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Design and Interpretation of Anthropometric and Fitness Testing of Basketball Players

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Abstract

The volume of literature on fitness testing in court sports such as basketball is considerably less than for field sports or individual sports such as running and cycling. Team sport performance is dependent upon a diverse range of qualities including size, fitness, sport-specific skills, team tactics, and psychological attributes. The game of basketball has evolved to have a high priority on body size and physical fitness by coaches and players. A player's size has a large influence on the position in the team, while the high-intensity, intermittent nature of the physical demands requires players to have a high level of fitness. Basketball coaches and sport scientists often use a battery of sport-specific physical tests to evaluate body size and composition, and aerobic fitness and power. This testing may be used to track changes within athletes over time to evaluate the effectiveness of training programmes or screen players for selection. Sports science research is establishing typical (or 'reference') values for both within-athlete changes and between-athlete differences. Newer statistical approaches such as magnitude-based inferences have emerged that are providing more meaningful interpretation of fitness testing results in the field for coaches and athletes. Careful selection and implementation of tests, and more pertinent interpretation of data, will enhance the value of fitness testing in high-level basketball programmes. This article presents reference values of fitness and body size in basketball players, and identifies practical methods of interpreting changes within players and differences between players beyond the null-hypothesis.

Basketball involves approximately 450 million registered participants from >200 national federations belonging to the Fédération Internationale de Basketball (FIBA).[1] The monetary value of basketball is substantial, particularly in the professional leagues, with the 30 teams in the 2006/07 National Basketball Association (NBA) season in the US paying its 510 players $US1.93 billion in salaries alone. With considerable international, national and local pride associated with winning, and the monetary rewards available, it is somewhat surprising to find very little well controlled research on the physical preparation of basketball players. The 2003–4 NBA regular season had an average point difference of 10.3 ± 6.6 points (mean ± standard deviation [SD]), indicating that the competitive edge would not need to be large to make a difference between winning and losing a game. Enhanced physical fitness may be one means of improving the likelihood of success in basketball.

Intermittent, high-intensity team sports such as the court sports (e.g. basketball, volleyball, netball) and field sports (e.g. football, field hockey) have complex demands that require a combination of individual skills, team plays, tactics and strategies, and motivational aspects.[2,3] Despite these complexities, it seems likely that a player's physical fitness and body size plays an important role in individual and team performance.[4] There have been many studies in team sports linking fitness and/or anthropometric test scores to playing level and success in sports such as American football,[5,6] soccer,[7] rugby union,[8] Australian rules football,[9] field hockey,[10] volleyball[11] and basketball.[12,13] Research showing the importance of anthropometric and fitness tests has increased the interest of coaches in the relative effectiveness of improving fitness on various outcomes of playing success.[14]

The value of physical testing for the purpose of identifying talent in young individuals or predicting future success in sport remains an open question. While there is large heritability of many important characteristics for sport,[15-17] most of these characteristics do not reach their full potential without proper sport-specific training. Therefore, most talent identification testing programmes are multifactorial in their approach, acknowledging that many different attributes are important to sporting success.[18] Clearly, sporting success is dependent on an interaction of both inherited and acquired characteristics. The purpose of this article is to examine the value of fitness and body size to competitive basketball players and the various methods used to assess player fitness. While the importance of fitness and body size in basketball may appear self-evident, basketball is a sport highly dependent on skill execution, with the biggest and fittest players not necessarily being the most skilled; fitness and anthropometric test scores should not be the only tool used to evaluate basketball players. Testing methods should also be carefully selected for their specificity to the game of basketball. Sport scientists should look to different methods of statistical processing to make more meaningful conclusions from data collected for athletes.

1. Size and Fitness Requirements for Basketball

1.1 Body Size and Team Position

A player's body size largely determines the position played on the team.[4,9-25] This approach is a consequence of a near universally accepted strategy in basketball to place the tallest and heaviest players in key positions close to the basket, while smaller players are placed in perimeter positions.[2,21] This strategy allows the smaller players of the offensive team to quickly move the ball down the court as the larger, stronger players position themselves close to the basket for high percentage shots on the basket.[26]

The five player positions on a basketball team can be classified in several different ways, primarily based on body size, fitness and skills. The most detailed system classifies each individual on the court in to a position. The 'point guard' or 'number 1' is mostly responsible for carrying the ball down the court and coordinating the offence of his/her team. The 'off guard', 'shooting guard' or 'number 2' is usually the team's best distance shooter, able to score from long distances. The 'small forward' or 'number 3' is a multi-disciplinary position, often referred to as 'utility player'. Players in this position should be capable of executing the skills of almost any other player on the court should the need arise. The 'power forward' or 'number 4' is typically a relatively larger player responsible for aggressive play close to the basket, such as gaining possession of the ball after a missed shot. Similarly, the 'centre' or 'number 5' is usually the team's largest player and is responsible for close range shooting on offence and coordinating the team's defence.[2,21] Since players often play overlapping roles (e.g. sometimes rotating between 'point guard' and 'off guard' duties), positions are also classified more broadly as 'guards', such as Michael Jordan, 'forwards', such as Larry Bird, and 'centre', such as Shaquille O'Neal.[21] Differences in movement patterns and intensities between guards, forwards and centres have recently been emphasized by Abdelkrim et al.[27] showing that there are particular differences between in the percentage of live time spent in high-intensity movements (17.1%, 16.6% and 14.7%, respectively). A 'power forward' can also play as a 'centre', or an 'off guard' can also play as a 'small forward', so both guards and the small forward can also be broadly classified as 'smalls', while the 'power forward' and 'centre' are referred to as 'bigs' (table I).

1.2 Physical Demands of Basketball

Under the rules of FIBA, a game consists of two halves, each half consisting of two 10-minute quarters, although quarters may be 12 minutes in some men's leagues. There is a 2-minute break between periods and a 15-minute break between halves in addition to any stoppages of play for incidents such as rule infractions or time-outs. As a result of these timing rules, <50% of the total time to play a basketball game is actually spent in live play.[28] These frequent stoppages of play allow for players to recover between bouts of activity, thus allowing repeated high-intensity bouts of play.[28] McInnes et al.[28] demonstrated that in male Australian professional players, the volume of live time spent in high-intensity activities (~15%) resulted in a mean heart rate of 165 beats/min with a peak of 188 beats/min and blood lactate concentrations of 6.8 mmol/L with a peak of 8.5 mmol/L. In studying elite under-19 players, Abdelkrim et al.[27] found a similar 16.2% of time was spent in high-intensity activities and mean peak heart rate of 171 beats/min and blood lactate concentrations of 5.5 mmol/L. A study by Rodriguez-Alonso et al.[29] reported peak heart rates of ~175 beats/min with slightly lower blood lactate concentration of approximately 4.6 mmol/L in female Greek national and international players. Tessitore et al.[30] reported that while blood lactate concentrations were lower in older players (3.7 mmol/L, mean age of 55 years) other measures of intensity such as time spent at >85% of maximal heart rate (HR_{max}) were similar (Tessitore: 59%, McInnes: 65%), as was time spent in low-intensity activities such as standing and walking (Tessitore: 63%, McInnes: 61%). Therefore, while rest intervals are frequent over the course of a basketball game,

Table I. Different classifications of basketball playing positions and major responsibilities of each

Classification number				Major responsibility of position
1	2	3	4	
	Guards	1	Point guard	Ball control; coordinating the offence
Smalls		2	Off guard/shooting guard	Distance shooting
	Forwards	3	Small forward	Mixture of distance and close-range shooting, particularly from awkward positions
Bigs		4	Power forward	Aggressive play close in to the basket (e.g. rebounding and close-range shooting)
	Centre	5	Centre	Close-range shooting on offence; coordinating the team's defence

the activity level of live play is typically high to very high intensity regardless of the gender or age group playing.

Much of the intensity of basketball is likely derived from the very frequent changing movement patterns over the duration of a game. Players have to repeatedly generate momentum and overcome inertia with frequent starts and stops. McInnes et al.[28] demonstrated that a basketball game is characterized by approximately 1000 changes of movement patterns, changing on average every 2 seconds. In the year 2000, FIBA introduced rules to make the offence more dependent on rapidly unfolding plan of attack to increase spectator excitement. A consequence of these changes was an increased demand on a player's need for speed and fitness.[31] Rule changes included reducing the time allowed for the offensive team to move the ball forward into the offensive court from 10 to 8 seconds, reducing the maximum time allowed for offence to shoot the ball once they take possession from 30 to 24 seconds, and dividing the game into four quarters rather than two halves. For this reason, research conducted since 2000 investigating the fitness demands of basketball is most relevant for this article.

Clearly, basketball players require high levels of fitness to maintain high levels of intensity, particularly in tournament play involving several games over several days. However, not all players play at the same level of intensity. A study by Rodrigues-Alonso et al.[29] reported that, among female guards, HR_{max} and blood lactate concentrations were 185 beats/min and 5.7 mmol/L, respectively, while forwards were 175 beats/min and 4.2 mmol/L and centres were 167 beats/min and 3.9 mmol/L. Differences also existed in HR_{max} between international-level (186 beats/min) and national-level (175 beats/min) players. Typically, during international-level games, players reached 95% of their HR_{max} while during national-level games, the players only reached 91% of their HR_{max}.[29] It appears that basketball players competing at a higher standard of

Table II. Summary of studies specifically investigating anthropometric and/or fitness field-test data in female basketball players, organized chronologically. Data expressed as means

Study	Subjects	Player position	Height (cm)	Mass (kg)	20-m sprint (sec)	∑7 skinfolds (mm)	Shuttle run (level)	CMVJ (cm)
Drinkwater et al.[12]	Female, Australian national	Unspecified	174.3	65.6	3.42	103.4	9.3	45.6
			177.9	69.6	3.38	95.9	10	45.7
Carter et al.;[23] Ackland et al.[20]	Female, international	Guards	171.9	66.1				
		Forwards	181.3	73.3				
		Centres	189.8	82.6				
Woolstenhulme et al.[51]	NCAA females	Unspecified	180	74				49.5
Hoare[13]	Female, Australian state (under 16 y)	Point guard	166.2	57.8	3.4	83.5	9.65	46.5
		Off guard	169.4	61.6	3.46	93.3	9.83	44.9
		Small forward	173.5	64.1	3.56	88.8	9.58	42.4
		Power forward	177.4	69.4	3.53	108.7	8.59	43
		Centre	181.6	70.5	3.53	96.6	8.63	46.6
Stapff[43]	Female, Australian state (14–17 y)	Unspecified	178.4	69.2	3.4	91.7	10.5	46.5
Lamonte et al.[19]	NCAA females	Guards	169.6	62.2				49.4
		Forwards	179.6	73.6				49.4
		Centres	188.1	80				43.5
Bale[4]	Female, English national (under 17 y)	Guards	162.2	57.9				47.6
		Forwards	172.6	63.9				47.2
		Centres	180	71.2				47.6

∑7 = sum of triceps, subscapular, biceps, supraspinale, abdominal, thigh, medial calf; **CMVJ** = countermovement vertical jump; **NCAA** = National Collegiate Athletic Association.

Table III. Summary of studies specifically investigating anthropometric and/or field-test fitness data in male basketball players, organized chronologically. Data expressed as means

Study	Subjects	Player position	Height (cm)	Mass (kg)	20-m sprint (sec)	∑7 skinfolds (mm)	Shuttle run (level)	CMVJ (cm)
Drinkwater	Male, Australian state		187.8	77.3	3.15	68.4	11.2	59.1
et al.[12]	Male, Australian national		194.9	84	3.08	67.5	11.6	62
Sallet et al.[52]	Male, French tier I and II	Guards	185.7	82				
		Forwards	195.8	89.4				
		Centres	203.9	103.9				
Apostolidis et al.[53]	Male, Greek juniors		199.5	95.5				40.1
Hoare[13]	Male, Australian state (under 16 y)	Point guard	177.9	68.1	3.12	57.5	11.78	63.6
		Off guard	180.5	71.3	3.15	51.6	11.62	63
		Small forward	186.1	76.4	3.21	66.3	11.36	59
		Power forward	191.3	83.8	3.24	69	11.21	58.5
		Centre	194.6	84.5	3.21	70	10.75	57.9
Stapff[43]	Male, Australian state (14–17 y)		198.4	94.4	3.04	72	12	65.5
Trninic et al.[21]	Male international, Olympic	Guards	192	88.7				
		Forwards	200.5	99.4				
		Centres	209.9	110.8				
Berg and Latin[39]	NCAA males	Unspecified	195.3	91.3				71.3
Latin et al.[22]	NCAA males	Unspecified	195.3	91.3				71.4

∑7 = sum of triceps, subscapular, biceps, supraspinale, abdominal, thigh, medial calf; **CMVJ** = countermovement vertical jump; **NCAA** = National Collegiate Athletic Association.

play tend to score higher, with less variability, on tests of physical fitness.[12,13]

2. Testing Protocols

2.1 Test Specificity

Many basketball coaches and sport researchers have subjected basketball players to different batteries of physical tests to assess the anthropometric and fitness attributes of both male and female players (table II and table III).[13,19,21,22,32-41] To provide coaches and athletes with a reference point for comparison both within and between players,[12,42] there are several anthropometric and fitness tests commonly employed by basketball programmes.[43] If tests of fitness are to be useful to sport coaches, the test must be specific to a sport.[43] McInnes et al.[28] identified that a mean of 46 jumps occur per player in a basketball game, a skill particularly important to the forwards, so a test of jumping is clearly indicated. With approximately 1000 changes in movement pattern and over 30% of movements occurring in a lateral fashion,[28] a test of agility is also required. A further 10% of movements are sprints,[28] but since a FIBA basketball court only measures 28 m in length, sprint tests should not be any longer than this. Given that sprints are an average of 1.7 seconds in duration,[28] sprint distances of only 10–20 m that focus on acceleration rather than speed are more appropriate.[28] With high volumes of active time in a basketball game,[28] most basketball testing protocols include a test of aerobic fitness.[43] Tests of strength are often included,[33,35,44,45] as strength training is an important component of most high-level basketball programmes.[44] Strength or resistance training has an important role in improving athletic power production.[46-48] Finally, most tests of body size and composition include measures of height, body mass and body fat.[22,43,49,50]

Some studies have investigated other qualities of basketball players such as muscle mass[54] and somatotype,[4,23] in addition to lung, blood, and muscle fibre characteristics.[23] Such tests are typically very time consuming and/or expensive so therefore rarely appear in large-scale basketball studies (>100 players). Other studies have investigated anthropometric characteristics such as limb length, breadths and circumferences,[4,55] but usually arrive at the same conclusion as less detailed anthropometric assessments: the order of biggest to smallest players are centres, forwards, then guards.[4]

2.2 Values of Size and Fitness in Basketball

There is little doubt that the modern game of basketball has evolved to a point where a player's fitness and body size play a pivotal role in the success of an individual player and a team's success. Anthropometric and fitness test scores have been linked with playing position and individual player success,[13,34] playing time,[32] team success,[23,56] resistance to overuse injury[57] and skills performance.[53,58] Anthropometric and fitness test scores have also been linked to level of play in some studies,[12,40] but this contention is not universally accepted.[52] Hoare[13] concluded that anthropometric and fitness tests accounted for ~40% in variance of playing performance, while Hoffman et al.[32] reported that fitness test scores accounted for up to 20% of playing time when the athlete was well known to the coach, or up to 80% if the athlete was not known. Trninic et al.[21] demonstrated the success of larger players in executing skills close to the basket, such as rebounds and blocked shots, while smaller players are more successful in perimeter skills, such as assists and three-point shooting. While the skill component also plays a vital role in basketball success,[59] there are very important interactions between body size, physical fitness, and position-specific skill performance.[34] Additionally, Apostolidis et al.[53] found correlations of Wingate maximal power output to game-related skills such as control dribble ($r = 0.58$), speed dribble ($r = 0.62$), and dribble shuttle run ($r = 0.73$). Therefore, the results of these studies generally reflect the moderate to high importance of endurance, speed and anthropometric characteristics in basketball.

Nowhere is the value of anthropometric characteristics in basketball more clearly illustrated than in the American-based NBA. In the decade between 1980 and 1990 the proportion of players over 7 feet (213 cm) tall rose from ~3.5% to ~11%.[60] Norton and Olds[60] modelled height and body mass against dollars earned and found that in 1993, for every 1.0 cm or 1.3 kg of the player, the player earned $US43 000 in additional payments over the playing career. These authors also concluded that most internationally born players in the NBA are recruited on the basis of their body size, since US-born players averaged 200 cm tall and weighed 99 kg, while internationally born players averaged 211 cm and 110 kg. This conclusion also applied to the Women's National Basketball Association where US-born players averaged 181 cm and 73 kg, while internationally born players averaged 187 cm and 78 kg.[60]

While tests of lower body power, such as sprinting and jumping, have clear specificity to basketball, the value of aerobic fitness has been questioned. In one study,[32] the authors reported a moderate (but non-significant) negative correlation of a 2.4-km (1.5-mile) timed run to playing time in the first of the four seasons assessed. In the second year, there was a negligible correlation, yet in the final 2 years there was a high and significant positive correlation between fitness and playing time. Hoare[13] compared the 'best' versus the 'rest' basketball players on various components of fitness and found that depending on player position there was either no difference (2 of 5 positions) or substantial differences (3 of 5 position) in aerobic fitness between the two levels. A similar study from Drinkwater et al.[12] demonstrated that both male and female Australian junior national-level basketball players had higher scores on their test of aerobic fitness than their state-level counterparts (small effect sizes of 0.29 in males and 0.47 in females) with lower variability (i.e. greater consistency). Furthermore, several studies have indicated improvements in aerobic fitness over a basketball season or competitive year,[36,61] indicating the need for adaptation of fitness parameters to the physical demands of basketball. Additionally, the importance of oxygen in recovery of creatine phosphate[62] and that the aerobically fittest individuals have the fastest creatine phosphate resynthesis rate[63] further establishes the importance of aerobic fitness to basketball players. Finally, there is evidence to indicate that fatigue can impair performance of motor skills. Heavy physical activity impairs fine motor control,[64] cognitive functioning, and choice reaction time.[65] Salmela and Ndoye[65] further specified that transition from rest to exercise inducing a heart rate of 145 beats/min facilitated choice reaction time performance, showing a peak at 115 beats/min, intensities described by Borg et al. as 'fairly light' to 'hard'.[66] The relationship between cognitive performance and exertion was later described as an 'inverted-U' by Fery and associates.[67] Since a more aerobically fit athlete has a lower heart rate for an absolute workload than one that is less fit,[68] it is possible that fitter players may make quicker, more accurate decisions as they are less fatigued for that workload. Therefore, while some may question the value of aerobic fitness to basketball performance, there are both physical and cognitive justifications for its inclusion in a testing programme.

2.3 Research Reporting Fitness and Anthropometric Data

While there are studies investigating changes in anthropometric and fitness parameters within basketball players over time, and between players in different groups (tables II and III), many published articles are limited by methodological problems. The existing basketball research lacks longitudinal studies that go beyond 1 year,[19,32,35] or studies with large sample sizes.[22,33,36-39] In many other fields of research, a researcher could overcome such shortcomings by performing a meta-analysis. Pooling data on a small number of athletes over long periods of time has been accomplished; however, variation in measurement techniques can make the aggregation of large amounts of data from different sources difficult.[22] For example, testing body fat, jump height, or running speed may seem like a relatively simple task, yet often there is inconsistency in test protocols used by different teams, associations, or researchers. For example, Hoffman[33] used a no-step vertical jump protocol, a 27-m sprint distance, and the sum of eight skinfold sites for assessing body fat. In contrast, Drinkwater et al.[12,42] used a step protocol, a 20-m sprint distance the sum of seven sites, while Bale[4] did not specify the vertical jump protocol and used sum of six skinfold sites, thus making results of the basketball studies difficult to compare. Some studies have combined different protocols to arrive at a single conclusion derived from different testing methods, such as establishing a category for 'running speed' from a range of different running sprint protocols.[22] Nationally agreed testing protocols, such as those established in some countries[43] or associations,[49] would allow compiling large amounts of data to permit a large-scale, detailed analysis of fitness characteristics of different ages, genders, levels of play, or secular changes over long periods of time.[12,42] These differences in fitness between players are largely unexplored yet remain critical issues for coaches and strength and conditioning staff in preparing and individualizing fitness training programmes for higher level basketball.

Another weakness of current research in basketball is that most studies tend to use basic forms of descriptive statistics,[20,21,43,55] mainly because small sample sizes and lack of homogeneity of variance can preclude the use of high-power statistical methods. Basic statistics describe a specific study sample, but are not always conducive to generalizing effects and estimates to a population. Many studies have reported descriptive measures of mean and standard deviation on specific samples, occasionally with p-values to discern the nature of differences between groups.[19,20,22,35,37,39] Only a few studies have utilized confidence limits to indicate the precision of estimates for generalizing to a population, or Cohen's d[69] to determine the magnitude of changes or differences within and between groups.[12,42] The approach of magnitude-based inferences is, however, gaining support in the exercise literature.[70] An under-utilized approach emerging in the sport science literature establishes the threshold for practical (clinical) significance as Cohen's small effect size.[48,69-72] The threshold or smallest worthwhile (practical) change is established as 0.20 of the between-athlete standard deviation for each particular measure of fitness. This method of evaluating the smallest worthwhile change or difference in test scores provides an objective means of quantifying the magnitude of observed effects in changes from test to test for a given individual, or in differences between groups.[48,70,73] Moreover, the precision of the mean change using confidence limits should be reported, and effect sizes shown with probability that the true effect is meaningful in clinical (practical) terms rather than strict statistical significance alone.[48,71,74,75] The approach of using Cohen effect sizes and confidence limits may help investigators[76] to avoid inappropriately discarding some effects reported as having 'no effect' (e.g. p = 0.07 or 0.15) that may actually be worthwhile in practical sporting terms.[70,74,75] The critical issue for coaches and athletes is to be informed of which changes and differences in basketball fitness are likely to be important, and the likely magnitude (size) of various training interventions.

Few studies of basketball fitness report the reliability of the anthropometric and fitness tests employed.[12,42] Almost every field test for basketball has methodological variation inherent in the set up and measurement of the physical performance, independent of biological variability in the athlete, even when it is the same researcher setting up and reading the test.[73] Another key source of variation is the motivation of the athlete when performing the test. Values reported in laboratory and field testing should account for this typical error of the measurement in both clinical and research settings.[12,42,73]

3. Evaluating Changes in Test Measures

3.1 Normal Variations and Changes in Physical Tests

Many differences in anthropometric and fitness test results between the genders and ages are related to biological changes associated with the adolescent growth spurt. Males after adolescence are typically taller and heavier than females,[77] have between 5–20% higher relative maximum oxygen consumption ($\dot{V}O_{2max}$),[78] and score at least one standard deviation greater on most tests of strength and power, such as sprinting and grip strength.[78] Gender differences are partly explained by the natural variation in biological maturation between adolescent males and females. Males typically have a longer prepuberal growth period with greater velocity curves of peak height and body mass stimulated by hormonal differences.[79] Differences between male and female adolescent basketball players are illustrated in table IV, in addition to differences between basketball players and non-athletes during adolescence. Substantial physical differences between older and younger individuals are evident during adolescent growth periods with both males and females showing sharp increases in body size and fitness during adolescence. [79] The smaller rate of increase in height with age of females compared with males is not surprising since females have a shorter growth period. Females tend to reach their peak height velocity at approximately 12 years and a height plateau by 15 years, whereas males peak at 14 years and often have not reached a growth plateau by 18 years.[80]

There is very little research investigating how anthropometric and fitness characteristics differ at different ages in adolescent athletes, although generally, participation in sport does not affect the onset of puberty.[79] Drinkwater et al.[12] reported that older male players, comparing 13- to 19-year-olds, typically scored substantially better (effect sizes of 'moderate' to 'large') on most anthropometric and fitness tests. Conversely, while national-level females scored higher on most tests than state-level

Table IV. Anthropometry and physical fitness test scores. Mean values ± SD of physical test results of male and female Australian junior basketball players collected between 1993 and 1996 with an age range of 14–17 years[43] compared with a 16-year-old urban New South Wales (NSW) Australian school population[81]

	Height (cm)	Body mass (kg)	∑7 skinfolds (mm)	CMVJ height (cm)	20-m sprint time (sec)	20-m shuttle run (levels)
Female basketball	178.4 ± 9.6 (n = 139)	69.2 ± 8.3 (n = 139)	91.7 ± 18.9 (n = 362)	46.5 ± 5.6 (n = 212)	3.4 ± 0.16 (n = 99)	10.5 ± 1.3 (n = 126)
Male basketball	198.4 ± 7.7 (n = 95)	94.4 ± 11.5 (n = 95)	72.0 ± 27.0 (n = 261)	65.5 ± 7.1 (n = 86)	3.04 ± 0.1 (n = 84)	12.0 ± 1.4 (n = 86)
Female NSW school	164.9 (n = 423)	57.2 (n = 421)	NA[a]	NA	NA	5.4 (n = 399)
Male NSW school	174.2 (n = 519)	62.2 (n = 519)	NA[a]	NA	NA	8.8 (n = 502)

a In the NSW schools report, only sum of three skinfolds was reported.

∑7 = sum of triceps, subscapular, biceps, supraspinale, abdominal, thigh, medial calf; **CMVJ** = countermovement vertical jump; **NA** = not assessed.

players, the national females often showed a U-shaped pattern, scoring worse between 13 and 17 years in 20-m sprint, 20-m shuttle run, and skinfolds to approach the scores of state-level players effect sizes of ‘moderate’ to ‘large’), but improving beyond 17 years. The worsening of test scores in females of this age likely reflects the disproportionate increase in adiposity compared with muscularity during adolescence. Both Drinkwater et al.[12] and Kellis et al.[37] reported that males scored better than females in testing.

There are significant implications in studying differences in athletic populations to assist coaches of age-group players tailor different style practices to different genders and ages of athletes. For example, many junior coaches are responsible for coaching several squads of players. For coaches of both male and female teams, the coach should be conscious not to re-use training programmes between teams as the physical demands placed on male players are different than those on female players. Physical demands should also be lower on younger male players than older players if, for example, the coach is using a training programme from a coaching magazine on young players that was designed for older ones. Coaches of female players must be further aware that during mid-to-late adolescence, the adolescent-induced increase in body fat may have detrimental effects on fitness, particularly when the athlete was performing at a very high level in the pre- and early adolescence phases. Further research is required to provide specific (quantitative) guidelines for coaches on how to modify their training programme to suit different circumstances.

3.2 Changes in Physical Fitness Over a Calendar Year

Coaches typically periodize athlete training programmes to develop the various components of fitness in athletes. A periodized approach typically involves an initial emphasis on high-volume and low-intensity training, before a gradual reduction in volume and increase in intensity over a period of several weeks to months.[82,83] In many sports, the year is divided into three primary phases: (i) the pre-season in which the athletes prepare for the upcoming competition; (ii) the in-season in which the athletes are competing; and (iii) the off-season in which the athletes are on a sustained break. The duration of each phase is dependent on the sport, but is inevitably several months.[84] Intuitively, the greatest fitness improvement should occur in the pre-season when athletes return from a prolonged period of light training and coaches can focus a substantial amount of time to developing fitness. During the in-season, coaches typically devote most of their time to refining individual and team skills, and spend very little time in dedicated fitness training so the athlete is not excessively fatigued for competition days. As a result, fitness is theoretically maintained or may slightly decrease during the in-season phase. Finally, the off-season is a period of recovery with only light to moderate conditioning activity so athletes typically lose some conditioning level during this phase. Much of this scenario has been learned by the collective experience of coaches and players, and a well planned fitness testing programme would be useful in confirming the direction and magnitude of fitness levels throughout the season.

While carefully periodized programmes lead to greater fitness improvements in the experimental environment,[85] there are less consistent observations on fitness benefits of the traditional periodized training programme in the typical training environment[86] (table V). Tavino et al.[36] tracked the progress of nine National Collegiate Athletic Association (NCAA) basketball players from the beginning of the pre-season to the post-season. They found that after 5 weeks of pre-season training, players substantially decreased their body fat by 26% as measured by densitometry, and increased their anaerobic power by 13% as measured by the Anaerobic Power Step test. Body fat levels then increased by 17% during the competition season with no accompanying changes in body mass or $\dot{V}O_{2max}$. Bolonchuk et al.[61] found no change in body mass or sum of seven skinfolds, but an improvement in $\dot{V}O_{2max}$ in eight NCAA players. Groves and Gayle[41] tested eight university players four times over a year for body composition, vertical jump and Margaria-Kalamen Stair Climb power. They found that body fat decreased 20% over a year of training and body mass decreased 2.1% between the first and second tests before increasing 2.7% between the second and fourth tests. Caterisano et al.[45] found in 17 NCAA

Table V. Fitness changes in a periodized programme: longitudinal fitness and anthropometric changes in American collegiate basketball players over different time periods

Study	Time period	Sample	Fitness characteristic	Change
Tavino et al.[36]	Pre-season[a]	9 NCAA males	Anaerobic Power Step test	13% ↑
	Pre-season[a]		Body fat	26% ↓
	In-season[b]		Body fat	17% ↑
	Competition year[c]		$\dot{V}O_{2max}$ (treadmill running)	↔
	Competition year[c]		Body mass	↔
Hoffman et al.[33]	15 wk of pre-season[a]	9 NCAA males	27-m sprint time	2% slower
	15 wk of pre-season[a]		Vertical jump height	9% ↓
	Competition year[c]		Body fat (skinfold)	↔
	Competition year[c]		Body mass	↔
	Competition year[c]		Endurance (2.4-km track run time)	↔
	Competition year[c]		Bench press	↔
Groves and Gayle[41]	In-season[b]	8 NCAA males	Body mass	2.7% ↑
	Competition year[c]		Body fat	20% ↓
	Competition year[c]		Sargent vertical jump	↔
	Competition year[c]		Margaria-Kalamen stair climb	↔
Bolonchuk et al.[61]	Competition year[c]	8 NCAA males	Body mass	↔
			Body fat (skinfolds)	↔
			$\dot{V}O_{2max}$ (treadmill running)	↑
Caterisano et al.[45]	Competition year[b]	17 NCAA males	Body mass	↔
			Body fat (skinfolds)	↔
			Bench press	7.5% ↓ for starters[d], 12% ↓ in bench players[e]
			$\dot{V}O_{2max}$ (treadmill running)	Starters[d] ↔, 10% ↓ in bench players[e]
Hunter et al.[35]	Competition year[c]	42 NCAA males	$\dot{V}O_{2max}$ (treadmill running)	↔
			Body fat (hydrostatic weighing)	↔
			Body mass	9% ↑
			Bench press	24% ↑
			Sargent vertical jump	8% ↑

a Period of time from the beginning of annual training to the start of competition.

b Period of time from the end of pre-season training to the end of the competition season.

c Period of time from the beginning of the pre-season to the end of the competition season.

d Players that are the first to play at the start of the game. The players are typically the players the coach has determined will have the greatest impact on the game.

e Team members put into the game to substitute starters.

NCAA = National Collegiate Athletic Association; $\dot{\mathbf{V}}\mathbf{O}_{\mathbf{2max}}$ = maximum oxygen consumption; ↓ indicates decrease; ↑ indicates increase; ↔ indicates no change.

basketball players that body mass, body fat and $\dot{V}O_{2max}$ did not change substantially over the course of a basketball season in starting players, while $\dot{V}O_{2max}$ declined by 10% in reserve players. Hoffman et al.[33] also studied nine NCAA players and reported no significant changes in body fat, body mass, or aerobic conditioning (2.4-km run time) after 5, 15 and 25 weeks. The only significant decrements at week 15 were 27-m sprint (−2%) and vertical jump height (−9%). Hunter et al.[35] tracked fitness progress over 4 years in 42 NCAA players. While they found some increase in body mass and vertical jump (9% and 8%, respectively), there were no substantial changes in $\dot{V}O_{2max}$ or body fat. Changes in strength measures such as the bench press range from showing no significant change[33] to improving by 7.5%[45] to 24%.[35] Finally, Drinkwater et al.[12] showed highly variable results depending on the competition level and gender of athletes, but most effects were either ‘trivial’ or ‘small’.

There are clearly several possibilities to why anthropometric and fitness parameters show inconsistent changes over a competitive year despite all programmes being designed and implemented by experienced American collegiate basketball coaches. Within all testing protocols are inherent sources of unreliability,[73] although test-retest reliability is rarely reported in basketball research.[12,42] By not accounting for test-retest variation as a source of error, an inferential statistical test (e.g. t-test, ANOVA) may often result in type I errors, indicating that no change has occurred even though a clinical change has been real and meaningful.

While reliability of testing may be one issue, validity is another. A sport scientist may go into great detail to design and document test protocols that reflect the demands of competition.[43] However, issues such as timing of testing sessions may also play a pivotal role in masking real changes that have been deemed ‘insignificant’ by null hypothesis significance testing. Total training volume for athletes in NCAA programmes, including resistance training, individual skills and fitness training, team practices and competitions routinely reach the NCAA rule of not more than 20 hours per week and 4 hours per day of required athletically related activities. Athletes may then exceed this limitation with additional voluntary training (i.e. training not supervised by coaching staff). Maintaining such a high training volume and intensity can lead to accumulated fatigue.[86] While an athlete may have made all the necessary physiological adaptations to improve fitness, the outcome of the testing may not reflect these changes if the athlete has not sufficiently recovered from intense training or competition. As a result, the test does not accurately reflect physiological adaptations.

One possible method of overcoming these inherent difficulties in testing lies in moving away from analysing tests using statistical significance. Researchers should report the precision of the mean change using confidence limits with an effect size to illustrate the magnitude of that difference to aid in the interpretation of the research findings.[48,71,74,75] Such an approach would make much better use of research findings over simple null-hypothesis significance testing. For example, Hunter and Hilyer[76] demonstrated a 1.2% reduction in body fat in NCAA players tested once in October (11.0% body fat) and again in May (9.8% body fat) of the following year with a standard deviation of 2.7 and an associated p-value of 0.07. While Hunter and Hilyer[76] assessed this result as ‘approached significance’, there is still an 85% probability that the results of the training had a substantial positive effect on body fat,[48] despite the p-value being >0.05, the established α for statistical significance. The 85% probability of a substantial change is based on a smallest worthwhile change of 0.54% (i.e. 0.2×2.7, the 0.20 representing the threshold for a ‘small’ Cohen’s d) compared with the observed change of 1.2%.[48] The Cohen’s d of such an effect is actually 0.45 (i.e. ‘small’ being 0.20–0.50). Furthermore, the 95% confidence limits of the 1.2% decrease in body fat ranges from −2.52% to +0.12%, so the 95% confidence limits for the Cohen’s d ranges from 0.93 (large decrease) to −0.04 (trivial increase). While Hunter and Hilyer[76] do not provide the number of subjects in their study, such calculations are based on 12 players being tested, as estimated from the provided observed t-statistic relative to the p-value.

A similar case could be made for the 2.5 mL/kg/min improvement in $\dot{V}O_{2max}$ in the same study by Hunter and Hilyer.[76] While the reported p-value was 0.15, the smallest worthwhile change was 1.3 mL/kg/min based on a combined team SD of 6.5, as calculated from the square root of the average of the squared 'pre' SD of 8.5 and the squared 'post' SD of 3.6 equaling 6.5, then multiplying by 0.2 (a 'small' Cohen effect size) to equal 1.3 mL/kg/min. Again, assuming 12 players were tested, there is still greater than a 75% likelihood that the 2.5 mL/kg/min change was clinically meaningful.[48] Expressed with stringent 95% confidence limits, the range of the 'true' change lies between −1.06 and 6.06 mL/kg/min, thus likely representing a meaningful and positive change in $\dot{V}O_{2max}$. The Cohen's d of the observed change was 0.41 (small increase) with 95% confidence limits on the Cohen's d of −0.17 (trivial decrease) to 0.99 (large increase). There are obvious limitations in reporting only statistical significance of effects without considering the practical implications of results.

4. Conclusion

While basketball is notionally classified as a non-contact sport, body contact is common, particularly among the comparatively bigger players on the team. For these players, body mass and muscular strength are required to maintain their positions when opponents contest for important positions under the basket. Relatively smaller players are responsible for carrying the ball quickly up the court and scoring points while defending their counterparts on the opposing team from doing the same. Speed, agility and rapid recovery are critical fitness components, particularly for smaller players. Therefore, assessing player fitness is important so coaches are aware of the fitness changes and limitations of different levels, ages and between the genders of their different teams. Fitness testing also allows a coach to monitor the effectiveness of their training programme over different phases of the competition year, or over several years that a coach may work with an athlete.

Some of the existing basketball literature is limited by methodological variations between studies. Conventional methods of null-hypothesis significance testing may be limited in detecting meaningful changes within athletes or meaningful differences between athletes. Much of the current research only reflects 95% certainty of changes or differences but not the likelihood of meaningful changes or differences. Effect sizes (i.e. Cohen's d), confidence limits, and even confidence limits of effect sizes provide much more meaningful interpretations to anthropometric and fitness data.

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