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ANTHROPOMETRIC AND STRENGTH CORRELATES OF FAST BOWLING SPEED IN JUNIOR AND SENIOR CRICKETERS

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ABSTRACT. Pyne, D.B., G.M. Duthie, P.U. Saunders, C.A. Petersen, and M. Portus. Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *J. Strength Cond. Res. 20(3):620–626. 2006.*—The aim of this study was to characterize relationships between anthropometric and isoinertial strength characteristics and bowling speed in junior and senior cricket fast bowlers. Subjects were first-class senior (n = 24; mean ± SD age = 23.9 ± 4.8 years, height = 187.4 ± 4.8 cm, mass = 87.8 ± 8.4 kg) and junior representative (n = 48; mean ± SD age = 14.8 ± 1.3 years, height = 175.7 ± 9.8 cm, mass = 65.8 ± 12.9 kg) male fast bowlers. A full anthropometric profile, upper- and lower-body isoinertial strength tests, and peak bowling speed (Vpeak) were assessed on the same day. The senior bowlers had a substantially faster Vpeak (126.7 km·h^{-1}) than the juniors (99.6 km·h^{-1}), a larger estimated muscle mass (seniors 40.0 ± 3.9 kg, juniors 28.3 ± 5.6 kg), and a greater bench press throw and deltoid throw (all $p < 0.01$). The best multiple predictors of Vpeak for the junior bowlers were the static jump, bench throw, body mass, percentage muscle mass, and height (multiple-correlation r = 0.86). For the senior bowlers, static jump and arm length correlated positively with Vpeak (multiple-correlation r = 0.74). The 1-legged countermovement jump was negatively correlated with Vpeak in both groups. We conclude that differences in Vpeak between junior and senior bowlers relate primarily to body mass and upper-body strength. However, lower body strength is a more important contributor to Vpeak in senior bowlers.

KEY WORDS. cricket, performance, isoinertial strength, anthropometry, ball-release speed, age

INTRODUCTION

Despite the popularity of cricket in many countries, and the large number of studies addressing the biomechanical and physiological correlates of back injuries (12, 14, 24), there is only limited information on anthropometric and fitness characteristics related to fast bowling performance. The increasing professionalism of preparing players for the physical demands of both test match and 1-day cricket is influencing the coaching of players at all levels of the game. A recent review of the literature on cricket concluded that much more research was required before a full understanding of the scientific aspects of the game could be made (5). Clearly, more cross-sectional, longitudinal, and intervention studies are required to address the physical preparation of players for the demands of contemporary international cricket.

A key element of fast bowling is ball-release speed or peak bowling speed (Vpeak). Ball-release speed in fast bowlers is influenced by various anthropometric, morphological, and kinematic factors. For example, higher ball-release speeds in senior bowlers has been attributed to longer limb lengths and higher approach speeds than in junior bowlers (23). A study of 9 collegiate fast-medium bowlers reported that ball-release speed was highly correlated with shoulder–wrist length and total arm length (15). Another study reported that chest girth and body composition were highly related to ball-release speed in first-grade fast bowlers during a simulated 8-over spell (20). Detailed anthropometric data on the proportions of different body compartments (muscle mass, fat mass, bone mass) is available for a number of sports (2), but this information is lacking in cricket. Given that body size affects overarm throwing performance (25), we were interested in quantifying relationships between various measures of body size and peak bowling speed in well-performed cricketers. More studies of bowlers of different ages and levels are needed to develop specific guidelines for cricket authorities, coaches, and players.

A further consideration is the importance of technique and movement coordination patterns in the bowling action. One study reported similar patterns of movement coordination in senior and junior bowlers after results were normalized to ball-release speed and total duration of the delivery stride (23). The finding of similar patterns of movement suggests that a combination of maturation-related morphological and strength characteristics might account for a substantial proportion of the variation in ball-release speed. Although strength and power characteristics are purported to be important factors influencing ball-release speed (8), the extent to which they explain variations in bowling speed between different fast bowlers is unclear. To the best of our knowledge, no previous study of cricket fast bowlers has determined whether differences in muscular strength account for variations in ball-release speed between fast bowlers of different ages and levels.

Isoinertial strength testing provides a sport-specific approach for evaluating strength qualities in trained athletes (18). Isoinertial testing involves acceleration and deceleration of a constant mass (typically a weighted barbell in the laboratory or gymnasium) about a joint at velocities similar to those experienced in training and competition. Although a number of studies have failed to establish substantial links between within-subject changes in isoinertial strength testing and functional performance (1, 10, 11), there is general support that testing is useful for discriminating these qualities between differing levels of performers (1, 19). A combination of upper- and lower-body isoinertial strength testing in a cross-sectional design would clarify the relative importance of these elements in the fitness profile of fast bowlers.

The purpose of this study was to compare the anthropometric and isoinertial strength characteristics of junior and senior first-class fast bowlers and use multiregression analysis to identify factors correlating with peak ball-release speed. The information derived from this study should allow cricket authorities and coaches to identify talented individuals with qualities necessary for progression to higher levels of the game, and to assess the strengths and weaknesses in the fitness profile of individual players.

METHODS

Experimental Approach to the Problem

We employed a cross-sectional design to compare the anthropometric and isoinertial strength qualities of junior and senior cricket fast bowlers. Initially, we established the test–retest reliability of the dependent measures. Multiple stepwise regression analysis was employed to examine relationships between anthropometric and strength qualities and peak ball-release speed.

Subjects

First-class senior (n = 24; mean ± SD age = 23.9 ± 4.8 years, height = 187.4 ± 4.8 cm, mass = 87.8 ± 8.4 kg, sum of skinfolds = 62.5 ± 19.2 mm) and junior representative (n = 48; mean ± SD age = 14.8 ± 1.3 years, height = 175.7 ± 9.8 cm, mass = 65.8 ± 12.9 kg, sum of skinfolds = 63.2 ± 21.5 mm) male fast bowlers were assessed on a single occasion in a cross-sectional design. Cricket is a popular field-based summer sport, particularly in countries of the Commonwealth, and is played between 2 teams of 11 players each. Each team has a number of fast bowlers who deliver the ball 22 yd (20.1 m) toward the batsman using a straight arm action. The senior bowlers were all contracted players to professional first-class Australian state teams and had a background of at least 5 years of structured strength training and conditioning programs. The junior bowlers had represented their local cricket association within their respective age groups, with a limited (<1 year) background of basic strength training and conditioning. All measurements were obtained in the first month of the competitive season. Subjects provided written informed consent after explanation of all the experimental procedures. Approval for the study was provided by the Ethics Committee of the Australian Institute of Sport (AIS).

Procedures

Peak bowling speed was determined at the AIS Biomechanics Laboratory on a synthetic pitch using a radar gun (Gestetner Australia Pty. Ltd., Sydney, Australia). The gun was positioned 5 m behind the bowling crease, pointing down a line joining middle stump at the bowler's end to middle stump at the batter's end. After a 15-min warm-up of running, stretching, and half-pace deliveries, bowlers were required to bowl 18 (equivalent to 3 × 6-ball overs) full-pace deliveries with approximately 40–60 seconds rest period between each. The typical error for ball-release speed in our laboratory is 1.4 (95% confidence limits 1.1–2.1) $km \cdot h^{-1}$ or 0.4 (0.3–0.6) $m \cdot sec^{-1}$ in absolute terms and 1.6% (1.2–2.3%) in relative terms.

Anthropometric Measures

One investigator, who was qualified as a Level 2 anthropometrist with the International Society for the Advancement of Kinanthropometry, collected all the anthropometric measures. Measures were collected in triplicate with the median value used as the criterion. Stretch height was measured during inspiration using a stadiometer (Holtain Ltd. Crymych, Dyfed, UK). Digital standing scales were used to measure body mass to the nearest 0.1 kg. Skinfolds comprised the sum of 7 skinfold thicknesses from triceps, subscapular, biceps, supraspinale, abdominal, front thigh, and medial calf, measured with Harpenden calipers (British Indicators Ltd., West Sussex, UK). A subgroup comprising 20 of the junior bowlers was used to assess the test-retest reliability or typical error (TE). The TE values for the primary anthropometric measures were: height, 0.2 cm (0.1%); mass, 0.0 kg (0.0%); sum of 7 skinfolds, 1.3 mm (1.5%); acromiale-radiale length, 0.4 cm (1.4%); and anterior-posterior chest depth, 0.3 cm (1.3%).

Four-way fractionation of body composition was used to partition total body mass into 4 different constituent compartments—fat mass, residual mass, muscle mass, and bone mass—according to methods outlined previously (13). The anthropometric profile consisted of the following measurements: height, mass, sum of 7 skinfolds, 11 girths, 8 lengths, and 8 breadths. The 4 compartment masses were estimated individually by measuring a representative subset of lengths, breadths, and girths scaled for a known height and mass. The percentage muscle mass was derived as the percentage of estimated muscle mass to the estimated total body mass. The TE values for estimating the fractionation components were: fat mass, 0.1 kg (1.4%); residual mass, 0.2 kg (0.9%); bone mass, 0.2 kg (1.3%); muscle mass, 0.2 kg (0.7%); and percentage muscle mass, 0.2% (0.5%).

Isoinertial Strength Testing

One-legged jumps and bar-throw tests were used to assess isoinertial strength qualities of the junior and senior bowlers. These tests were chosen partly because their dynamic acceleration more closely approximates athletic movements, and partly because many of the junior bowlers were not sufficiently strong or experienced with traditional 1 or 3 repetition maximum (RM) strength testing. For the purpose of this study we have defined these tests as isoinertial strength testing, although the dynamics of the underlying force-velocity relationship are presumably speed-strength in character given the lower resistances and higher movement velocities involved. A combination of strength-oriented and speed-oriented testing and training strategies would provide a more comprehensive picture of the broad spectrum of strength and power adaptations (4).

The 1-legged vertical jump test using a Smith machine (Plyometric Technologies, Lismore, Australia) was employed to characterize the lower-body isoinertial strength qualities of the bowlers (18). The subject, standing in an upright position with the feet approximately shoulder width apart, held a light 9-kg (88.2-N) barbell across the shoulders. The initial height of the bar (cm) was recorded using a marked scale on the vertical support column of

Table 1. Comparison of anthropometric measures and body composition fractionation components between senior and junior fast bowlers (mean ± *SD*). Rating shows magnitude of difference between groups.

Fraction	Senior	Junior	Effect size
Height (cm)	187.4 ± 4.8	175.7 ± 9.8	1.2; moderate
Body mass (kg)	87.3 ± 8.4	65.8 ± 12.9	1.5; large
Fat mass (kg)	8.3 ± 2.2	7.5 ± 2.3	0.3; small
Bone mass (kg)	14.0 ± 1.4	12.1 ± 2.0	1.0; moderate
Residual mass (kg)	23.0 ± 2.4	16.9 ± 2.8	1.6; large
Muscle mass (kg)	40.0 ± 3.9	28.3 ± 5.6	1.5; large
Percentage muscle mass	46.8 ± 2.0	43.8 ± 2.2	1.2; moderate

the Smith machine. The subject then placed all weight on 1 leg with the knee placed at an angle of 120°. While holding this angle the subject was required to jump as high as possible while maintaining the bar against the body (shoulders), with the vertical displacement of the bar (cm) recorded against the graduated scale. After warm up and familiarization trials, the subject executed 3 maximal-effort static jumps on each leg. After a short rest, testing was repeated using a short self-selected countermovement, starting from a standing position and squatting down and jumping up in 1 motion. The best score of each trial was used as the test score. The 1-legged vertical jump has been shown to be a reliable estimate of lower-body functional strength in individual limbs (26). The TE values for the strength measures were: left leg static jump, 1.8 cm (8.1%); right leg static jump, 1.6 cm (7.4%); left leg countermovement jump (CMJ), 2.2 cm (10.9%); and right leg CMJ, 2.4 cm (10.9%).

The Smith machine was also used to assess the isoinertial strength qualities of the upper body (18). A bench press throw was employed with a 9-kg (88.2-N) barbell using the Smith machine with the subject lying supine on the bench with knees flexed at approximately 90°. A protocol involving a throw component reduced the limitations of conventional 1RM tasks that require the subject to decelerate the barbell at the completion of the movement. The barbell was thrown upwards in a vertical line and the displacement measured against the graduated scale on the vertical supports of the Smith machine. A modification of this test was used for the deltoid throw. In this case, the subject sat upright on the bench in line with the vertical supports, with the bar resting comfortably on the shoulders and the head tilted slightly forward. Two of the study investigators acted as spotters on either side of the barbell throughout the test. No countermovements were permitted, ensuring that the movements could be used to gauge isoinertial concentric speed strength qualities of the upper-limb musculature (18). Similar to the lower-body tests, 3 maximal effort-trials were undertaken and the best score recorded. The TE values for the upper-body measures were: bench press throw, 4.6 cm (9.6%) and deltoid throw, 3.9 cm (13.4%).

All strength results were reported in absolute (cm displacement of the bar throw) and relative (cm displacement per kg of estimated muscle mass) units. Isoinertial strength results were normalized to muscle mass (kg) raised to the power of 0.67, to permit equitable comparison of strength estimates between athletes and groups (3, 17, 25). Jump displacements for the CMJ and static jump tests were also converted to (surrogate) estimates of power (W) using previously validated regression equations (22). No prescribed equations were available to convert barbell displacement to estimates of power for the upper-body bench and deltoid throws.

Statistical Analyses

Measures of centrality and spread are presented as mean ± *SD*. The magnitudes of differences in anthropometric and strength measures between junior and senior bowlers were interpreted with a standardized (Cohen) effect size (21). Thresholds for assigning qualitative terms to the magnitude of the effect size (ES) were: 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; and >2.0, very large (16). A raw correlation between Vpeak and the independent anthropometric and strength variables was used to identify the strength of association. The criteria for evaluating the correlation coefficient (r) were: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; and 0.7–0.9, very large. Multiple stepwise regression analysis was used to examine relationships between the outcome (Vpeak) and predictor (anthropometric and strength) variables. We report both the multiple r and r^2 values. The multiple r characterizes the strength of the relationship between outcome and multiple predictor variables, whereas the multiple r^2 value measures the reduction in the total variation of the dependent variable (Vpeak) attributable to the (multiple) independent variables. The TE for each test was established in our laboratory by conducting test-retest reliability trials on a subgroup of 20 junior cricketers in this study within a 7-day period. All analyses were conducted with the statistical package Statistica 6.0 (Stats Soft Inc., Tulsa, OK). Statistical significance was accepted at $p \leq 0.05$.

Results

Bowling Performance

The senior bowlers had a higher Vpeak (35.2 ± 1.5 $m \cdot s^{-1}$, approximately 127 $km \cdot h^{-1}$ vs. 27.7 ± 2.5, approximately 100 $km \cdot h^{-1}$, $p = 0.00$) and mean bowling velocity Vave (34.2 ± 1.2 $m \cdot s^{-1}$, approximately 123 $km \cdot h^{-1}$ vs. 26.6 ± 2.7, approximately 96 $km \cdot h^{-1}$, $p = 0.00$) than the junior bowlers. The magnitude of the difference between seniors and juniors in Vpeak (ES = 1.8) and Vave (ES = 1.8) was large.

Anthropometry—Basic and Fractionation

The basic anthropometric measures of height and mass, the mean fractionation components (fat mass, bone mass, residual mass, and muscle mass), and the derived index of percentage muscle mass are shown in Table 1. The senior bowlers were substantially taller and heavier than the junior bowlers. The senior bowlers also had more mass in each of the 4 compartments than the junior bowlers. All components were substantially greater in the se-

TABLE 2. Comparison of selected anthropometric lengths and breadths between senior and junior fast bowlers (mean ± *SD*). Rating shows magnitude of difference between groups.

Length/breadth (cm)	Senior	Junior	Effect size
Acromiale-radiale	35.5 ± 0.8	32.0 ± 2.3	1.4; large
Radiale-stylion	26.9 ± 1.2	24.5 ± 1.6	1.3; large
Stylion-dactylion	20.7 ± 0.7	19.1 ± 1.2	1.2; large
Arm length	82.0 ± 4.8	75.8 ± 4.7	1.1; moderate
Trochanterion	98.5 ± 3.0	92.5 ± 5.2	1.1; moderate
Biacromial	43.8 ± 2.7	39.0 ± 2.4	1.4; large
Bi-iliocristal	30.0 ± 1.6	27.1 ± 2.1	1.2; large
Anterior-posterior chest depth	21.3 ± 1.9	17.8 ± 1.7	1.5; large

nior bowlers ($p < 0.01$) with the exception of fat mass ($p = 0.14$). Inspection of the effect sizes shows that the magnitude of the difference between senior and junior bowlers was small for fat mass, moderate for bone mass and percentage muscle mass, and large for residual mass and muscle mass.

Anthropometry—Lengths and Breadths

Comparison of selected anthropometric lengths and breadths between the groups is shown in Table 2. The senior bowlers had substantially greater lengths and breadths in both the upper- and lower-body regions (all comparisons $p < 0.05$). The magnitude of the differences was large, with the exception of arm length and trochanterion (leg) length, which were only moderately larger in the senior bowlers. The seniors also exhibited much larger bioacromial (shoulder) and bi-iliocristal (hip) breadths, and a larger anterior-posterior chest depth, indicative of more substantial upper-body physical development.

Isoinertial Strength

The senior bowlers exhibited substantially greater isoinertial strength characteristics ($p < 0.01$) of the upper and lower body compared with the junior bowlers (Table 3). In absolute displacement (cm) the magnitude of the difference between the groups was large for the upper-body measures of bench press throw and deltoid throw (>100% greater displacement in the seniors), and moderate for the lower-body measures of static and CMJ jump strength (approximately 20% greater displacement in the seniors). After the magnitude of bar displacement to $kg^{0.67}$ of estimated muscle mass was normalized, the differences between the seniors and juniors remained large for measures of upper-body isoinertial strength and moderate for lower isoinertial strength and estimated power.

TABLE 4. Multiple linear regression analysis showing the correlation between peak bowling speed (Vpeak) and selected anthropometric and strength variables in junior and senior fast bowlers. The multiple *r* value is the strength of the relationship between outcome and multiple predictor variables. The multiple r^2 value shows the reduction in the total variation of Vpeak attributable to the (multiple) independent variables.*

Group	Step	Predictor variable	Multiple *r*	Multiple r^2
Junior	1	Static jump (+)	0.86	0.74
	2	Bench throw (+)		
	3	CMJ (−)†		
	4	Body mass (+)		
Senior	1	Deltoid throw (−)‡	0.74	0.54
	2	Static jump (+)		
	3	CMJ(−)†		
	4	Arm length (+)		
	5	A-P chest depth (+)		

* (+) = predictor variable correlated positively with Vpeak (−) = predictor variable correlated negatively with Vpeak; CMJ = countermovement jump; A-P = anterior-posterior.

† Counterintuitive result, with faster bowlers having a lower CMJ.

‡ Counterintuitive result, with faster bowlers having a lower deltoid throw.

Predictors of Peak Bowling Speed

Multiple regression analysis was used to determine how well anthropometric and isoinertial strength variables predicted Vpeak. A representative subset of anthropometric (height [cm], mass [kg], muscle mass [kg], arm length [cm], and anterior-posterior chest depth) and strength (deltoid throw, bench throw, CMJ, and static jump) variables were correlated with Vpeak separately for the junior and senior bowlers. Table 4 shows the best combination of predictor variables used in the analysis for each group. The correlation coefficient shows the strength of the combined variables in predicting Vpeak with a large correlation for both junior and senior groups. The sign (− or +) after each predictor variable indicates the direction of the correlation. A negative sign (−) indicates that this variable was lower when all other predictor variables were controlled for, whereas a positive sign (+) indicates that this variable correlated positively with the outcome variable. In the junior bowlers, 5 of the 6 measures correlated positively with Vpeak, accounting for approximately 74% of the variation in Vpeak. However, in

TABLE 3. Comparison of isoinertial strength and power characteristics of junior and senior fast bowlers in absolute (cm displacement) and relative (cm displacement per kg of muscle mass) values (mean ± *SD*). Rating shows magnitude of difference between groups.

Test	Unit	Senior	Junior	Effect size
Bench throw	cm	75.1 ± 11.7	36.8 ± 14.5	1.7; large
	$cm{\cdot}kg^{-0.67}$	6.4 ± 0.8	3.9 ± 1.2	1.5; large
Deltoid throw	cm	50.5 ± 9.4	22.8 ± 11.3	1.7; large
	$cm{\cdot}kg^{-0.67}$	4.4 ± 0.7	2.4 ± 1.0	1.5; large
Static jump	cm	32.8 ± 3.7	26.9 ± 5.8	1.0; moderate
	W	3,414 ± 311	2,229 ± 801	1.3; large
	$W{\cdot}kg^{-0.67}$	291 ± 23	228 ± 57	1.1; moderate
Countermovement jump	cm	27.8 ± 4.2	22.4 ± 4.8	0.9; moderate
	W	3,364 ± 401	2,161 ± 755	1.4; large
	$W{\cdot}kg^{-0.67}$	286 ± 24	221 ± 53	1.1; moderate

the senior bowlers, both the deltoid throw and the CMJ were counterintuitively lower in bowlers with a higher Vpeak, and the predictor variables collectively only accounted for approximately 54% of the variation in Vpeak.

Discussion

This study shows that growth and maturation primarily account for greater Vpeak in senior fast bowlers compared with their junior counterparts. We demonstrated that the best set of predictor variables for junior fast bowlers (static jump, bench throw, CMJ, and body mass) was strongly correlated with Vpeak, and explained approximately 74% of the variation in Vpeak. For senior bowlers, the best set of predictor variables (deltoid throw, static jump, CMJ, arm length, and anterior-posterior chest depth) explained approximately 54% of the variation. The negative correlation of CMJ with Vpeak in both junior and senior bowlers suggests that the inclusion of this test should be reviewed. Although junior bowlers should be encouraged to develop adequate upper- and lower-body size and strength, ultimately a combination of physical conditioning and technical proficiency is required to progress to the senior ranks of fast bowling.

Clearly body size had a strong positive influence on bowling performance in a heterogenous population of different ages, with bowlers of larger physical stature and greater strength generally having a higher Vpeak. However, this effect was markedly reduced when measures of isoinertial strength and (estimated) power were expressed per $kg^{0.67}$ of muscle mass. Removal of the covariate influence of body size from physiological and performance measures is necessary for valid intergroup or intragroup comparisons in heterogeneous or homogenous groups (6). A key question for researchers is whether ratio (linear scaling—dividing the independent measure directly by mass) or allometric (curvilinear scaling—dividing by mass raised to an exponent value, typically 0.67) normalization is the preferred analytical approach (3). Although opinion varies between studies, there is consensus for allometric scaling using fat-free mass as the most appropriate body-size variable in strength and performance testing of athletes (7, 17, 25). Partitioning out the effects of body size is also required to establish valid reference standards for assessing isoinertial strength qualities in various athletic groups.

The finding that arm length was one of the multiple independent predictors of Vpeak in the senior bowlers confirms previous findings that this measure is an important determinant of bowling speed (15, 23). Both of these studies demonstrated that total arm length was significantly correlated with Vpeak. Glazier et al. (15) estimated that the arm action of bowling accounted for 62% of Vpeak, with a correlation of $r = 0.58$ between total arm length and Vpeak. Given that peak linear speed of the wrist is proportional to the length of the radius for any given angular velocity, a greater arm length should translate into a greater linear speed for the wrist, and consequently into a greater Vpeak. These relationships assume that the correct temporal sequencing and coordination of the bowling action (hip-shoulder-elbow-wrist) is maintained. However, arm length did not enter the best combination of predictors in the junior bowlers, indicating that overall measures of size such as body mass and height have a larger influence on Vpeak in this cohort.

As with arm length, we observed large differences in chest depth as a function of age, with the senior bowlers having a mean chest depth 3.5 cm greater than the junior bowlers. The magnitude of the difference in anterior-posterior chest depth between the juniors and the seniors was the largest for all the anthropometric variables. A larger anterior-posterior chest depth would reflect a combination of normal physical growth and maturation in older adolescents and young adults, and increased mass of the upper body (chest) as a consequence of specific strength or resistance training programs. The finding that anterior-posterior chest depth was positively correlated with Vpeak in the senior bowlers confirms the earlier findings of Portus et al. (20), who reported corrected chest girth was highly related to ball-release speed in first-grade fast bowlers during a simulated 8-over spell. The observation of large differences in upper-body strength (bench press throw and deltoid throw) but only moderate differences in lower-body strength (1-legged static jumps and CMJs) between senior and junior bowlers confirms the notion that upper-body strength develops more rapidly in the late teens and early twenties age bracket. Taken together, these findings provide some justification for a balanced physical conditioning program with an emphasis on muscular development of the upper body and chest region.

In an athletic setting, fractionation of body composition into its 4 constituent components is useful in quantifying the relative proportions of fat and fat-free (lean) mass (13, 27). We were particularly interested in quantifying the relative proportions of fat and muscle mass and the relationship between these measures and Vpeak. Our working hypothesis was that bowlers with higher absolute and relative proportions of muscle mass would have a higher Vpeak. The seniors bowlers had approximately 12 kg or 35% more muscle mass than the junior bowlers. The percentage of muscle mass entered the prediction model for Vpeak for the junior but not for the senior bowlers. Younger bowlers who mature more rapidly and possess greater total mass and relative muscle mass than bowlers of the same chronological age are likely to have some advantage with respect to Vpeak, but this advantage dissipates slightly during the transition to senior ranks. Our findings are consistent with the contention that fat-free or lean mass is an appropriate measure for expressing body size when assessing overarm throwing performance (25).

Comparison of the isoinertial strength characteristics showed large absolute differences between senior and junior bowlers for the upper-body tests of bench press throw and deltoid throw, but only moderate differences in the lower-body static jumps and CMJs. In absolute terms the senior bowlers exhibited approximately 100% greater upper-body strength, approximately 25% greater displacement in lower-body strength tests, and approximately 35% greater lower-body power than the junior bowlers. After normalization for muscle mass, these differences decreased to approximately 50% for upper-body strength and approximately 20% for lower-body strength per $kg^{0.67}$ of muscle mass. These findings provide further evidence for the notion that the development of upper-body strength in younger adolescent athletes tends to lag behind that of the lower body. Although the training history of the bowlers was not surveyed in this study, it is likely that very few of the junior bowlers had been exposed to an organized strength training program. The conflicting findings for the CMJ and static jumps as predictors of Vpeak may partly reflect limitations of the 1-legged CMJ protocol. Several subjects found this a difficult jump to execute, and the typical error for the CMJ test was approximately 40% greater than that for the static jump. Given this degree of variability and findings of negative correlations with Vpeak in both junior and senior bowlers, we do not recommend the 1-legged CMJ as a useful measure of lower-body isoinertial strength for fast bowlers. The deltoid throw also appears to have only limited value as a predictive test for cricket fast bowlers.

PRACTICAL APPLICATIONS

The present findings provide some justification for inclusion of isoinertial testing to discriminate upper- and lower-body strength qualities in a mixed cohort of cricket fast bowlers. Although use of jump displacements and bar throws is attractive for simple assessments of these isoinertial strength qualities in larger groups of subjects, we concede that they offer little direct insight into specific isoinertial qualities such as starting, explosive, and stretch–shorten cycle strength. Accurate assessment of these qualities requires use of ground reaction force (GRF) plates, although the reliability of horizontal and vertical GRF parameters remains an issue (9).

Although a number of studies have failed to establish substantial links for within-subject changes in isoinertial strength testing and functional performance (1, 10, 11), there is general support that testing is useful for discriminating these qualities between differing levels of performers (1, 19). Our results lend support for the inclusion of isoinertial strength assessment using the bench press throw and the static jump to assist young developing bowlers make the transition from junior to senior ranks. The value of testing appears more limited for senior bowlers, for whom other technique factors are likely to be involved. Further studies are required to determine the utility of isoinertial strength testing in tracking the improvement of given individual bowlers (employing a within-subject repeated measures design) during preparations for a competitive cricket season. These studies may identify a minimum threshold of isoinertial strength for cricket fast bowlers beyond which no further gains in performance are easily obtained.

In conclusion, a cross-sectional analysis of the anthropometric and isoinertial strength characteristics of a group of senior and junior fast bowlers has identified large absolute differences in body mass, muscle mass, and upper-body strength. Body mass and percentage muscle mass were useful predictors of Vpeak in junior but not in senior bowlers. For these reasons, early-maturing young bowlers may possess a performance advantage over their late-maturing counterparts, but this difference is likely to dissipate as a player reaches the end of the junior phase of the cricket career.

These findings suggest that cricket training programs for younger fast bowlers should focus on skills and technique development, with older juniors making the transition to senior ranks requiring more specific strength and conditioning work. Given that the 1-legged static jump was a moderate predictor of Vpeak for senior bowlers, these players are likely to benefit from a combined program of skills training and physical conditioning. Studies on anthropometric and strength measures and bowling performance should employ scaling methods for valid intergroup and intragroup comparisons.

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