] illustrate the degree of skewness in salary payments for these professional athletes. Between 1945 and 1980, average player payments to NFL players were stable at ≈5 times the male median income. In the 13 years to 1993, average player payments have risen to over 40 times (basketball), 25 to 30 times (football and baseball) and about 10 times (ice hockey) male median income. Over the most recent 6 years the salaries for the hockey and baseball players have continued to climb exponentially. There are now individual players in all of these sports earning the equivalent of over 400 years of the median male salary per annum. Australian football is following a similar acceleration in player payments albeit at an earlier point along its evolutionary path. This graph reflects not only the influx of money into the game, but also the incentives required to recruit players with competitive physical characteristics.

Where is the money coming from to support this exponential increase in players' salaries? Figure 12 illustrates the attendance records for major league baseball (using combined American League and National League figures for 1901 to 1990).[34] It is apparent the growth in spectators has mirrored the growth in player salaries. This is likely to have been one of the stimuli for greater salary caps and individual player contracts. Furthermore, the billion dollar arrangements between the television companies and the major sporting organisations filter down to support the spiralling payments. Up to and including 1994, the top 10 all-time television audiences in the US included 9 sporting events. Eight of these were for American football games and one for an Olympic event (based on A.C. Nielson figures).[1]

Figure 13 illustrates the growth in both advertising expenditure and in NFL royalties over the past 50 years (adjusted to 1993 $US values). The popularity of sports is so great that a 30 second advertisement during the 1999 NFL superbowl cost $US1.6 million. Total television advertising is rising linearly yet the distribution to individual teams is accelerating. This situation may have some limitation although the make-up of total advertising is changing such that 'sport' advertising is increasing its share of the market leading to sporting organisations receiving a disproportionate rate of royalties. In 1990 it was estimated to account for 25% of all network television advertising.[36] This source of funding resulted in each team receiving over $US60 million for the 1998 to 1999 season (1999 dollars). Put simply, contemporary sport cannot survive without media and media cannot survive without sport, a fact that is probably the reason why many professional sports teams are owned by the media. The potential for profit is enormous.

4.2 Market-Driven Changes

The data in section 4.1 highlight the enormous financial interests tied up in professional sports. This leads to some interesting agreements between the media and sports administrators for mutual 'benefit'. Sewart[4] outlines numerous examples of the commodification of sport, specifically the way that market-induced rule changes can impact the game. For example, he lists 16 rule changes and technical innovations that were introduced in the NFL in the early 1970s to increase interest, spectatorship, advertising and, ultimately, profit for the media and football club owners. These changes, and others since this time, have resulted in a turnaround to the levelling off in spectator numbers to a point where almost every year in the 1980s and 1990s record numbers of fans were attending football games (the increased number of franchises and games played each season also help this statistic).[35]

There are some rule changes and technological developments (for example, a referee now using a microphone to explain decisions) that have little or no impact on the requirements of the players. However, other changes that were introduced have consequences and impact on player preparation, player

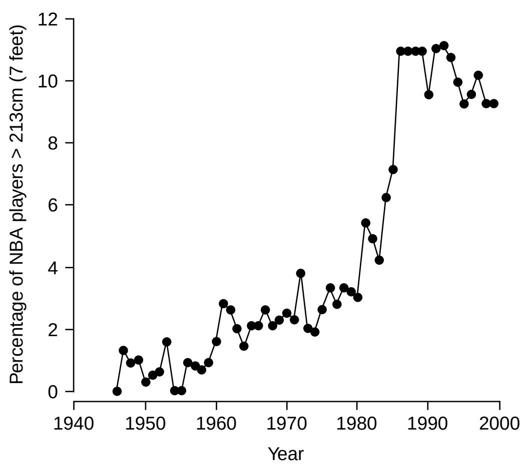

Fig. 10. The percentage of all National Basketball Association (NBA) players who were greater than 213cm (7 feet) in each year from 1946 to 1998.

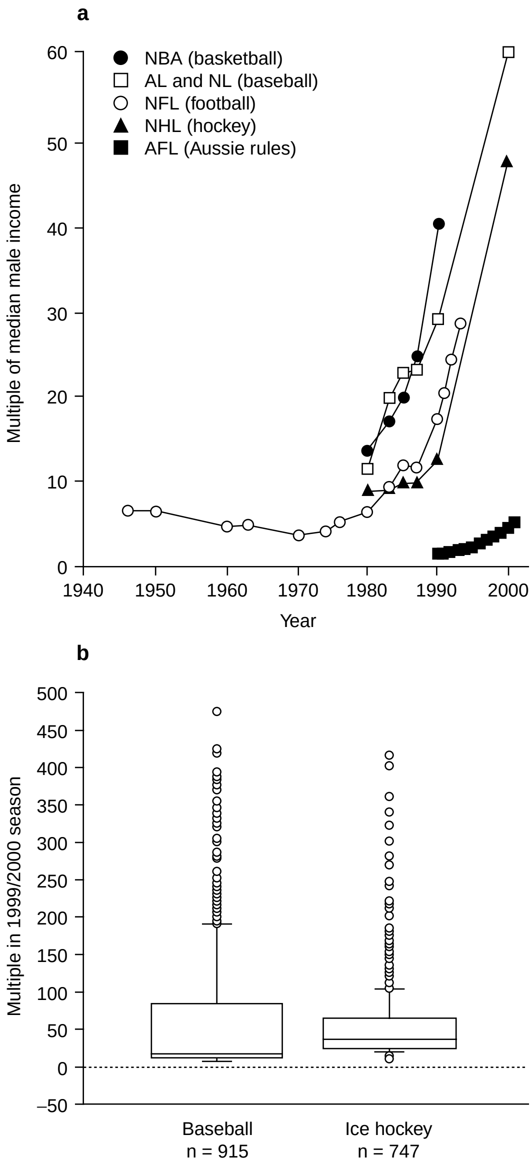

Fig. 11. The evolution of mean player salaries: (**a**) mean male player salaries in American football, basketball, baseball, ice hockey and Australian football, expressed as multiples of the median male income in each year.[27-31] Male median income data from US Census Bureau[32] and data for Consumer Price Index adjustments from Bureau of Labor Statistics[33]; (**b**) box plots of the individual salaries for baseball and hockey players in the 1999/2000 seasons.[29-31] **AFL** = Australian Football League; **AL** = American League; **NBA** = National Basketball Association; **NFL** = National Football League; **NHL** = National Hockey League; **NL** = National League.

demands in the game and the required physical attributes. For example, the facts that the defensive team can raise their arms to block the ball, that a greater number of players are allowed per team (increasing interchange opportunities) and that there are more frequent rest periods (often mandated by the media), permit taller and more massive players. The new game now demands this type of player and, over time, the game evolves to produce (find) these athletes, rewarding them handsomely. This in turn drives player behaviours, administrator recruitment tactics and reference populations. For many players behaviours are driven in directions that are taken purely for financial incentives even at great personal risk. Often rule changes are made with little regard to player safety and the 'dangerous' areas of the game may be left untouched.[4] Australian football is a good example of this trend. The professional game has changed quite dramatically in recent years due to a large extent to media-linked rule changes. There is strong evidence to show that these modifications have resulted in shorter, higher intensity play periods interspersed with longer rest periods, relative to the games of yesteryear. This change in game structure is more spectacular and accommodates larger players than previously. It is likely, however, to be a major factor in the high and increasing injury rate.[37]

Often the ultimate effect of rule modifications and sports evolution is the changing bias for player types. The desirable morphology for a particular sport or position in a sport can be modified to such an extent as a consequence of rule changes that a particular player type becomes more or less suited to the game. There have been some obvious examples in technology changes and the impact on player suitability.[5] Seemingly small changes in the structure of the game, often in response to media requirements, have had enormous 'ripple effects' in a variety of sports and are intimately associated with the evolution of player size and shape. Other examples of media-influenced rule changes are outlined by Sage.[36] The relationship between sports and the media is summarised by Leonard Shecter (US sports journalist): 'Television buys sports . . .

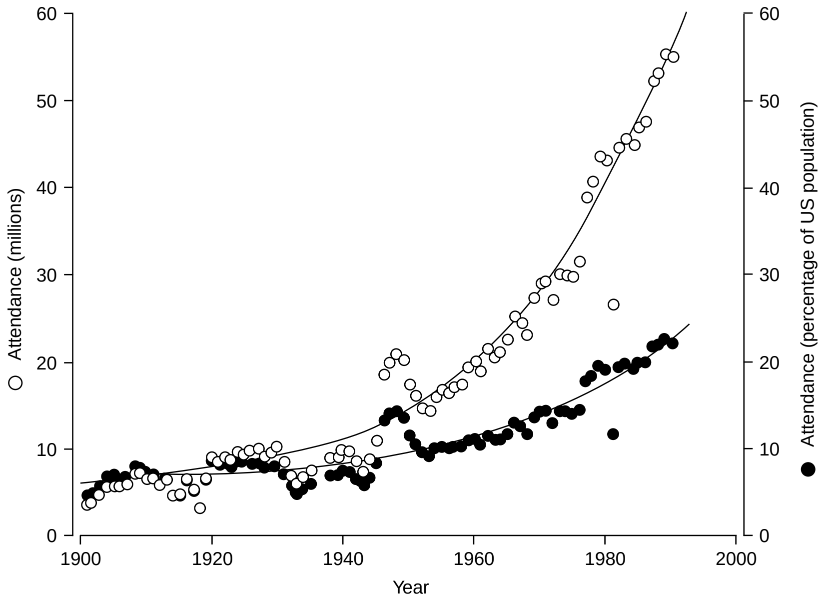

Fig. 12. Annual attendance for the combined American and National League Baseball competitions 1901 to 1990. Data are shown as both absolute numbers and relative to the US population over the same period. The lines of best fit are third order polynomials (r = 0.98 and 0.93) for the absolute and relative attendances, respectively. Calculations based on data from Kurian.[34]

Television tells sports what to do. It *is* sports and it runs them the way it does most other things, more flamboyantly than honestly.' (reported by Sage,[36] page 115).

On the one hand this symbiotic relationship may be ideal for the administrators/owners and the media, and there is little question it results in huge financial rewards to the players. On the other hand it is potentially difficult to accept for the athlete and sports purist who are forced to either play a different game style and/or watch the game evolve into a different form (e.g. the development of 1-day and night cricket, the tie-breaker in tennis, the shot-clock and 3-point shot in basketball, the sudden-death tie-breaker system in the NFL or the Skins game in golf). Importantly, the media have little inherent interest in sport. Their primary objectives are ratings and profit and yet their ability to control and modify sport is overwhelming. When sports teams are also privately owned, as is the case for every US professional sports team, it is fair to say that the intention is also profit. This combination has resulted in a range of changes introduced to sports with the expectation it will modify the game in ways helping to boost spectator numbers and advertising dollars; it has obviously worked.

However, the rise in player payments cannot continue if the sports are to survive. In recent years there have been a series of player strikes in a number of major sports. For example, the NFL players held a 24-day strike in 1982 and another 57-day strike in 1987.[23] A strike by the NBA players in 1998 to 1999 forced the season to be effectively halved. This ended when a collective bargaining agreement between the NBA players association and the NBA owners resulted in the minimum annual salary of a first round rookie of $US500 000 and that of a player with a 10-year service record at $US1 000 000. Maximum salaries are now capped at approximately $US15 million per season although salaries up to $US34 million per season for the superstars were possible in the 1997 to 1998 season.[24] These changes will result in the distribution of payments being markedly less skewed and may

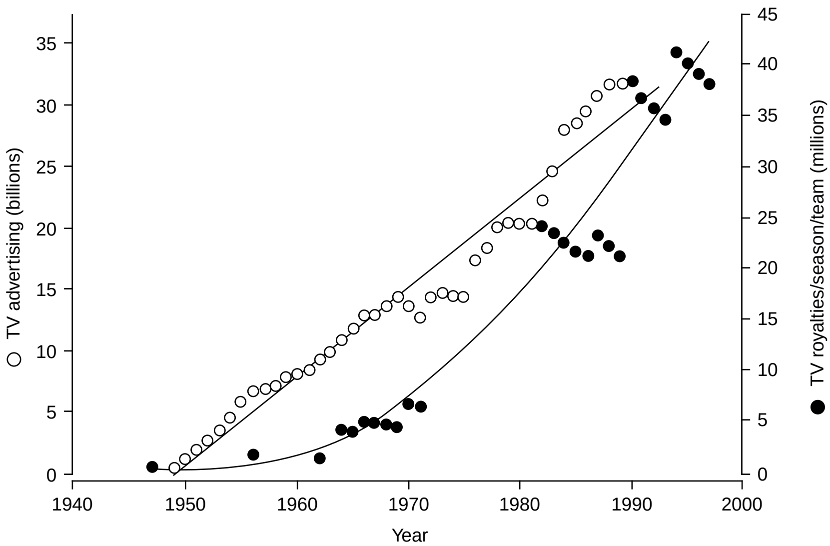

Fig. 13. Television advertising expenditure (billions) in the US and National Football League royalties (millions) to each team per season. Values have been adjusted to 1993 $US (hence the apparent depreciation in royalties in later years when multiple year contracts are used). The royalty data for 1947 and 1956 were estimated on the basis of the biggest single team contract multiplied by the number of teams in the competition.[34,35]

help to limit the rate of rise in the salary cap and player walk-outs. Notwithstanding these agreements, the prospect of extraordinary salaries to previously unemployed college students can drive decisions and behaviours taken to gain advantages in sport. Consequently, much depends on player size, and body mass is one area that can be manipulated.

5. 'Artificial' Growth and the Use of Drugs in Sport

During announced drug testing less than 1% of Olympic athletes tested from 1984 to 1989 were found to be positive. However, despite this low percentage, it is almost universally accepted by senior sports administrators that the use of performance-enhancing drugs, most notably anabolic steroids is likely the greatest problem facing sport today (for an example see Chapter 10 in Lucas[38]). In support of this statement, Voy[39] reported that when the US Olympic Committee conducted unannounced drug tests involving no punitive actions, ≈50% of athletes tested positive to anabolic steroids. There is also considerable evidence that in the NFL steroid use in some positions runs as high as 90% of the players.[40] Given the financial and publicity incentives for reaching the professional ranks in football it is not surprising that significant levels of drug taking also exist among collegiate and high school players.[40] The lust for sports success and the fame and fortune accompanying these feats drive many behaviours.

Robert Voy[39] (page 127), the US Olympic Committee's Medical Director for 5 years said: 'If you have to weigh 280 to 300 pounds to be college lineman, forget it; we'll never stop anabolic androgenic steroid use in football.'

However, many people in the general sporting public are becoming desensitised and ambivalent about issues of drugs in sport. The media have a lot to do with this changing attitude. For example, it was reported that Ben Johnson was still able to receive between $US3000 to 5000 for celebrity guest appearances 2 years after testing positive for drug use at the 1988 Olympics.[38]

How much can players gain from steroid taking? Many scientific studies have shown the immense tissue-building properties of anabolic steroids.[40], even under controlled, clinical doses. Figure 14 summarises a number of studies into the anabolic effects of exogenous testosterone and anabolic steroids.

There is a close logarithmic relationship between the change in fat-free mass (FFM) [expressed as a percentage of initial values] and the steroid 'load' (in mg/kg bodyweight). Based on these data, it appears that there is a plateau in FFM gains at about 15 to 20% above initial values. A similar pattern has been reported previously.[44] There is a close relationship between the change in FFM and the change in body mass: for every kilogram of body mass gained, about 1.25kg of FFM is gained. Therefore, there is usually a loss of body fat. Given the secular rate of increase in body mass of about 1kg per decade, the steroid-induced change represents a shift of over a century, achieved in as short as 4 months!

The premise that 'some is good but more is better' is probably responsible for the reported doses of over 100 times therapeutic concentrations being taken for cosmetic purposes.[40,51] There is every likelihood that the incidence of drug taking, particularly tissue building drugs such as growth hormone and anabolic steroids, will continue to increase in the future. Given the high and growing rate of drug abuse [estimated to be over a million in the US alone (Voy[39] page 168, Yesalis and Cowart[53] page 6)], it is unlikely a levelling off in the rate of player growth will be seen in the near future despite the plateau effect illustrated. New drugs are continually being developed, multiple drugs are taken in combination, and the potential rewards for professional athletes are far too great to prevent a large section of the general population attempting to emulate the sporting population. For many to reach and/or survive in professional sport requires them to adopt illegal and dangerous behaviours. These practices, in turn, modify player size and shape.

Figure 15 shows a striking pattern of BMI in the starting year for 18 517 NFL players. Why is it that from about the early 1980s players (particularly linemen) are entering the NFL at a BMI that is rising at a significantly greater rate than at any other time over the previous 80 years? Between 1920 and 1979 the rate of rise in BMI was 0.032 BMI units per year. Since 1980 the rate has increased to 0.159 BMI units per year. The difference in the slopes is highly significant ($p < 0.0001$). Although better training and nutrition would contribute to this 5-fold increase in the growth rate, it is strongly suggestive that ergogenic aids have been involved. These data along with other evidence and testimonies indicate steroid abuse became widespread in college and professional football in the middle to late 1970s and has continued since this time.

Who could argue against the fact that huge economic incentives in sport persuade athletes to take drugs? Ben Johnson, for example, stood to gain an estimated $US30 million in endorsements for his sprint victory.[39] One only has to look closely at

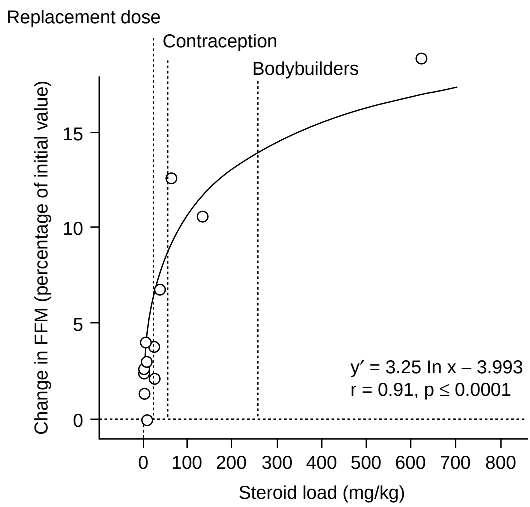

Fig. 14. Change in fat-free mass (FFM) expressed as a percentage of initial values as a function of total anabolic steroid load (mg/kg bodyweight). Each dot represents a separate study.[41-51] Typical loads for a 6-week course for replacement of endogenous testosterone, male contraception[52] and a bodybuilder are shown. Where control groups were used, the changes in FFM represent the difference between the steroid group and the control group. In most studies, the participants were resistance training while taking steroids, and often were experienced weight-trainers.

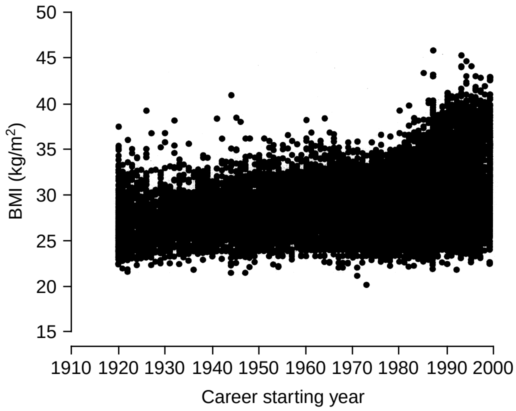

Fig. 15. The body mass index (BMI) of 18 517 National Football League players shown against their starting year (1920 to 1999). Two regression lines were generated to determine the rates of change in BMI from (i) 1920 to 1979 (n = 10 602); and (ii) 1980 to 1999 (n = 7915). The regressions used the 6 heaviest players each year against the playing year for the 2 time periods. The slopes of the regression lines were significantly different indicating that the rate of increase in player mass accelerated from about 1980 (see text for details).

the practices of jockeys, wrestlers, boxers and other 'weight-limited' athletes to see how extreme the behaviours can become. Brownell et al.[54] reported examples in wrestling of dietary and/or dehydration reductions resulting in up to 9kg body mass in 1 week. This regimen might be repeated up to 30 times per season. In sports such as women's gymnastics a smaller, lighter frame is highly desirable. So much so that over the past 30 years of international competition gymnasts have steadily decreased from 1.6m, 47.7kg in 1976 to 1.45m, 40kg in 1992. The average age of these competitors has also decreased from 22.7 years in 1964 to 16.5 years in 1987.[5] This demand for pre-pubertal athletes has driven the age down but has also led to the use of age-slowing drugs (called 'brake-drugs') to maintain child-like growth features.[39]

"When it becomes possible to earn big money in athletics, the pressures to be successful and win become more intense. When that situation is combined with the availability of drugs that can help an athlete achieve his goals, the pressure to use the drugs is great."

Joe Paterno, Professor and Head Football Coach, Pennsylvania State University, USA (Yesalis and Cowart[53] page vi).

6. Athlete 'Gene-Farming'

Assortative mating among athletes often leads to the production of genetic polymorphisms of the next generation of gifted athletes. Athletes often marry and produce offspring with other top athletes. Lawson[55] gave a synopsis of all world record holders in track and field athletics. In this summary he listed at least 26 world record holders who had married other world record holders, Olympic or national champions. Furthermore, he presented 18 cases of world record holders running in families, either second generation or sibling combinations.

This is probably not surprising given the fact that humans often select partners of similar build and that elite athletes often resemble one another.[5] Furthermore, in the competitive, demanding and extremely focussed world of professional sport there is less opportunity for players to socialise with and court those other than similar quality athletes.

Sports require a specific morphology for success and individual sports have their own unique set of required physical characteristics. Since body size, shape and composition are under considerable genetic influence,[56] it is not uncommon to find second and third generations of professional athletes from the same families. In the NFL, for example, where size is an obvious advantage, there have been 241 sets of brothers (including a set of 7 brothers and identical twins), 99 second generation and 2 third generation players who have played at the professional level.[57] Several father/son combinations are also listed in the hall of fame. This does not just happen by chance. The total population of 20- to 35-year-old males in the US during the period 1920 to 1996 is estimated to be about 110 million, where 30 million families have at least 2 brothers.[34] During this same period 17 037 players played at the professional level in the NFL.[35] The probability of this pattern of familial selection happening by chance is infinitely small. There is obviously considerable genetic influence in the pre-selection of potential athletes.

There have been tremendous advances in molecular biology in recent years. Cryopreservation of gametes and fertilised eggs, for example, is now common in many countries. There is little question that these techniques will be utilised in sport, most likely in talent identification and the production of 'athletic genotypes'. According to Bouchard and colleagues,[58] all of the technologies are available to make this possibility exist. The only thing to be determined is the exact location of genes (yet to be identified) that are important in sporting prowess. However, is it really necessary to know the exact location of the genes for physical ability in order for 'gene-farming' to become a reality? The answer is probably no since the location of 'athletic' genes is not known for race horses yet selective breeding has been going on for centuries. The pattern of athletic success within human families also suggests that genetics do not always need to be understood at the DNA level when predicting the likelihood of sporting success. This is because athletes, like race horses, are carriers of some obviously desirable genotypes relative to high-performance sports, for example, size, lean body mass and anatomical proportions required at the elite level.

Bouchard[58] stated that within 10 to 15 years top athletes are likely to be offered incentives to serve as gamete donors. Positive eugenics is already occurring in the area of intellectual capacity. Many reports indicate that targeting intellectual ability is practised in artificial insemination, often by medical practitioners who have been shown to bias selection of the donor sperm towards university and medical students.[59] A 1980 Hasting Center report[60] indicated 4 Nobel prize winners and others in Mensa (a group for the top 2% of IQ) had donated sperm for insemination purposes. This was advertised throughout the Mensa networks and only Mensa members were eligible to donate or receive the sperm (see also Sappideen[61]).

Top athletes can earn much more than top scientists and almost always have greater public appeal. It is likely, therefore, that gametes from elite athletes will become a highly sought after investment. Given that there are an estimated 170 000 women each year who receive donor sperm in the US alone, and that this is accelerating, the demand is likely to grow for greater choice or 'pre-selection'.[62] Interestingly, women choosing among the profiles of potential sperm donors in a clinic showed a preference for a tall donor.[63] Furthermore, there is evolutionary pressure selecting taller men who have been shown to be more likely to have a partner and to father more children.[64]

7. Conclusion

In this article we have shown that elite athletes in many sports are evolving in physical size and shape. The secular trend has been responsible for some of this evolution. However, athletes, particularly at the open-ended region of morphological optimisation, have been increasing at a much greater rate than the secular trend. There have also been periods in some sports where the rate of change in the size of the athletes has accelerated. Other significant contributors to these patterns of growth include the increased size of the reference population through increased world population, globalisation, offering greater incentives that both strengthen the position of 'strong' sports while weakening those of marginal or nonprofessional sports, and the widespread use of growth-enhancing drugs such as growth hormone and anabolic steroids.

Furthermore, we have argued that modifications to the game rules and technologies, often the response to media pressure, changes the nature of the game and the physical requirements of those participating in the sport. For many athletes this reinforces the need to adopt questionable and illegal behaviours to reach the required size and shape to compete at the top level. We expect this evolution to continue into the foreseeable future as sports become even more specialised, globalised, offer greater financial incentives, and combine with a persistent secular trend in much of the world. The potential, therefore, for individuals within the general populations to reach the pinnacle of world competition through natural selection is diminishing and will continue to do so in almost all sports.

References

1. McDonough W, editor. 75 seasons: the complete story of the National Football League 1920-1995. Atlanta (GA): Turner Publishing Company, Inc., 1994
2. National Football League. Official site of the National Football League. NFL.com [online]. Available from: URL: http://www.nfl.com/rosters/ [Accessed 1999 Mar 31]
3. Bemies CO. Physical characteristics of the runner and jumper. Am Phys Ed Rev 1900; 5 (3): 235-45
4. Sewart J. The commodification of sport. Int Rev Sociol Sport 1987; 22: 171-92
5. Norton K, Olds T, Olive S, et al. Anthropometry and sports performance. In: Norton K, Olds T, editors. Anthropometrica. Sydney: University of New South Wales Press, 1996: 287-364
6. Department of the Arts, Sport, the Environment and Territories (DASET). DASET pilot survey of the fitness of Australians. Canberra: Australian Government Printing Service, 1992
7. Reilly T. Football. In: Reilly T, Secher N, Snell PS, et al., editors. Physiology of sports. London: E & F.N. Spon, 1990: 371-425
8. Withers RT, Craig NP, Bourdon PC, et al. Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol 1987; 56: 191-200
9. Foley JP, Bird SR, White JA. Anthropometric comparison of cyclists from different events. Br J Sports Med 1989; 23: 30-3
10. Tittel K, Wutscherk H. Anatomical and anthropometric fundamentals of endurance. In: Shepherd RJ, Astrand P-O, editors. Endurance sports. London: Blackwell Scientific, 1992: 35-45
11. Stepnicka J. Somatotype in relation to physical performance, sports and body posture. In: Reilly T, Watkins J, Borms J, editors. Kinanthropometry. III. London: E & F.N. Spon, 1986: 39-52
12. Defrise-Gussenhoven E. Croissance et débilité: étude biométrique d'écoliers bruxellois. Inst R Sci Nat Belg 1954; 128: 1-54
13. Norton K, Olds T, Olive S, et al. Ken and Barbie at life size. Sex Roles 1996; 34: 287-94
14. US Department of Health and Human Services, National Centre for Health Statistics. Department National Health and Nutrition Examination Survey III (NHANES III) 1988-1994 [CD-Rom]. Hyattsville (MD): Centers of Disease Control and Prevention. Updated 1997 Oct; CD-Rom series II: No. 1
15. Models online. Available from: URL: http://www.models-online.com [Accessed 1999 Feb 21]
16. Online talent portfolios. New Faces Talent [online]. Available from: URL: http://newfaces.com/supermodels/modelpage.html [Accessed 1999 Mar 2]
17. Floud R, Wachter KW, Gregory A. Height, health and history: nutritional status in the United Kingdom. Cambridge: Cambridge University Press, 1990: 1750-980
18. Olds T, Dollman J, Norton K, et al. A century of growth in Australian children. In: Jurimae T, Hills A, editors. Body composition assessment in children and adolescents [Medicine and Sports Science series, 44]. London: Karger, 2001: 85-103
19. Hathaway ML, Foard ED. Heights and weights of adults in the United States Home Economics Research Report No. 10. United States Department of Agriculture. Washington, DC: US Government Printing Office, 1960
20. US Department of Health and Human Services, National Centre for Health Statistics. Department National Health and Nutrition Examination Survey I (NHANES I) 1960. Hyattsville (MD): Centers of Disease Control and Prevention
21. US Department of Health and Human Services, National Centre for Health Statistics. Department National Health and Nutrition Examination Survey II (NHANES II) 1978. Hyattsville (MD): Centers of Disease Control and Prevention
22. Sachare A, editor. The official NBA basketball encyclopedia. New York (NY): Villard Books, 1994
23. Neft D, Cohan R, Korch R. The sports encyclopedia: pro football. 16th ed. The modern era 1973–1997. New York (NY): St. Martin Griffin, 1998
24. Statistics on players. National Basketball Association [online]. Available from: URL: http://www.nba.com/teams/ [Accessed 1999 Feb 18]
25. Statistics on players. Women's National Basketball Association [online]. Available from: URL: http://www.wnba.com/teamindex.html [Accessed 1999 Feb 18]
26. Bale J. Sport geography. New York (NY): E. & F.N. Spon, 1989
27. US Bureau of Census. Statistical abstracts of the United States, 1992. 112th ed. Washington, DC: US Department of Commerce; 1992
28. Lovett M. AFL '2001: the official statistical history of the AFL. Melbourne: Australian Football League (AFL), 2001
29. AccessArizona's 1999-2000 National Hockey League salaries. AccessArizona [online]. Available from: URL: http://www.accessarizona.com/shared/sports/nhl/stats/salaries.html [Accessed 2001 Mar 14]
30. Baseball: American League player salaries. USA Today & Baseball Weekly [online]. Available from: URL: http://www.usatoday.com/sports/baseball/salary/99alsal.htm
31. Baseball: National League player salaries. USA Today & Baseball Weekly [online]. Available from: URL: http://www.usatoday.com/sports/baseball/salary/99nlsal.htm.
32. Income. US Census Bureau [online]. US Census Bureau [online]. Available from: URL: http://www.census.gov/hhes/www/income.html [Accessed 1999 Feb 18]
33. Bureau of Labor Statistics. Consumer price index: all urban consumers – (CPI-U). Bureau of Labor Statistics, US Department of Labor [online]. Available from: URL: ftp://ftp.bis.gov/pub/special.requests/cpi/cpiai.txt [Accessed 1999 Feb 18]
34. Kurian G. Datapedia of the United States. Lantham (MD): Bernan Press, 1994: 1790-2000
35. Barnidge T. The NFL on TV. In: B. Carroll, M. Gershman, Neft D, et al., editors. Total football. New York (NY): Harper Collins, 1997; 25: 445-7
36. Sage GH. Power and ideology in American Sport. Champaign (IL): Human Kinetics, 1990
37. Norton K, Craig N, Olds T. The evolution of Australian football. J Sci Med Sport 1999; 2: 389-404
38. Lucas JA. Future of the Olympic games. Champaign (IL): Human Kinetics, 1992
39. Voy R. Drugs, sport and politics. Champaign (IL): Leisure Press, 1991
40. Yesalis C. Anabolic steroids in sport and exercise. Champaign (IL): Human Kinetics, 1993
41. Alen M, Hakkinen K, Komi PV. Changes in neuromuscular performance and muscle fibre characteristics of elite power athletes self-administering androgenic and anabolic steroids. Acta Physiol Scand 1984; 122: 535-44
42. Casner SW, Early RG, Carlson BB. Anabolic steroid effects on body composition in normal young men. J Sports Med Phys Fitness 1971; 11: 98-103
43. Fahey TD, Brown CH. The effects of an anabolic steroid on the strength, body composition and endurance of college males

when accompanied by a weight training program. Med Sci Sports 1973; 5: 272-6

44. Forbes GB, Porta CR, Herr BE, et al. Sequence of changes in body composition induced by testosterone and reversal of changes after the drug is stopped. JAMA 1992; 267: 397-9
45. Freed DLJ, Banks AJ, Longson D, et al. Anabolic steroids in athletics: cross-over double-blind trial on weightlifters. BMJ 1975; 2: 471-3
46. Friedl KE, Dettori JR, Hannon CJ, et al. Comparison of the effects of high dose testosterone and 19-nortestosterone to a replacement dose of testosterone on strength and body composition in normal men. J Steroid Biochem Mol Biol 1991; 40: 607-12
47. Griggs RC, Kingston W, Jozefowicz RF, et al. Effect of testosterone on muscle mass and muscle protein synthesis. J Appl Physiol 1989; 66: 498-503
48. Hervey GR, Hutchinson L, Knibbs AV, et al. 'Anabolic' effects of methandienone in men undergoing athletic training. Lancet 1976; II: 699-702
49. Johnson LC, Fisher G, Silverster LJ, et al. Anabolic steroids: effects of strength, body weight, oxygen uptake and spermatogenesis upon mature males. Med Sci Sports 1972; 4: 43-5
50. Ward P. The effect of an anabolic steroid on strength and lean body mass. Med Sci Sports 1973; 5: 277-82
51. Wright JE. Anabolic steroids and athletes. Exerc Sports Sci Rev 1980; 8: 149-202
52. World Health Organisation task force on methods for the regulation of male fertility: contraceptive efficacy of testosterone-induced azoospermia in normal men. Lancet 1990; 336: 955-9
53. Yesalis C, Cowart V. The steroid game. Champaign (IL): Human Kinetics, 1998
54. Brownell KD, Nelson-Steen S, Wilmore J. Weight regulation practices in athletes: analysis of metabolic and health effects. Med Sci Sports Exerc 1987; 19: 546-56
55. Lawson G. World record breakers in track and field athletics. Champaign (IL): Human Kinetics, 1997
56. Bouchard C, Lortie G. Heredity and endurance performance. Sports Med 1984; 1: 38-64
57. Harrigan J. Football families. In: Carroll B, Gershman M, Neft D, et al., editors. Total football. New York (NY): Harper Collins, 1997; 11: 305-13
58. Bouchard C, Malina R, Pérusse L. Genetics, fitness and physical performance. Champaign (IL): Human Kinetics, 1997
59. Annas GL. Artificial insemination: beyond the best interests of the donor. Hastings Center Report 1979; 9 (4): 14
60. In brief. Hastings Cent Rep 1980; 10 (2): 29
61. Sappideen C. The surrogate mother: a growing problem. Univ N S Wales Law J 1983; 6; 79-102
62. Moghissi K. Reflections on the new guidelines for the use of semen donor insemination. Fertil Steril 1990; 53: 399-400
63. Etcoff N. Survival of the prettiest: the science of beauty. New York (NY): Doubleday, 1999
64. Pawlowski B, Dunbar RIM, Lipowicz A. Tall men have more reproductive success. Nature 2000 13 Jan; 403: 156

Correspondence and offprints: *Kevin Norton*, School of Physical Education, Exercise and Sport Studies, University of South Australia, Underdale, South Australia 5032, Australia
E-mail: Kevin.Norton@unisa.edu.au

