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Physiological characteristics of elite and sub-elite badminton players

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Abstract

The aims of this study were to establish the physical and physiological attributes of elite and sub-elite Malaysian male badminton players and to determine whether these attributes discriminate elite players from sub-elite players. Measurements and tests of basic anthropometry, explosive power, anaerobic recovery capacity, badminton-specific movement agility, maximum strength, and aerobic capacity were conducted on two occasions, separated by at least one day. The elite ($n = 12$) and sub-elite ($n = 12$) players' characteristics were, respectively: mean age 24.6 years ($s = 3.7$) and 20.5 years ($s = 0.7$); mass 73.2 kg ($s = 7.6$) and 62.7 kg ($s = 4.2$); stature 1.76 m ($s = 0.07$) and 1.71 m ($s = 0.05$); body fat 12.5% (s = 4.8) and 9.5% ($s = 3.4$); estimated VO_{2max} 56.9 ml · kg^{-1} · min^{-1} ($s = 3.7$) and 59.5 ml · kg^{-1} · min^{-1} ($s = 5.2$). The elite players had greater maximum absolute strength in one-repetition maximum bench press ($P = 0.015$) compared with the sub-elite players. There were significant differences in instantaneous lower body power estimated from vertical jump height between the elite and sub-elite groups ($P < 0.01$). However, there was no significant difference between groups in shuttle run tests and on-court badminton-specific movement agility tests. Our results show that elite Malaysian male badminton players are taller, heavier, and stronger than their sub-elite counterparts. The test battery, however, did not allow us to discriminate between the elite and sub-elite players, suggesting that at the elite level tactical knowledge, technical skills, and psychological readiness could be of greater importance.

Keywords: *Physiological characteristics, badminton, elite players, racket sport*

Introduction

Badminton has been an Olympic sport since the Barcelona Olympic Games in 1992. The sport has undergone considerable development since the first rules were written in 1877 by members of the British Army and Diplomatic Corps. Currently, there are five full-medal events on the Olympic programme (men's singles, men's doubles, women's singles, women's doubles, and mixed doubles). Badminton is claimed to be the world's fastest racket sport, with the shuttle velocity following a smash being over 100 m · s^{-1} and average shuttle velocity during match-play ranging from 50 to 75 m · s^{-1} (Gowitzke & Waddell, 1978). The demands of the sport require a blend of fine technical skills, intelligent game tactics, specific physiological fitness, and thorough psychological preparation to succeed at elite international level (Omosegaard, 1996).

The new "scoring system" introduced by the Badminton World Federation (BWF) in 2006 has also added a further dimension to the game. Under this new format, a match consists of the best of three games and the player who scores 21 points first wins the game (www.internationalbadminton.org/statues-pdf/law.pdf). A recent study comparing the temporal structure of the new and conventional scoring systems for men's singles revealed that rally times and the number of shots per rally were significantly greater in matches played under the new scoring system (Chen & Chen, 2008). The increased match duration and work-to-rest ratio after the first game further suggests that contemporary competitive badminton may require different training strategies and preparation (Chen & Chen, 2008).

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Aside from the technical, tactical, and training aspects of modern competitive badminton, the physical demands are continually changing, with players in action demonstrating intense rhythmic movement involving shuffling, jumping, twisting, stretching, striking with a combination of superior anticipation, quick reflexes, and superb visual acuity – all in a reactive context. This combination of physical movement skills raises the question of what physical and physiological attributes of elite badminton players sets them apart from sub-elite players. Unfortunately, there is relatively limited information in the research literature on the physical and physiological profiles of Asian players who dominate at all major international tournaments.

A number of studies have addressed the validity of a limited range of specific tests to determine the physiological capacity and badminton performance of elite players (Baum, Hoy, Leyk, Papadopoulos, & Effeld, 1997; Chin et al., 1995; Hughes & Fullerton, 1995; Wonisch, Hofmann, Schwaberger, von Duvillard, & Klein, 2003). Several studies have also assessed the relationship between muscle activity of the lower limbs and performance of the badminton smash stroke (Sakurai & Ohtsuki, 2000; Tsai, Yang, Lin, Huang, & Chang, 2006). Other studies include those that describe the physical profiles, oxygen deficit, ''explosive'' muscle strength, and maximal force production of badminton players from adolescents to elite seniors (Andersen, Larsson, Overgaard, & Aagaard, 2007; Chang, Zhang, & Chen, 2006; Naughton et al., 1997; Withers et al., 1987). The physiological demands on badminton players during training and matches have also been widely investigated (Araragi, Omori, & Iwata, 1999; Cabello, Padial, Lees, & Rivas, 2004; Cabello-Manrique & Gonzalez-Badillo, 2003; Faccini & Dal Monte, 1996; Faude et al., 2007; Hughes, 1995), with some of this research specifically focused on analysis of heart rate and blood lactate responses during training or simulated badminton competition (Dias & Ghosh, 1995; Majumdar et al., 1997; Smith & Chang, 1999). Further research has been concerned with the epidemiology of injuries in badminton (Fahlstrom, Yeap, Alfredson, & Soderman, 2006; Hoy, Lindblad, Terkelsen, Helleland, & Terkelsen, 1994; Jorgensen & Winge, 1990; Kroner et al., 1990).

Malaysia has an outstanding record of producing world-ranked badminton players over many years. Thus, the physiological profile of Malaysian elite badminton players should provide an insight into some of the attributes required to play the game at an international elite level. Furthermore, the organization of high-level badminton in Malaysia comprises an elite squad of players and a back-up squad of sub-elite players who include promising junior players. This organization of badminton in Malaysia has enabled us to draw comparisons between the sub-elite players and the truly elite players.

The present study is primarily a descriptive one that seeks to provide physical and physiological characteristics of elite and sub-elite Malaysian male badminton players. We hypothesized that the elite players would have superior physiological fitness as demonstrated by their performance on a range of common fitness assessment tests and measurements.

Methods

Participants and protocols

All participants were national male badminton players under the sanctioned programme of the National Sports Council of Malaysia (NSCM) and the Badminton Association of Malaysia (BAM). They included elite squad players who are part of a centralized training programme at the NSCM and a back-up squad of players who participated in national training camps held at BAM. The 12 most successful players from each of these two groups, based on their highest world ranking achieved over the period 2005–2007, were included in the study. During this period, the physiological fitness of these two groups of players was assessed frequently at the Sports Science Laboratory/Gymnasium at the National Sports Institute of Malaysia; the world ranking of each player was also obtained from the BWF's official website (www.internationalbadminton.org/ranking.asp) and recorded at the time of the test. The study was approved by the Research Committee of the National Sports Institute of Malaysia in compliance with the principles of the Declaration of Helsinki. The players were informed of the possible risks and discomfort related to the battery of physical performance tests before written informed consent was obtained before testing began.

To emphasize the international calibre of the players in this study, it should be noted that they had represented Malaysia internationally at prestigious tournaments authorized by the BWF. Eight of the elite players were at least quarter- or semi-finalists in previous Olympic Games and/or World Championships, and all 12 of them had won at least one BWF championships or multi-sport event (such as Asian Badminton Championship, Asian Games, Commonwealth Games), BWF Super Series or BWF Grand Prix. In comparison, the sub-elite players had achieved international success during their junior years, having reached the finals of continental tournaments and/or Asia/World Junior Championships, with most of them having been medal winners. The sub-elite players are regarded as potential Malaysian representatives in future Olympic Games by BAM.

All players were familiar and well practised with the test protocols and procedures, which are part of their regular serial physical fitness assessments. Care was taken to advise the players to avoid high-intensity and strenuous training within 24 h of their scheduled test. Aside from skinfold measurements for estimating body fatness, the battery of physical performance tests was undertaken over two separate occasions, at least one day apart to minimize the effect of residual fatigue on the subsequent test results (Figure 1).

Basic anthropometry

Standing height was measured using a wall-mounted stadiometer with a horizontal head board. Players stood barefoot, feet together, and were requested to "stand tall". Height was measured to within 0.1 cm. We used a beam balance to measure body mass that was regularly calibrated with known weights and accurate to 100 g. Arm span was measured from the tip of the middle finger of one arm to the tip of the middle finger of the other arm, with the players standing with their back to the wall. Arm span was recorded to the nearest 0.1 cm with both arms abducted to approximately 90°, the elbows and wrists extended, and the palms facing forward. Each measurement was completed in the morning before breakfast and after voiding urine. The skinfold measures were taken at seven sites using a Harpenden skinfold calliper (British Indicators, UK) based on protocols described in the International Society for the Advancement of Kinanthropometry's assessment manual (ISAK, 2001).

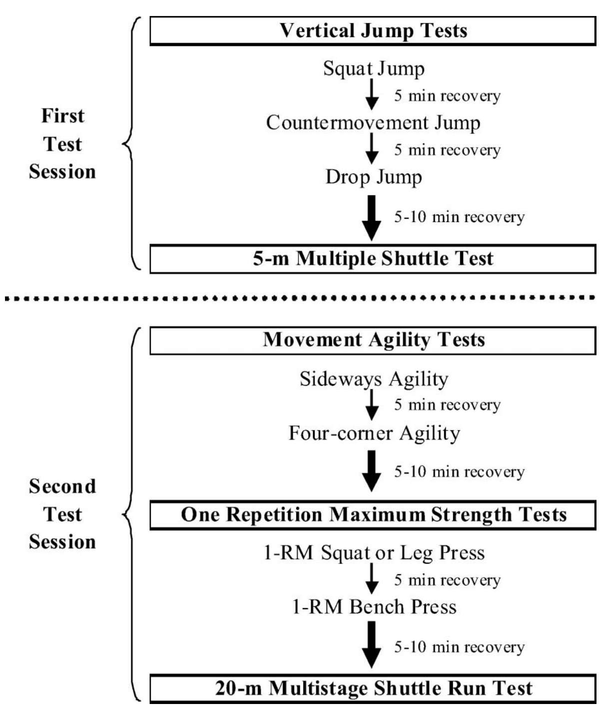

Figure 1. The order of physiological performance tests in the present study.

Field-based physiological assessments

The first test session consisted of vertical jump tests, followed by a 5-m multiple shuttle run test. At the second test session, the participants undertook the badminton-specific movement agility tests, before proceeding to one-repetition maximum strength tests, and finally the 20-m multi-stage shuttle run test (Figure 1). There was at least 5–10 min of rest between tests on each test occasion. Players were asked to perform shuttle run tests and the badminton-specific movement agility tests with their usual competition court shoes. The tests included in the physical/physiological performance test battery and associated protocols are as follows:

Vertical jump tests. A series of vertical jump tests that included a squat jump, countermovement vertical jump, and drop jump from a height of ~42.5 cm (step box) was performed sequentially (Markovic, Dizdar, Jukic, & Cardinale, 2004). A portable contact timing mat system (Swift Performance Equipment, Australia) was used to measure the time between the feet leaving the mat and landing on the mat. Players performed at least five trials for each vertical jump test with approximately 10 s recovery between trials; approximately 5 min of rest was allowed between tests. Players were instructed to execute all vertical jumps with their hands on the hips to diminish upper body movement and standardize the movement pattern. The squat jump was performed after a squat position was assumed for 3–5 s with the knee joint angle at approximately 90° and with no countermovement. The countermovement jump commenced from a standing position followed by rapid flexion of the legs to a squat position that was immediately then followed by extension of the legs as fast and as powerfully as possible. During the drop jump, players were reminded to rebound as "quickly" and as "high" as possible once in contact with the mat, subsequent to the drop from the step box. The players were encouraged to perform with maximal effort throughout the tests with the highest score in each of the three vertical jump tests being used for analysis. The jump heights of squat and countermovement jumps, as well as the body mass of the players, were used in the equations developed by Sayers and colleagues (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999) to compute the estimated power required to perform the jump.

One-repetition maximum strength tests. One-repetition maximum (1-RM) bench press and squat or leg press tests were employed for the determination of upper body and lower body strength (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997). These tests were performed with a standard Olympic bar and weights. These maximum strength tests required the players to start lifting a weight of approximating 50% of their estimated 1-RM based on their training loads. The weight was increased by 2.5–10.0% depending on the perceived exertion of the players. The rating of perceived exertion (RPE) was determined using Borg's RPE category-ratio scale (0–10) (Borg, 1982). A weight increment of 6.0–10.0% and 2.5–5.0% was applied for a RPE of ≤ 6 and > 6, respectively. As the effort to lift the weight increased, smaller increments were made. When the player could only successfully lift the weight once with proper technique, this weight was considered the player's maximum absolute strength (1-RM) and expressed in kilograms. Relative strength was calculated by dividing the absolute strength (kg) by the player's body mass (kg). Players rested for 3–5 min between attempts to produce a 1-RM measure of strength.

Badminton-specific movement agility tests. These agility tests were conducted on a singles badminton court setting and required rapid sideways shuffling (sideways agility test) and forward/diagonal four-corner movements (four-corner agility test) with abrupt changes in direction (Figure 2). The tests were modified from the general movement speed and specific badminton speed tests as described by Hughes and Bopf (2005). During both agility tests, the players assumed their badminton playing ready position on the central base of the court facing the net (without a racket in hand). The test was started and hand timing was commenced immediately the players began to move from the central base. For the tester to stop the stopwatch and for a trial to be valid, at least one of the player's feet had to return to the central base. The sideways agility test required the players to shuffle laterally across the width of the court for a total of 10 repetitions, and to strike each of the up-turned shuttlecocks placed on the line that marked the outside of the single's court (Figure 2). The four-corner agility test required the players to move around the four corners of the court for a total of 16 repetitions, in an ordered sequence of four directions, and to strike each of the up-turned shuttlecocks placed at each corner (Figure 2). Before both agility tests, players were reminded to adhere to badminton-specific movements, start by moving towards the direction of their dominant hand (racket-holding hand), and to strike the up-turned shuttlecock also with their dominant hand. A minimum of two trials was undertaken with the best performance time recorded. At least 5 min recovery was allowed between the trials and tests.

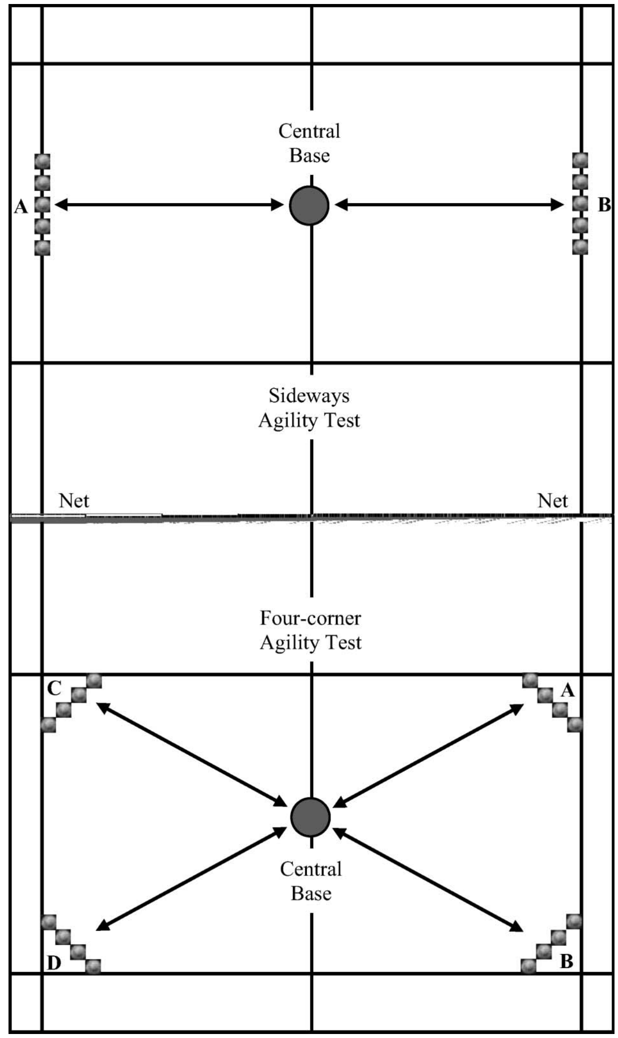

Figure 2. The set-up for the badminton-specific movement agility tests on court.
Notes: ■ = placement of shuttlecock.
Sideways agility, order of movement = Central Base → A → Central Base → B → Central Base (right-handed) or Central Base → B → Central Base → A → Central Base (left-handed), and repeat until the player strikes each of the ten shuttlecocks.

Four-corner agility, order of movement = Central Base → A → Central Base → B → Central Base → C → Central Base → D → Central Base (right-handed) or Central Base → C → Central Base → D → Central Base → A → Central Base → B → Central Base (left-handed), and repeat until the player strikes each of the 16 shuttlecocks.

Shuttle run tests. The 20-m multi-stage shuttle run test (20-m MST) was conducted in a spacious indoor gymnasium in accordance with standard protocols (Brewer, Ramsbottom, & Williams, 1988). The test involved continuous running between two lines 20 m apart according to the pace of the recorded beeps. Before the test, players stood behind one of the lines facing the other line. The test began with the first beep and the players ran to the opposite line, turning back when signalled by the second beep, and so on. The pace at the beginning of the test was relatively slow and was gradually increased after each minute (level). The test was terminated when the players were unable to maintain the required pace (within 1.5 m) for two consecutive shuttles. The total number of shuttles completed was recorded and converted to $\dot{V}O_{2max}$ equivalent scores (Brewer et al., 1988). The 5-m multiple shuttle test (5-m MST) procedures were also undertaken according to the methods described by Boddington and colleagues (Boddington, Lambert, St. Clair Gibson, & Noakes, 2001). In this test, six plastic cones were placed 5 m apart in a straight line for a total distance of 25 m. Players began the test in line with the first cone and upon an auditory signal, they sprinted 5 m to the second cone, touched the ground adjacent to that cone with their racket-holding hand, and sprinted back to the first cone, touching down on the ground adjacent to the cone with their hand again. The players then sprinted 10 m to the third cone and back to the first cone again, and then sprinted 15 m to the fourth cone and back to the first cone, and so on, until 30 s of repeated-sprint shuttle running had been completed. Players were allowed 35 s recovery during which they walked back to the starting line. This 30-s shuttle run and 35-s recovery were repeated six times and the total distance covered by each player during the 6×30-s shuttles was recorded (Boddington et al., 2001).

Data analysis

Only the best test score achieved in each test battery was included in the data analysis. Data are presented as means ± standard deviations (*s*) and range (min–max). Comparison of physical and physiological performance data between elite and sub-elite players was carried out using independent *t*-test. Statistical significance was set at $P < 0.05$ and all the analyses were computed using SPSS 16.0 for Windows (SPSS Inc., USA).

Table I. Physical characteristic and world ranking of the participants.

	Elite	Sub-elite	*P*-value
Age (years)	24.6 ± 3.7 (19.8–31.3)	20.5 ± 0.7 (19.2–21.4)	0.003
Body mass (kg)	73.2 ± 7.6 (63.6–89.0)	62.7 ± 4.2 (57.2–69.9)	<0.001
Standing height (m)	1.76 ± 0.07 (1.65–1.88)	1.71 ± 0.05 (1.61–1.78)	0.034
Arm span (cm)	177.6 ± 7.7 (165.8–190.3)*	173.0 ± 6.5 (160.1–181.8)	0.141
Body mass index ($kg \cdot m^{-2}$)	23.5 ± 2.0 (21.0–26.6)	21.6 ± 1.4 (19.4–24.3)	0.012
Body fat (%)	12.5 ± 4.8 (5.9–19.6)	9.5 ± 3.4 (6.1–17.3)#	0.095
Lean body mass (kg)	63.6 ± 5.8 (55.1–57.4)	56.3 ± 4.1 (50.7–63.9)#	0.002
Estimated $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.9 ± 3.7 (50.8–64.0)	59.5 ± 5.2 (50.8–69.5)	0.168
BWF world ranking	6 ± 3 (2–11)	110 ± 41 (46–175)	–

Note: Values are mean ± *s* (min–max); $n = 12$ for each of the elite and sub-elite groups (except $^{\#}n = 11$ and $^{\star}n = 10$). Body fat was computed based on the sum of seven skinfold thicknesses. Estimated $\dot{V}O_{2max}$ = maximal oxygen uptake predicted from 20-m multi-stage shuttle run test; BWF world ranking = the highest Badminton World Federation world ranking achieved by the players during the test sessions.

Table II. Absolute strength and lower body power of Malaysian male badminton players.

	Elite	Sub-elite	*P*-value
1-RM bench press (kg)	76.9 ± 9.9 (60.0–96.6)	66.0 ± 10.3 (52.4–79.1)	0.015
1-RM bench press ($kg \cdot kg^{-1}$ BM)	1.05 ± 0.13 (0.80–1.23)	1.05 ± 0.13 (0.91–1.26)	0.933
1-RM squat (kg)	143.2 ± 17.3 (118.6–172.0)	129.9 ± 14.1 (110.0–155.7)#	0.087
I-RM squat ($kg \cdot kg^{-1}$ BM)	1.98 ± 0.35 (1.44–2.71)	2.05 ± 0.20 (1.6–2.24)#	0.634
SJ height (cm)	42.7 ± 5.2 (35.0–50.0)	41.5 ± 5.2 (35.0–51.0)	0.589
SJ power (W)*	3851 ± 431 (3281–4526)	3306 ± 377 (2807–4207)	0.003
CJ height (cm)	46.3 ± 5.4 (38.0–57.0)	46.0 ± 3.7 (41.0–53.0)	0.861
CJ power (W)*	3977 ± 385 (3457–4629)	3448 ± 304 (2918–4162)	0.001
SJ:CJ ratio	1.09 ± 0.05 (1.02–1.18)	1.11 ± 0.07 (1.00–1.26)	0.275
DJ height (cm)	34.4 ± 5.5 (26.0–45.0)	32.6 ± 4.4 (27.0–41.0)	0.378
DJ contact time (s)	0.23 ± 0.01 (0.19–0.25)	0.23 ± 0.00 (0.23–0.24)	0.955
DJ reactive speed ($m \cdot s^{-1}$)	1.50 ± 0.33 (1.15–2.36)	1.41 ± 0.19 (1.16–1.78)	0.409

Note: Values are mean ± *s* (min–max); $n = 12$ for each of the elite and sub-elite groups (except $^{\#}n = 8$). 1-RM = one-repetition maximum; BM = body mass; SJ = squat jump; CJ = countermovement jump; DJ = bounce drop jump from a height of ~42.5 cm. *Estimated peak mechanical power using the equations of Sayers et al. (1999).

Results

All 24 players undertook the test battery and none reported any injury that may have affected their performance. In several instances, a complete set of data on a test item was not collected on all players as indicated in Tables I, II, and IV. Since these physical fitness performance tests had been conducted regularly in a serial fashion over several years, we are confident that all players were well practised in performing to their best ability. The elite group consisted of superior badminton players compared with the sub-elite group. All the elite players were in the top 11 positions of the world rankings during the course of the study, and thus their rankings were higher than those of the sub-elite players.

The physical characteristics and world ranking of the players during the study period are presented in Table I. Malaysian elite and sub-elite male badminton players differed in age, body mass, standing height, body mass index, and lean body mass, with the former being significantly taller and heavier. However, the two groups did not differ in terms of arm span, percentage of body fat, and cardiorespiratory fitness as indicated by the estimation of $\dot{V}O_{2max}$ from the 20-m multi-stage shuttle run test.

Table II shows the absolute strength and lower body power performance of the players. Elite players were able to exert more force than sub-elite players during the 1-RM bench press ($P = 0.015$) and squat ($P = 0.087$). We did not observe a significant difference in their vertical jump height as measured in vertical jump performance (squat jump, countermovement jump, and drop jump). However, the estimated power of the squat ($P = 0.003$) and countermovement ($P = 0.001$) jumps were both statistically higher in elite players.

There was no significant difference between the two groups of players in either aerobic or anaerobic capacity as determined by the shuttle run tests (Table III). However, sub-elite players tended to perform the 20-m multi-stage shuttle run test better than the elite players ($P = 0.094$).

There was no apparent difference between elite and sub-elite players in the time taken to execute the badminton-specific movement agility tests, which required rapid changes in direction and speed of movement on the badminton court (Table IV). While sub-elite players were inclined to be faster in lateral movements across the width of the court, elite players were superior in shuffling around the corners of the court.

Discussion

The physical fitness test battery used to develop the physiological profile data in this study is based on the perception that specific tests define the attributes required of elite badminton players. Despite a number of reports (Baum et al., 1997; Chin et al., 1995; Hughes & Fullerton, 1995; Wonisch et al., 2003) on the validity of tests to determine the physiological characteristics of elite badminton players, there is no consensus as to the most appropriate tests that should be employed. Many of the tests are common to talent identification in other sports (basketball, squash, volleyball), with some similarity in patterns of movement. It is axiomatic that a sport that involves jumping, lunging, short, quick shuffling patterns of movement, and an ability to repeat these physical movements in rapid succession should use tests that replicate in part some of these patterns of movement to identify talent. Of course, performance on such a test battery alone

Table III. Shuttle run performance of Malaysian male badminton players.

(A) Elite vs. sub-elite players	Elite ($n = 12$)	Sub-elite ($n = 12$)	*P*-value
20-m MSR (# shuttles)	118 ± 13 (96–144)	129 ± 18 (96–165)	0.094
5-m MST (m)	735.2 ± 24.3 (700.0–775.0)	734.8 ± 34.7 (680.0–780.0)	0.973
(B) Singles vs. doubles players	Singles ($n = 10$)	Doubles ($n = 14$)	*P*-value
20-m MSR (# shuttles)	135 ± 16 (109–165)	115 ± 10 (96–133)	0.001
5-m MST (m)	752.8 ± 21.2 (720.0–780.0)	722.3 ± 28.2 (680.0–775.0)	0.009

Note: Values are mean ± *s* (min–max). 20-m MSR = 20-m multi-stage shuttle run test; 5-m MST = 5-m multiple shuttle test.

Table IV. Badminton-specific movement agility of Malaysian male badminton players.

	Elite	Sub-elite	*P*-value
10-rep sideways agility (s)	15.3 ± 0.7 (14.3–16.0)	15.0 ± 0.6 (14.0–15.9)	0.282
16-rep four-corner agility (s)	32.4 ± 1.1 (30.8–33.8)	32.9 ± 1.8 (29.3–36.3)	0.530

Note: Values are mean ± *s* (min–max); $n = 7$ for elite and $n = 12$ for sub-elite group. rep = repetitions.

does not readily identify talented players, as there are many other factors that we did not test that are likely to contribute to being an elite badminton player (e.g. tactics, finesse, deftness). Nevertheless, we believe that the present results advance our understanding of the physical fitness attributes of elite badminton players versus sub-elite players.

Physique of elite badminton players

The standing height of Malaysian elite badminton players was similar to those reported in Indian national-calibre badminton players (Majumdar et al., 1997). However, Malaysian elite players and Indian national players are shorter than the top Chinese and European badminton players (Chang et al., 2006; Faccini & Dal Monte, 1996; Zakaria et al., 2008). Malaysian elite players had a higher body mass than reported for these Indian, Chinese, and European players. The Malaysian elite badminton players were taller, have a greater body mass, greater lean body mass, and are older than their sub-elite counterparts. Since the mean age of the sub-elite players was $\sim$20 years, it is unlikely that their height will increase. It would appear that possessing a tall stature is likely to be advantageous for badminton success, as it contributes to the ability to reach and cover more of the court. However, this is only one of a number of factors enabling court coverage and there is a common contention that stature is not a critical determinant of success in badminton (Reilly, 1997).

Maximal strength and power

Malaysian elite badminton players had a greater absolute upper body strength (bench press) than the sub-elite group, which reflected the differences in lean body mass. However, the 10% greater absolute strength in elite players during the squat test was not statistically different from the sub-elite players. When the maximal strength test data were normalized for body mass, the relative upper and lower body strength measures (absolute strength $\div$ body mass) were similar between the elite and sub-elite players. These test results suggest that strength alone is not important in discriminating elite from sub-elite badminton players. However, strength is an essential component in power production and thus a contributor to vertical jump performance, which intuitively appears to be important for success in badminton.

When vertical jumping power was calculated from the body weights and vertical jump displacements, we found that peak instantaneous power output during both the squat and countermovement jumps was significantly higher in the elite than the sub-elite players. These results could be possibly associated with higher body mass as well as long-term adaptation induced by the badminton-specific training in elite players (Andersen et al., 2007). However, there was no significant difference in jump heights based on vertical jump performance between the two groups of players. Given that the relative strength was similar and vertical jump height was similar between the two groups, it can be speculated that the contractile velocity of the active muscles must have been similar for both groups of players. Future research should analyse the kinematics of ballistic movements in badminton players of various standards to determine what are the optimal muscle strength and power required for highly competitive badminton players.

Shuttle run performance

The mean $\dot{V}O_{2max}$ of 56.9 ml · kg^{-1} · min^{-1} ($s =$ 3.7) for Malaysian elite badminton players, as predicted from the 20-m multi-stage shuttle run test, was very similar to that reported for British elite players (57 $\pm$ 4 ml · kg^{-1} · min^{-1}: Hughes, Andrews, & Ramsay, 2003) but lower than that for elite Chinese (63.4 ml · kg^{-1} · min^{-1}, $s = 4.0$: Chin et al., 1995; 61.6 ml · kg^{-1} · min^{-1}, $s = 4.3$: Chang et al., 2006) and Danish (63–65 ml · kg^{-1} · min^{-1}: Andersen et al., 2007; Omosegaard, 1996, 2005) badminton players. The relatively low $\dot{V}O_{2max}$ values observed in the present study may reflect the differences in methods and protocols used to measure $\dot{V}O_{2max}$ across the studies cited. For example, in the present study, $\dot{V}O_{2max}$ was estimated from 20-m multi-stage shuttle run performance, whereas other studies used indirect calorimetry to determine the $\dot{V}O_{2max}$ of players during an incremental continuous treadmill run to exhaustion.

It should be noted that most of the Malaysian sub-elite group tended to perform better than their elite counterparts in terms of total shuttles completed in the incremental shuttle run test (Table IIIA). The sub-elite group also performed equally well as the elite group in the 5-m shuttle run test, which arguably is a measure of "match-related fitness". It is plausible that a lower body mass in sub-elite players might have enabled them to change direction more easily than the heavier elite players from a biomechanical perspective, and consequently resulted in better performance in shuttle run tests. We would like to emphasize that both groups of badminton players recruited in the present study were a combination of players from both singles and doubles disciplines. Generally, singles players would display a better endurance fitness due to a higher physiological demand of the singles game, as well as badminton-specific training that required the players in this specialization to cover more court area, make more intense strokes and movements, and play relatively longer rally times (Liddle, Murphy, & Bleakley, 1996). This contention is further supported by a comparison of the shuttle run performance between the singles and doubles players in the present study (Table IIIB), which revealed that singles players were able to perform approximately 17% and 4% better than doubles players in the 20-m and 5-m shuttle run test, respectively.

Badminton-specific movement agility

Notational analysis of European players during international tournaments indicated that badminton can be characterized by repetitive, short-duration, high-intensity efforts with high-frequency movement (Cabello-Manrique & Gonzalez-Badillo, 2003). These characteristics of international badminton suggest that to succeed in elite competition, players need to demonstrate a high level of performance in tests purported to assess these characteristics. However, our data show that there were no significant differences in badminton-specific movement speed between the elite and sub-elite players (Table IV). This finding might be attributable to the similarity in maximal isoinertial and reactive strength of the lower body of both elite and sub-elite players, despite the estimated power outputs for both squat and countermovement jumps being substantially different between the two groups (Table II). Although Hughes and Bopf (2005) reported no association between the vertical jump (with countermovement) and badminton-specific movement speed tests, further analysis of the pooled data on countermovement height and badminton-specific movement agility tests in the present study showed otherwise. We found that 63% and 49% of the variance in sideways and four-corner agility test results, respectively, was significantly associated with countermovement jump test performance. Future research should address this inconsistency with a greater cohort of badminton players from various disciplines (singles vs. doubles/mixed events). Perhaps studies focusing on the measurement and evaluation of skeletal dimensions that are known to be related to ethnicity might help to explain the differences in agility performance.

Conclusion

In conclusion, this study shows that elite male Malaysian badminton players are taller, heavier, and stronger (in absolute terms) than their sub-elite counterparts. The difference in strength (upper and lower limb) was not apparent when normalized to body mass. There were no differences in a range of other physiological attributes between elite and sub-elite Malaysian male badminton players, as determined by specific physical performance tests. This test battery, therefore, did not allow us to discriminate between the elite and sub-elite players, suggesting that the tests either did not test specific physiological attributes important to badminton performance, or that at the elite level of the sport, other factors such as tactical knowledge, technical skills, and psychological readiness are possibly of more importance.

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