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優秀的運動員 —— 對體形、體積、比例和身體組成進行評估

The elite athlete – assessing body shape, size, proportion and composition

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In the quest to optimize performance of the elite athlete the sport scientist has sought to determine the ideal physique for a given sport or event. For some sports, specific structural characteristics offer definite performance advantages; for example in rowing, in addition to height, a large arm span has been identified as important. In other sports, such as long distance running, low levels of adiposity or 'fatness' appear to be linked with faster running times. There are four areas where appraisal of the athlete's physique can provide useful information: (1) identication of talented athletes; (2) to assess and monitor the growing athlete; (3) to monitor training and performance; and (4) to determine 'race weight' in weight-category sports. As a research tool a particular method must be reliable and valid. Other considerations include how expensive the method is, if it is suitable for a field situation and if large amounts of data on a number of subjects can be collected quickly. The method should be safe for both the athlete and the tester and provide useful feedback for the athlete or coach. Anthropometry, with training is able to fulfil most of these criteria and is the most widely used method of physique assessment in sports science. Large anthropometric data bases have been collected on elite athletes at Olympic games and world championships according to a standard protocol. Kinanthropometry, which has developed from anthropometry, is concerned with measurement and evaluation of different aspects of human movement and individual variation in body shape, size, proportion and composition. For the assessment of adiposity a sum of skinfolds, usually over six sites, is most commonly used rather than percentage body fat formulae. Muscle mass can be assessed indirectly through girth and corrected girth measurements. Limb lengths and breadths are used to assess skeletal structure and proportional differences in limb size. The anthropometric methods most commonly used to describe the physique of the athlete, which appraise shape, size, proportion and composition, will be discussed.

Introduction

For more than one hundred years scientists have attempted to describe the physique characteristics of elite athletes with the objective of relating their physiques to athletic performance[1]. Theoretically, the most successful athletes are those with the appropriate structure to perform their event[2] and Olympic or world championship athletes represent the optimum combination of genetic and environmental influences to produce maximum performance[3]. Since the first studies on athletes at the winter and summer Olympics in 1928[4], major studies have been conducted on athletes at six different Olympic Games. In the main, anthropometric data has been collected in these investigations since the methods are non-invasive and do not interfere with the subject's performance.

A major advantage of using anthropometry to study the physique of elite athletes is that large amounts of data can be collected quickly. This was shown during the 1991 World Swimming Championships. Investigators in the Kinanthropometric Aquatic Sports Project (KASP)[5] collected over 40 anthropometric measures on 920 aquatic sports athletes during a 3-week period of practice and competition. Testers underwent extensive training beforehand and all measurements were taken according to a standard protocol[6]. By using a measurement team it was possible to measure 15 athletes per hour. A high percentage of finalists were included in the final sample and 88% of all athletes participating in the championships were measured. The variables chosen for measurement enabled differences in physique between events to be assessed.

Many of the methods for physique assessment are laboratory-based techniques and are impractical or too expensive for the routine testing of athletes or for large scale data collection. In addition most of these methods provide estimates of body fat or the fat-free mass. For some sports or events however, structural characteristics, such as limb lengths or bone breadths may be more important than body fat. Anthropometry is the most commonly used method of physique assessment in athletic populations and is the only method that has been validated against a cadaver sample[7]. Kinanthropometry, which has developed from anthropometry, is concerned with measurement and evaluation of different aspects of human movement and individual variation in body shape, size proportion and composition[6]. This paper will discuss the purpose of physique assessment and the various methodologies used for describing physique in the elite athlete.

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The purpose of physique assessment

Describing the link between exercise performance and body shape, size, proportion and composition provides clues to the ideal physique for a sport or event. Collecting data on the elite athlete can therefore be used as a research tool to facilitate an understanding of the link between performance and physique and to provide on-going feedback to the coach and athlete. It is important to remember that although an athlete may have the appropriate physical structure, factors such as physiological function, psychological make-up and biomechanical constraints all contribute to athletic performance. The assessment of physique has four major applications: (1) identification of talented athletes; (2) to assess and monitor the growing athlete; (3) to monitor training and performance; (4) to determine optimal muscularity and adiposity for weight-class events.

Identification of talented athletes

Describing the physique of the elite assists in understanding the link between performance and physique. Within a sport there will be a degree of individual variation in physique that reflects the athlete's genetic and ethnic make-up as well as their dietary intake. For some sports there is a much greater tolerance in physique as other performance factors dominate; for example tennis and football. Other sports however, tolerate a very narrow range in certain physique characteristics at the elite level. In the sport of gymnastics, female gymnasts must be lean and muscular but also cannot be tall.

One sport where talent identification has recently been used successfully is rowing. Studies on elite rowers have found that tallness is not the only important factor, but also the ratio of height to arm span, such that proportionately longer arms provide for a greater stroke length. In addition to physiological parameters, anthropometry has been used as part of the selection criteria for potentially talented rowers. In a study undertaken by the Australian Institute of Sport approximately 500 boys and girls aged 14–16 years were tested[8]. From this group 25 males and 25 females were selected to undergo more extensive testing. A final squad of 24 rowers began training in 1988. After 16 months of rowing, both the girls and the boys finished second in the junior fours at the National championships and four girls were selected in the 1990 Australian junior team.

To assess and monitor the growing athlete

Longitudinal anthropometric data provides the best data for monitoring individual growth patterns while cross-sectional analysis results in a smoothing of the growth curves. The timing of maturation varies considerably between the earliest and the latest maturing athlete. In boys, as the strength spurt tends to occur once the height velocity is falling, for sport selection it is important to recognize that developmental age is more relevant than chronological age. Similarly for girls, the onset of menarche signals the development of the secondary sex characteristics which may be followed by an increase in adiposity[6]. Delayed maturation can occur in female athletes particularly for those who achieve success in ballet or gymnastics. By monitoring growth it is possible to examine the link between performance and maturation.

To monitor training and performance

Skinfold measures are the most common anthropometric measures taken on elite athletes for the purpose of providing an estimate of the adipose tissue mass. Whilst it is actually a double layer of subcutaneous adipose tissue and skin that is being measured, it is commonly referred to as 'body fat'. Many sports have 'cut-off' points or target scores for the sum of skinfold values. In sports such as distance running lower levels of 'body fat' are generally associated with better performances[9].

The appraisal of body composition can provide valuable data for both the athlete and the coach through the sequential monitoring of the influences of training and nutrition. Neither body mass nor the body mass index (wt/ht^2) are acceptable in distinguishing the contribution of various tissue mass proportions to body mass[10]. The O-scale physique assessment system is a practical tool for monitoring changes in skinfolds and girths[11].

To determine optimal muscularity and adiposity for weight-class events

When transporting the body in the performance of athletic tasks where the body weight must be supported, adipose tissue does not contribute to the movement. Tittel referred to adipose tissue as 'ballast substance'[12] since skeletal muscle provides the propulsive force to move the body. In weight category sports such as light weight rowing, boxing and wrestling, athletes aim to have a high 'power-to-mass' ratio whereby, for a given body weight, adiposity is minimized and muscularity is maximized.

It is extremely common in weight-category sports for athletes to undergo rapid loss several days before competition to 'make weight'. This can be extremely detrimental to performance. Anthropometric assessment can assist in determining the appropriate weight class for the athlete as most aim to compete in a lower class to gain a competitive advantage. Athletes are advised to undertake weight reduction early in the season and avoid rapid weight gain post competition. Monitoring of skinfolds, girths and skinfold-corrected girths will indicate changes in the adipose and muscle masses.

Methods of assessing physique

Most methods assess physique indirectly. The only direct method is by either chemical extraction or cadaver dissection, which can provide theoretical validation for the indirect procedures. The Brussels Cadaver Study completed full anatomical dissections and extensive anthropometry on 25 cadavers. The normative data collected for weights and densities of the various tissue components cast serious doubts on the assumptions of the two-compartment models[13].

Assessing body composition

Densitometry

Densitometry has been a widely used method in the sport science discipline for the assessment of 'body fat'. In order to make a prediction of percent fat from body density it is necessary to assume that the body is composed of two compartments, fat and non-fat and that the densities of each are known and are the same for all individuals. The most significant variation in the density of the fat-free mass (FFM) constituents occurs in bone due to differences in bone mineralization[14]. Body fat would therefore be underpredicted in athletes with a high bone density and overpredicted in athletes with a low bone density. The negative percentage fat values obtained for a team of Canadian football players suggest the degree of error that can arise by assuming a constant density for the FFM[15]. Many of the players were black and were known to have a generally higher bone density.

Skinfold caliper readings
The observation that skinfolds were correlated with criterion techniques such as densitometry, total body water and whole body counting, has led to a proliferation of regression equations to predict body fat. Since 1950 more than 100 equations to predict body fat from skinfolds have been reported in the literature[16]. The problem with these equations is they are population specific[17] and based on the desitometry technique which in turn adopts spurious assumptions as outlined above. Most sport scientists now use the raw skinfold data, reported as a skinfold sum, rather than predicting percent body fat. Sport specific skinfold data on national level athletes has been reported by Telford et al.[18].

Anthropometry
The advantages of anthropometry as opposed to other methods of body composition assessment are: (1) it is non-invasive and will not adversely affect performance; (2) mobile laboratories can be set up at any location; (3) the equipment is inexpensive and; (4) an extensive battery of measurements can be taken quickly on a large number of subjects. In addition to providing estimates of the adipose tissue mass, anthropometry can also provide structural characteristics such as limb lengths or bone breadths which for some sports or events are of greater importance than adipose tissue.

The use of anthropometry in the assessment of physique relies on the expertise of the anthropometrist. With training and acute attention to technique it is possible to minimize the potential error. Prior to the KASP data collection all testers underwent extensive training with an experienced (criterion) anthropometrist prior to the project. The technical error of measurement (TEM)[6] was obtained between testers.

To reduce technical error in anthropometry it is recommended that standard anthropometry be used. The protocol of Ross & Marfell-Jones[6] has been used in the collection of several large international studies on elite athletes[1,5] and has recently been recommended for adoption as the protocol for the Australian Laboratory Standards Assistance Scheme[19].

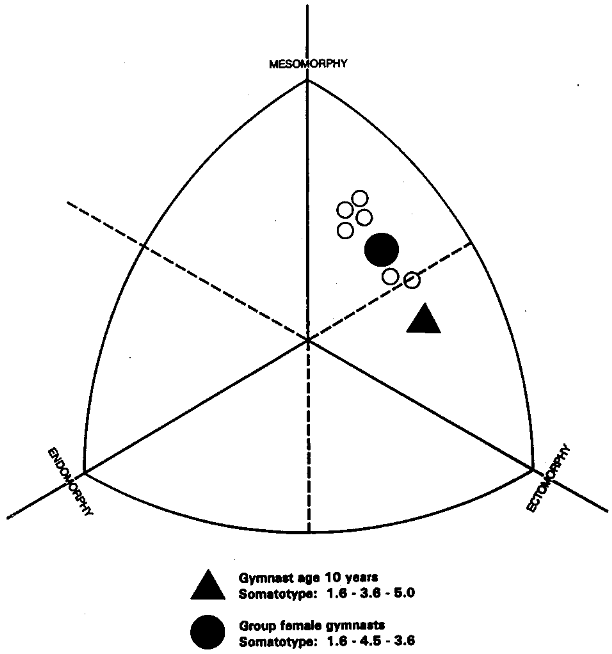

Figure 1. The mean somatoplot for seven female gymnasts (closed circle) plotted against a female gymnast aged 10 years (closed tiangle) and the individual somatoplots (open circles).

Assessing body shape

Somatotype
Somatotyping is a method for physique classification, which provides an overall description of physique. It provides a numerical, three-number rating representing the components of endomorphy and ectomorphy which are independent of body size[20]. The Heath-Carter method of somatotyping is the

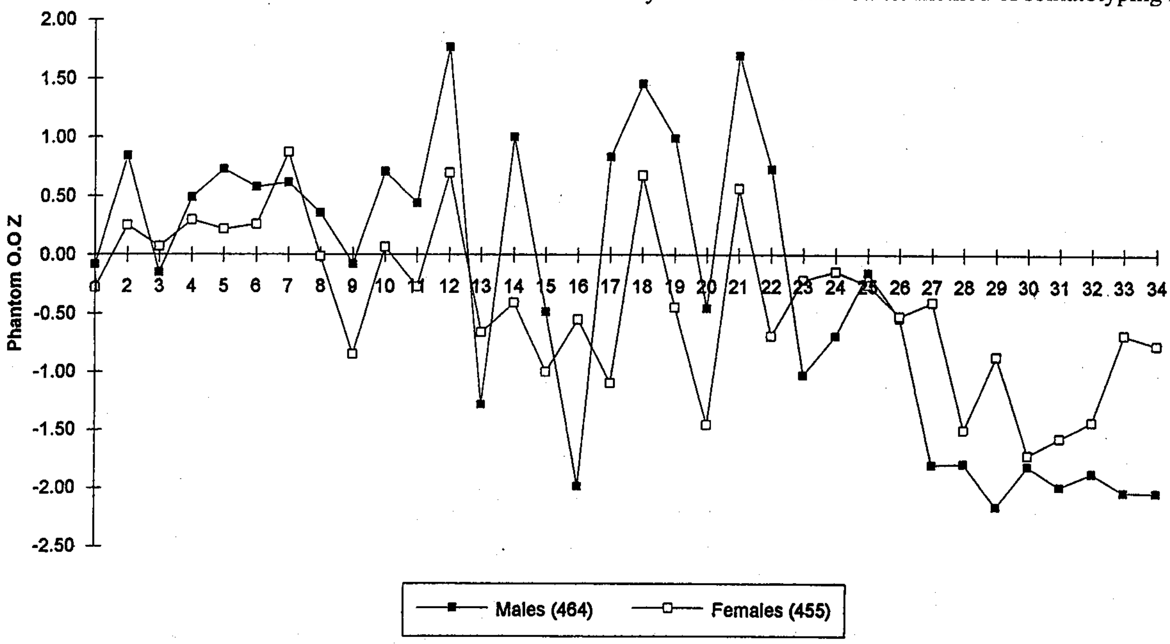

Figure 2. Proportionality profile for aquatic sport males (filled squares) and female (open squares) form the Kinanthropometric Aquatic Sports Project[6] scaled to the Phantom stature (170.18 cm). Anthropometric variables: 1) proportional weight, 2) arm span, 3) sitting height, 4) arm length, 5) forearm length, 6) hand length, 7) thigh length, 8) leg length, 9) foot length, 10) biacromial breadth, 11) tranverse chest breadth, 12) anterior-posterior chest breadth, 13) biiliocristal breadth, 14) humerus breadth, 15) femur breadth, 16) head girth, 17) neck girth, 18) arm girth, 19) forearm girth, 20) wrist girth, 21) chest girth, 23) hip girth, 24) thigh girth, 25) calf girth, 26) ankle girth, 27) triceps skinfold, 28) subscapular skinfold, 29) bicep skinfold, 30) iliac skinfold, 31) supraspinale skinfold, 32) abdominal skinfold, 33) front thigh skinfold and 34) medial calf skinfold.

most widely used[21]. It provides for both photoscopic and anthropometric ratings of physique and demonstrates the relative dominance of: (1) endomorphy, or relative fatness; (2) mesomorphy, or relative musculoskeletal robustness; and (3) ectomorphy, or relative linearity. Figure 1 shows the somatotype plot for seven elite female gymnasts. As can be seen by her somatotype, she is a mesomorphic ectomorph, which means she is higher in the ectomorphic component than in mesomorphy. She has not had the years of training to develop the high degree of mesomorphy possessed by the older gymnasts. Somatoype distributions can assess the influences of training and growth in combination with other methods of physique assessment.

Assessing body proportion

Proportionality

Proportionality differences between athletes in various sports and events, or between males and females may be examined using the Phantom stratagem. This approach, proposed by Ross and Wilson[22], makes use of a unisex reference human or Phantom as a calculation device. It is not a normative system but enables proportional differences in anthropometric characteristics within and between subjects to be quantified.

All anthropometric variables are adjusted geometrically to the Phantom stature (170.18 cm) using the subject's obtained height. A proportionally score, or z-value, can be determined for over 100 anthropometric measurements. This z-value represents the deviation from the phantom mean value so that a z-value of 1.00 for example, indicates the item is one standard deviation above the phantom value.

Proportionality scores can be displayed graphically to demonstrate differences between groups. Figure 2 shows how the Phantom stratagem can be used to demonstrate proportionality differences between male and female aquatic sport athletes from the Kinanthropometric Aquatic Sports Project[4]. When both males and females were scaled to a common stature, the males had a proportionately greater arm span (1) than the females. The males were proportionally larger in the shoulder breadth (10-biacromial) and chest depth (12-AP chest) but the females were proportionately larger in the hips (13-biiliocostal). For the skinfolds the females had proportionally greater skinfolds than the males (27–34). The upper body girths, such as forearm (19), arm (18) and chest (21), were greater in the males indicating their greater muscularity. Proportionality profiles demonstrate physique characteristics as well as individual adaptations to the sport[23].

Assessing body size

The O- Scale system

The O-Scale system[11] is a normative-based system which does not require the assumption of any biological constants. The system is intended to replace the prediction of percent body fat. Its primary use is as a professional system to provide feedback for the athlete and coach. It requires eight skinfolds, ten girths, four skinfold-corrected girths and two bone breadths. The inclusion of girths provides an indication of musculo-skeletal robustness. A geometric adjustment to a standard stature (170.18 cm) and a simple scaling of the sum of skinfolds and body weight is performed prior to the competition of the individual with the norm for the same sex and age group. These norms were constructed from a comprehensive data assembly on 1236 children and young adults from one laboratory and over 19000 adults from the YMCA Life Project[24]. The O-Scale system is comprised of two ratings which are scaled in Standard Nine or STANINE categories:

(1) Adiposity (A) — the sum of six skinfolds (S6SF) are size-adjusted and compared to the appropriate age/sex norm. In other words, the S6SF is scaled to an appropriate value if the subject were 170.18 cm.

(2) Proportional Weight (pWT) — the body weight is size-adjusted and compared to the appropriate age/sex norm. That is, pWT is the expected weight if the subject were geometrically scaled to a height of 170.18 cm.

Table 1: O-scale rating comparing two female gymnasts aged 10 (*) and 13 years (o).

O-Scale assessment: female gymnasts			
13/3/93	:	Date	: 13/3/93
13.0	:	Age (decimal years)	: 10.0
144.0	:	Height (centimetres)	: 130.8
38.1	:	Weight (kilograms)	: 23.2
36.4	:	Sum of six Skinfolds (millimetres)	: 30.2
43.0	:	Proportional Sum of six Skinfolds (mm)	: 39.3
62.9	:	Proportional Weight (kilograms)	: 51.1

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  I....1....I....2....I....3....I....4....I....5....I....6....I....7....I....8....I....9....I
  I         I         I         I         I         I         I         I         I         I
A I    o    I         I         I         I         I         I         I         I         I
  I         I         I         I         I         I         I         I         I         I
  I.........I.........I.........I.........I.........I.........I.........I.........I.........I
  I         I         I         I         I         I         I         I         I         I
  I         I         I         I         I         I         I         I         I         I
W I         I    *    I         I         I         I    o    I         I         I         I
  I         I         I         I         I         I         I         I         I         I
  I.......4%.....11%....23%...40%....60%....77%....89%....96%.....I
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Table 2. O-scale size profile comparing two female gymnasts aged 10 (*) and 13 years (o).

O-Scale assessment: female gymnasts					
SIZE PROFILE					
			Norm percentiles		
	Present	Comparison	4%	50%	96%
Weight	23.2	38.1	25.2	37.2	58.7
Height	130.8	144.0	129.8	143.1	160.5
Skinfolds					
Triceps	6.8	6.6	7.4	12.8	22.6
Subscapular	3.7	4.8	5.0	8.6	19.0
Supraspinale	2.8	3.2	4.0	8.3	22.2
Abdominal	3.4	4.9	4.5	10.5	27.2
Front thigh	8.4	11.5	11.3	21.6	45.0
Medial calf	5.1	5.4	5.5	12.5	25.2
Girths					
Arm (relaxed)	18.0	23.1	18.2	21.7	28.2
Arm (flexed)	19.5	24.8	19.7	23.0	29.5
Forearm (maximum)	17.5	21.6	18.2	20.5	24.7
Wrist	12.3	14.8	12.3	13.8	16.6
Chest	61.8	77.0	60.5	70.3	84.4
Thigh	35.4	44.1	36.7	44.4	57.9
Calf (maximum)	24.0	30.1	24.7	28.7	34.5
Ankle	15.8	18.3	16.7	19.2	23.0
Widths					
Humerus	5.3	5.9	5.0	5.5	6.5
Femur	7.2	7.7	7.4	8.3	9.6
Corrected Girths					
Arm	15.9	21.0	15.0	17.7	21.5
Chest	60.6	75.5	58.9	67.4	78.0
Thigh	32.8	40.5	31.7	37.7	46.4
Calf	22.4	28.4	21.2	25.0	29.1

The O-Scale system software provides for detailed analysis in the form of a computer printout. An example of part of the output is shown in Table 1, which compares a 10 and a 13-year-old gymnast with the norms for a girl aged 10 years. Both gymnasts had a low S6SK as is required for their sport. As both gymnasts have an A-Rating of one, which places them less than the 4th percentile, the rating appears as one overlapping circle. The older gymnast's pWT-Rating was much higher than the younger gymnast, indicating a greater musculo-skeletal development. Table 2 shows the raw data compared with the 4th, 50th and 96th percentile scaling against their own age and sex norm. The proportionality profile (Table 3) shows the size- and age-adjusted anthropometric values. Although both are very similar in skinfold measures there is a marked difference in the girths and corrected girths, which reflects the older gymnast's greater muscular development from more years of training.

Table 3. O-scale proportionality profile comparing two female gymnasts aged 10(*) and 13 years (o).

O-scale assessment: female gymnasts

PROPORTIONALITY PROFILE

Your measurements are scaled to a common stature and then plotted relative to your age and sex norms.

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                        4%        50%       96%
Weight              ............|....*...... |...o......... |....................
Skinfolds
Triceps             .......o.*..|............ |.............. |....................
Subscapular         ....*.o.....|............ |.............. |....................
Supraspinale        .......*o...|............ |.............. |....................
Abdominal           ............*o.......... |.............. |....................
Front Thigh         ..........*..o.......... |.............. |....................
Medial Calf         .........o..|............ |.............. |....................
Girths
Arm (relaxed)       ............|..*........ |...o......... |....................
Arm (flexed)        ............|.....*...... |....o........ |....................
Forearm (maximum)   ............|..*........ |....o........ |....................
Wrist               ............|........*.. |.........o... |....................
Chest               ............|........*.. |.............. |....................
Thigh               .........*:.|............ o.............|....................
Calf (maximum)      ............|..*........ |....o........ |....................
Ankle               ............|*...o...... |.............. |....................
Widths
Humerus             ............|............ |..*o........ |....................
Femur               ............|..o....*... |.............. |....................
Corrected Girths
Arm                 ............|...........*|.............. |..o................
Chest               ............|............ |*............ |o..................
Thigh               ............|........*... |......o...... |....................
Calf                ............|............*..............|....o..............
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Conclusion

Elite athletes represent the ideal combination of genetic inheritance and environmental influences. The assessment of physique includes measures of body shape, size, proportion and composition each of which provide clues as to the ideal characteristics for a sport or event.

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