Physical and physiological profiles in badminton athletes

***Darren L Richardson**, BSc, MSc, and **Michael J Duncan**, BA (Hons), PgCert, MPhil, PhD, FBASES, Centre for Applied Biological and Exercise Sciences, Coventry University*

OVERVIEW

Badminton is a physically demanding racket sport, played internationally, requiring high levels of physical fitness. The physical and physiological demands of badminton require athletes to be proficient in several aspects of fitness. This review fills a gap in the scientific literature by critically exploring the physical and physiological characteristics of badminton athletes; it also presents implications for training and future research.

Elite level badminton athletes are generally taller and heavier than non-elite athletes, with both groups possessing relatively low body fat percentages. There is some variation in the maximal oxygen uptake of badminton athletes, but the majority of data suggest that these athletes present moderate to high levels of cardio-respiratory fitness. It appears that good levels of strength, flexibility and agility are important in supporting the physical, technical and tactical demands of badminton. However, these conclusions have been drawn from the small body of literature that exists relating to these components of fitness in badminton. More extensive research is therefore required into the physical and physiological characteristics of badminton athletes to extend existing knowledge and better develop specialised conditioning programmes within the sport.

Introduction

Badminton is a racket sport played by more than 200 million people world-wide,[16] and it has been an Olympic sport since 1992.[25] Following the rule change in 2006 a competitive match is played as the best of three games with every serve resulting in a point: the player winning the rally serves for the subsequent point. When one player/team reaches 11 points in each game, there is a 60 second interval and a further two-minute interval between games. The first player/team to reach 21 points wins the game. In the event that the game reaches 20-all, the player/team that gains a 2-point lead first wins that game and in the event that the game reaches 29 all, the first player/team to win the 30th point wins the game.[4]

Badminton is described as a high-intensity, intermittent sport,[17] requiring large amounts of technical skill,[37] mental acuity, psychological preparation, tactical awareness and game strategy.[11] Some of the most important aspects of fitness required for badminton highlighted in the literature include: speed, agility, stamina, strength, endurance,[11] flexibility[45] and power.[9]

At the elite level, competitive matches last approximately 33 minutes,[17] but can last for as long as an hour.[47] In singles, the court dimensions are 6.70m x 5.18m: in doubles they are slightly larger (6.70m x 6.10m).[17] Elite male singles players cover an average of 1,862m and elite male doubles players 1,108m per game.[30] Rallies last between 6.4–12.9 seconds, with an average of 6.1 shots played per rally.[8]

Badminton utilises both aerobic and anaerobic metabolism, with the dependency on each system varying with length of the rally and shot selection.[11] It is believed that the prevalent method of energy production during high-intensity, short rallies is anaerobic metabolism,[9] with 85-90% of rallies utilising the phosphocreatine system.[7] For longer, moderate to high intensity rallies, however, the aerobic system supplies the energy[33] and it also promotes recovery in the breaks between points.[47] This results in around 70% of energy for badminton being delivered by the aerobic energy system[11] and the remaining 30% being delivered by the anaerobic systems.[15]

An understanding of the physical characteristics in a given sport modality is important as it contributes to distinguishing differences between athletes.[9] Furthermore, the study of physiological variables such as lactate production and heart rate (HR) has been important in determining energy system usage and energy expenditure,[2,50] which further contribute to an understanding of the demands of the sport and can be used in the development of athlete training programmes[25] to improve sport specific fitness.[20]

The objective of this review is to present, examine and critique the current data on the physical and physiological characteristics of badminton athletes, whilst highlighting possible areas for further research. This review will assist strength and conditioning (S&C) coaches to understand the demands of badminton and help to facilitate the development of effective training programmes and therefore enhance the performance of their athletes.

Methods

The articles included in this review were identified by a systematic search using PubMed, Google Scholar and EBSCO Host using the following keywords: 'badminton', 'badminton AND characteristics', 'badminton AND physiological' ,'badminton AND performance', 'badminton AND fitness', 'badminton AND aerobic fitness', 'badminton AND anaerobic fitness', 'badminton AND agility' and 'badminton AND strength'. This electronic search was also backed up by manual inspection of the reference list of all relevant journal articles found for additional articles that matched the keywords or themes of this review. The themes of the review were included to represent the components that support the physical and physiological demands of badminton match play. These included: aerobic fitness, anaerobic fitness, flexibility, agility, HR, strength, endurance, anthropometric data and body composition. Both male and female data were collected for senior and junior athletes at both the elite and non-elite level in order to draw comparisons between groups at all levels of competition. Fifteen English-language, peer reviewed articles – examining some or all of the above mentioned fitness components – met the inclusion criteria and were included in this review.

Physical and physiological characteristics

HEIGHT

Previously, anthropometrical measures have correlated well with sporting performance, with height being identified as a pre-requisite for elite performance in many sports.[47] It is suggested that elite badminton athletes are taller than non-elite athletes, providing superior ability to reach the shuttle[29] and cover the court.[37] Gucluover and Esen[25] concluded that height was one of the distinguishing characteristics between elite and non-elite level; however, Reilly[40] argues that height is not a critical factor in determining success, as other aspects of performance such as strength, agility and flexibility, can compensate for smaller stature.

Table 1 shows the height of badminton athletes and reveals that on average elite male badminton athletes are ~5cm taller than their non-elite counterparts. Unfortunately, not enough data exist in the literature to be able to draw comparisons between female elite and non-elite athletes. Elite male youth players are on average ~9cm taller than non-elite male youth players, but only a ~1cm height difference existed between junior elite and non-elite females. When examining variables for junior athletes, it is important to remember that the age range considered to be 'junior' in the literature varies widely, from young adolescents to nearly adult age (Table 1, on page 15), which will impact anthropometric data due to the effect of puberty. The data presented in this review largely agree with Jeyaraman and Kalidasan[29] that athletes who are taller are more likely to reach the elite level in badminton, although height appears similar in junior elite and non-elite female athletes in the few studies that exist.

BODY MASS AND COMPOSITION

Body mass has been highlighted as a variable for predicting playing ability in intercollegiate badminton athletes,[29] with the elite generally being heavier as well as taller than their non-elite counterparts.[37] This extra mass is accounted for as muscle, because extra fat in sports such as badminton, where the body is repeatedly lifted against gravity, is a disadvantage[41] as it reduces court mobility and jump height.[32] Gucluover and Esen[25] concluded that there were no significant differences in mass between women from different countries competing in the European team badminton championship, suggesting that elite level body mass may fall into a narrow range.

Table 1 reveals that elite male badminton athletes are on average ~7kg heavier than their non-elite counterparts. Again, there is insufficient data in order to compare elite and non-elite female athletes. Elite junior males were on average ~6.5kg heavier than non-elite junior males, but there were no differences in body mass between the elite and non-elite junior females.

This review demonstrates that elite senior and junior male badminton athletes have a greater body mass than non-elite athletes, whereas elite and non-elite junior females are alike; in general, all groups have low body fat percentages (Table 1). As can be seen from Table 1, there are few studies which compare accurately body fat percentages between groups. There was less than 0.5% difference between elite and non-elite male body fat percentages. Elite male juniors were around 6% less body fat than the non-elite group of Spanish juniors. Heller[27] calculated a group of elite females body fat at 9.2% using 10 site skin fold measures, which is very low and possibly unhealthy;[21] body fat levels that low in female athletes could be an indicator of deliberate low calorie consumption or eating disorders, which could possibly lead to conditions such as amenorrhoea and osteoporosis.[6]

Female junior elite athletes' body fat percentages differed by ~10% between groups, which may vary so widely due to age ranges of the junior females between studies.

Based on the limited anthropometric and body composition data available it is hard to draw valid conclusions, so it is recommended that more studies look further into the anthropometric characteristics of successful badminton athletes. From the studies in this review for the male game at least, it could be favourable for a badminton athlete to be of above average height, but no evidence exists for this assumption in the female game, mainly due to a lack of investigation. Because of variances in height, age and sex, an ideal body mass cannot be recommended, but in this review and in agreement with the review by Phomsoupha and Laffaye[38] it could be favourable for badminton athletes to have a low, but healthy body fat percentage in the ranges of 10–13% for elite males, sub-elite males and junior males, ~18–19% for females and ~14–15% for junior females.

HEART RATE

HR is a useful physiological variable to study as it can help to establish energy expenditure and calorific needs of athletes.[8] All data collected across genders, ages and abilities show that badminton elicits near maximal HRs (Table 2). Badminton has previously been reported to elicit average HRs of over 90% of an individual's maximum,[38] with simulated match play eliciting max HR values of ~186 beats·min^{-1}.[28] Furthermore, badminton has been shown to elicit high maximum and average HRs throughout a game, which proves that athletes endure significant cardiovascular strain[33] which is comparable between all groups.[18] The data collected in this review show that both during match and simulated match play, badminton elicits near

Table 1: Age, anthropometric and body composition data of badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	AGE (YEARS)	HEIGHT (CM)	MASS (KG)	BODY FAT (%)	REFERENCE
MALE						
Elite junior	8	-	180.4 ± 8.1	73.4 ± 9.7	9.6 ± 1.6	(49)
Elite	4	21.3±1.7	177.0 ± 2.0	70.3 ± 5.5	-	(18)
Malaysian elite	12	24.6±3.7	176.0 ± 0.1	73.2 ± 7.6	12.5 ± 4.8	(37)
Malaysian sub-elite	12	20.5±0.7	171.0 ± 0.1	62.7 ± 4.2	9.5 ± 3.4	(37)
Brazilian junior	10	17.2±1.9	172.4±0.5	68.0±7.8	-	(9)
Youth elite	8	16.0±1.4	177.0±4.3	68.5±5.6	-	(20)
Indian national (gender not specified)	8	26.4±1.8	167.9±3.3	63.4±5.5	-	(22)
National	6	24.3±4.1	175.4±5.4	64.8±6.9	12.1±3.4	(33)
Intercollegiate	84	18-24	175.0±5.7	68.7±20.1	-	(29)
National and international	17	26±8	179.0±7.0	74.0±10.0	-	(51)
Spanish junior	12	16.5±3.7	170.8±11.2	61.1±16.7	12.0±2.8	(39)
Elite	8	26.5±4.2	184.1±9.7	78.9±6.5	-	(7)
Elite junior	29	17.2 ± 1.2	183.2 ± 5.5	71.2 ± 7.4	6.1 ± 2.6	(27)
Elite	25	21.3 ± 2.2	182.0 ± 4.3	75.1 ± 3.6	8.3 ± 2.6	(27)
FEMALE						
Elite junior	7	-	161.2 ± 4.3	58.1 ± 7.9	19.2 ± 4.5	(49)
Elite	8	21.8±2.1	166.0 ± 5.0	59.8 ± 6.8	-	(18)
Brazilian junior	10	15.2±2.1	163.8±0.3	61.7±6.9	-	(9)
Youth elite	8	16.0±2.3	165.0±6.7	58.0±4.3	-	(20)
Youth elite	14	16.9±1.6	165.2±5.5	56.0±5.7	22.8±6	(25)
Youth amateur	15	16.1±0.6	161±4.7	53.2±4.9	23.5±3.4	(25)
Spanish junior	7	13.3±1.7	165.4±3.6	59.3±5.2	15.5±3.1	(39)
Elite	6	24.3±3.2	169.5±5.1	63.3±4.1	-	(8)
Elite junior	16	17.6 ± 0.8	165.8 ± 4.6	59.6 ± 6.0	12.7 ± 3.7	(27)
Elite	10	24.5 ± 2.5	167.1 ± 7.3	58.7 ± 8.3	9.2 ± 3.6	(27)
MIXED						
International (1 female)	11	21.8±3.3	175.2 ± 6.8	67.5 ± 8.7	-	(8)

Table 2: HR data during match or simulated match play for badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	MAX HR (BEATS·MIN-1)	REFERENCES
MALE			
Elite	4	166±6 (Average)	(18)
Youth elite	8	170±9 (Average)	(20)
National	6	183±6	(33)
Indian national (gender not specified)	8	197±7	(22)
National and international	17	195± 6	(51)
Spanish junior	12	195±5	(39)
National and international	28	191±9	(7)
Junior international	8	198 ± 7	(27)
Junior national	21	194± 8	(27)
Senior international	9	189 ± 8	(27)
Senior national	16	187 ± 9	(27)
FEMALE			
Elite	8	170±10(Average)	(18)
Youth elite	8	174±7(Average)	(20)
Spanish junior	7	201±3	(39)
National and international	26	193±9	(7)
Senior international	9	203 ± 8	(27)
Senior national	17	198.1 ± 9	(27)
MIXED			
International (1 female)	11	191±6	(8)
Elite (6 males, 6 females)	12	187±8	(11)

maximal HR values.[1,22,28] Collecting HR is relatively easy and can be used to collect data over short bouts or long intervals of play.[14]

HR has been strongly related to oxygen consumption[23] and energy expenditure[10] and so offers a time and labour effective tool that S&C coaches can use to assess intensity of sessions when more accurate methods are unavailable due to time constraints or cost. Although understanding the HR response that badminton elicits, and measuring athlete HR during training may be useful for S&C coaches in planning training, the predominant use of phosphocreatine (PCr) as an energy source for badminton rallies potentially limits the utility of HR monitoring. In such instances, use of session RPE or other self-report metrics may provide more practically useable data for coaches to plan effective and more ecologically valid training tasks for their athletes.[39]

Furthermore, quantifying intensity based solely on max HR may not be optimal for developing effective and sport-specific coaching programmes in badminton, as max HR may only reflect one moment in a match. Moving to a monitoring process where HR is monitored throughout match play may provide a more holistic indicator of the demands of badminton.

Recent development of GPS and accelerometer-based movement systems may offer a more effective means to monitor badminton match performance as they have done in a range of team sports.[12] However, GPS systems do not work indoors and so this has led to the development of radio-frequency local positioning systems (LPS), which have been shown to overestimate distance covered indoors by ~2.7% on a non-linear course.[43] Nevertheless, this system has been deemed an acceptable tool for tracking indoor court movements in wheel chair sports,[42] but to our knowledge this system has yet to be extensively tested during indoor court sports such as badminton and squash.

BLOOD LACTATE

Blood lactate measurements have been shown to be good estimations of intensity in racket sports,[34] and can be used as an indirect marker of energy supplied from glycolysis.[31] Faccini and Dai Monte[15] concluded that 60-70% of the energy yield in badminton is from the aerobic system while the other 30% is from the anaerobic systems, which may explain why multiple badminton studies have shown moderate levels of lactate production (~5mmol·L^{-1}).[22] Due to the intermittent nature of badminton, lactate levels may be low, as there is time for oxidation of muscle lactate in the rest periods between points[15] Furthermore, badminton athletes have a high level of aerobic capacity gained through previous training,[8] which could reduce reliance on the anaerobic systems and therefore reduce production of lactate.

As can be seen from Table 3, lactate values for both males and females vary largely. Although females appear to have lower mean lactate production than males, it is probable that this is due to a small sample size, as direct comparisons have found no significant differences in lactate production between genders.[18, 20]

With the exception of data from Heller,[27] most of the recorded blood lactate data seems to be fairly low considering the high HR responses observed, which implies PCr contributes to energy production. This is especially so when compared with squash, which elicits similar HR responses but a higher average lactate response (~8mmol),[24] probably due to the shorter work to rest ratios observed in squash.

However, caution must be taken when interpreting the data in Table 3 as factors such as individual fitness level, age and training status[38] – as well as method and the time at which the samples were taken – may affect lactate values.[20] For example, the blood lactate values from Heller[27] were taken from the fingertip three minutes after cessation of activity, and samples taken by Faude et al[18] were from the ear lobe before, during and after exercise and average lactate values were reported. Feliu et al[19] reported that lactate concentrations taken from the fingertip were significantly higher than those from the ear lobe when samples were taken at the same time.

In conclusion, although previous authors have reported blood lactate responses during badminton, its utility as a metric to assist coaches in planning training is open to question. Blood lactate values taken during badminton at best reflect whether a particular energy system is being utilised at a given moment. Given the huge variation in lactate values reported (Table 3), it is extremely difficult to discern a consistent pattern for blood lactate responses in badminton and it is likely the previously published data reflect the aforementioned point. In an intermittent sport such as badminton it is likely that blood lactate will vary considerably throughout game play and, in isolation, blood lactate data may not contribute much to help the S&C coach.[38]

MAXIMAL OXYGEN UPTAKE (VO_2MAX)

It is suggested that approximately 60-70% of the energy required for badminton comes from the aerobic energy system;[15,38] badminton performance, therefore, has a considerable aerobic component.[15] Data from VO_2max testing in badminton athletes are important in understanding the maximum rate of oxygen consumption of top badminton athletes, so that training programmes can be designed to help athletes reach that level.

Table 4 shows elite and non-elite adult male athletes both had a VO_2max of ~60 ml·kg^{-1}·min^{-1}, which is higher than those typically found in squash (54.4 ml·kg^{-1}·min^{-1})[24] and tennis (57.3 ml·kg^{-1}·min^{-1}).[46]

Table 3: Max lactate (mmol·L-1) of badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	MAX LACTATE (MMOL/L)	REFERENCES
MALE			
Elite	4	1.9 ± 0.1 (*Average)	(18)
Youth elite	8	3.2 ± 1.8 (*Average)	(20)
National	6	4.7 ± 1.9	(33)
National and international	17	7.6 ± 2.1	(51)
Spanish junior	12	3.2 ± 2.0	(39)
National and international	12	3.9 ± 2.2	(7)
International junior	8	11.3 ± 1.3	(27)
National junior	21	12.3 ± 1.8	(27)
International senior	9	12.0 ± 1.9	(27)
National senior	16	10.4 ± 2.5	(27)
FEMALE			
Elite	8	1.9 ± 0.9 (*Average)	(18)
Youth elite	8	2.5 ± 1.3 (*Average)	(20)
Spanish junior	7	3.3 ± 1.1	(39)
National and international	11	2.4 ± 1.0	(7)
International senior	9	10.5 ± 1.5	(27)
National senior	17	12.2 ± 1.6	(27)
MIXED			
International (1 female)	11	3.8 ± 0.1	(8)
Elite (6 males, 6 females)	12	10.4 ± 2.9	(11)

* (Average) indicates lactate values measured multiple times and averaged out

Table 4: VO_2max data for badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	VO2 MAX (ML. KG-1. MIN-1)	REFERENCES
MALE			
Elite junior	8	50.7 ± 3.0	(49)
Elite	4	61.8 ± 5.9	(18)
Malaysian elite	12	56.9 ± 3.7 (Estimated)	(37)
Malaysian sub- elite	12	59.5 ± 5.2 (Estimated)	(37)
Brazilian junior	10	49.7±2.5	(9)
National	6	55.7±4.4	(33)
Indian national (gender not specified)	8	57.4±7.0	(22)
Spanish junior	12	58.2±6.1	(39)
International junior	8	67.0 ± 3.3	(27)
National junior	21	63.7 ± 4.3	(27)
Senior international	9	62.4 ± 3.2	(27)
Senior national	16	63.0 ± 3.4	(27)
FEMALE			
Elite junior	7	42.0 ± 2.8	(49)
Elite	8	50.3 ± 4.1	(18)
Brazilian junior	10	42.9±3.0	(9)
Spanish junior	7	49.6±1.6	(39)
Senior international	9	54.8 ± 2.0	(27)
Senior national	17	55.2 ± 2.8	(27)

As there appears to be no difference in VO_2max between elite and non-elite athletes, it may not be a distinguishing factor for top level performance. Junior elite and non-elite males had VO_2max values that varied widely, and as VO_2max has been shown to parallel an increase in bodyweight in maturing children to adults,[13] the large differences may be found in the way VO_2max has been measured or estimated which is discussed below. There were limited data available for female players, so drawing valid comparisons between ages and ability is impossible.

VO_2max values reported by Ooi et al[37] for elite males were slightly lower than the average VO_2max values for other elite badminton athletes, whereas the non-elite males appeared to have slightly higher values (Table 4), which again suggests that VO_2max may not be a distinguishing factor between elite and non-elite badminton athletes.[40] However, it should be considered that the VO_2max values collected between studies have been estimated from different tests and protocols that have varied in mode of exercise, speed or resistance used and determination of fatigue. Few studies have stated the mode of exercise used in the VO_2max test, and neither have they disclosed details of the protocols used. One study tested on a treadmill[39] and a further employed cycle ergometry,[22] which may cause variation in values achieved, as participants are more likely to reach a higher VO_2max on a treadmill test because of a greater volume of active muscle mass.[35]

In conclusion, moderate to high VO_2max values are important in badminton, but with the elite and non-elite players both exhibiting similar VO_2max it appears that there could be a 'ceiling' to which badminton athletes reach while playing and training for badminton. As a consequence VO_2max might not be considered[9] a distinguishing factor in terms of standard of badminton performance. As there is no analysis of training that these badminton athletes are completing alongside their playing of matches, it is difficult to make recommendations as to whether VO_2max is an attribute that S&C coaches should actively try and improve, or whether this VO_2max is achieved simply by regular match play and practice. Further investigation is needed into the training loads required to help badminton athletes reach a VO_2max of around 60ml·kg^{-1}·min^{-1} in male athletes. However, as badminton is a high intensity intermittent sport, the use of high intensity interval training (HIIT) would be a useful tool to improve the VO_2max of athletes looking to gain fitness for badminton.

Flexibility

Flexibility refers to the range of movement permitted at a joint[26] and has been highlighted as an important characteristic for success in badminton,[33, 47] although very few studies have actually assessed it (Table 5). However, Gucluover and Esen[25] concluded that there were no significant differences between elite and amateur youth athletes (Table 5) and that flexibility is not a determinant of elite

Table 5: Flexibility tests used on badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	FLEXIBILITY TEST	RESULTS (CM)	REFERENCES
MALE				
Inter collegiate	84	Modified sit and reach	11.1±6.5	(29)
FEMALE				
Youth elite	14	Sit and reach	35.7±7.8	(25)
Youth amateur	15	Sit and reach	34.5±6.5	(25)

Table 6: Strength tests used on badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	TEST FOR STRENGTH	RESULTS	REFERENCE
MALE				
Malaysian elite	12	1-RM Bench press (kg)	76.9 ± 9.9	(37)
		1-RM Squat (kg)	143.2 + 17.3	
		CMJ (cm)	46.3 + 5.4	
Malaysian sub-elite	12	1-RM Bench press (kg)	66 ± 10.3	
		1-RM Squat (kg)	129.9 + 14.1	
		CMJ (cm)	46.0 + 3.7	(37)
Brazilian junior	10	CMJ (cm)	36.7 ± 6.0	(9)
Intercollegiate	84	Standing broad jump SBJ (cm)	46.5 ± 7.9	(29)
FEMALE				
Brazilian junior	10	CMJ (cm)	27.1 ± 2.1	(9)
Youth elite	14	Peak power (w/kg) (wingate test)	8.5 ± 2.8	(25)
Youth amateur	15	Peak power (w/kg) (wingate test)	8.0 ± 2.2	(25)

players. Conversely, Subramanian[47] concluded that flexibility was a top factor in determining playing ability of college level badminton players. Singh et al[45] used a Person's Product Moment Coefficient of Correlation to determine the relationship between badminton performance and selected variables such as spine and wrist flexibility in professional male badminton athletes. Based on their correlational analysis, the authors concluded that level of flexibility correlated well with badminton performance.

This shows some conflict in the literature which needs further clarification. However, it must also be noted that Singh et al[45] based their conclusions on only a moderate (r = .55) relationship between wrist flexibility and badminton performance, using a non-validated, linear (0-10) rating of badminton performance. As such, their assertions require further testing using more robust methods and analysis before confident conclusions regarding the link between flexibility and badminton performance can be made.

Strength

Badminton is considered a highly explosive sport,[28] employing strength through both the upper and lower body[37]. Therefore, it is important to understand the role strength plays in badminton performance. Omosegaard[36] suggested that there are various types of strength used in badminton, for example during acceleration and braking, muscular power is important. Hitting the shuttle requires muscular strength and the braking when landing and pushing-off towards the playing centre requires eccentric strength.

Table 6 displays the strength and power tests that have been conducted. Most of the tests have either employed a 1RM strength test of the upper and/or lower body or an explosive jump test of some kind. However, maximal strength in the arms and chest is not a great requirement in badminton as there is low resistance for the arm to overcome, the rackets are ~100g and the shuttle is extremely light, meaning that explosive and speed strength may be more desirable.[36] But it is well known that high levels of maximal strength are essential in the development of

Table 7: Agility test scores for badminton athletes (data are presented as mean±SD)

POPULATION AND COMPETITION LEVEL	SAMPLE SIZE (N)	AGILITY TESTRESULTS (S)	REFERENCE	
MALE				
Malaysian elite	12	10-rep sideways agility test	15.3±0.7	(37)
		16-rep four corner agility	32.4+1.1	
Malaysian sub-elite	12	10-rep sideways agility test	15.0±0.6	
		16-rep four corner agility	32.9+1.8	(37)
Intercollegiate	84	Semo-agility test	12.2±0.6	(29)
FEMALE				
Youth elite	14	Badminton-specific 505 agility test	2.7±0.1	(25)
Youth amateur	15	Badminton-specific 505 agility test	3.1±0.2	(25)

high power outputs in a variety of sports.[5] The development of peak power production at higher velocity and lower external loads may be more beneficial to badminton players. However, as strength underpins power, development and maintenance of strength must be considered the prerequisite before S&C coaches shift focus to the enhancement of power.

It may be stating the obvious but leg strength is the most important for badminton athletes and is essential for effective movement around the court and execution of the other dynamic movements needed in match play.[36] World class badminton athletes have been shown to have great leg strength,[41] as can be seen from 1RM squat scores in Table 6. However, it is suggested that most badminton athletes have an imbalanced quadriceps:hamstrings ratio, leading to a greater rate of knee injuries[36] which should be a consideration of S&C coaches when designing athlete training or prehabilitation programmes.

In conclusion, the literature would benefit from a greater variety of strength test data in badminton athletes. This would provide S&C coaches with a greater picture of the types and amounts of strength required by top level badminton athletes and subsequently would provide more effective guidance to coaches when designing the strength and power phases of badminton training programmes.

Agility

Agility can be defined as the ability to perform a rapid, whole body movement with a change of velocity or direction in response to a stimulus[44] and is considered important in badminton as it enables athletes to cover the court quickly.[48] In the previously mentioned study by Singh et al,[45] agility was also a physical variable that correlated well with playing performance. As can be observed in Table 7, the agility test data is hard to compare as there is little data and different studies have used different protocols.

The 505 test was originally developed for cricket as it incorporates a 180 degree turn similar to what batsmen do at the crease.[44] Gucluover and Esen[25] state they used a badminton-specific form of the 505 test, although they provided no clear explanation of how the test was made to be specific to the demands of badminton. The semo agility test mimics the badminton court: participants have to sprint forward and then back pedal diagonally.[29] The agility tests conducted by Ooi et al[37] also have badminton-style movements in them, with the 10-rep sideways agility test focusing on left to right court movements at speed and the 16-rep, four corner agility test gets participants to move to each of the four corners of the court as quickly as possible.

In conclusion, agility appears to be an important asset of a good badminton athlete; however, at the present the literature does not provide sufficient data to draw conclusions on just how important it is. The lack of badminton-specific tests used in the literature highlights the need for further investigation into how much more agile – if at all – elite badminton players are from the non-elite so that S&C coaches can better understand how much time to spend on developing this area.

Conclusions and further research

From this review it is evident that there are relatively few studies adequately examining the physical and physiological characteristics of badminton athletes. The data gathered highlight the limited information available (especially in females), with very few comparable tests for many fitness components that have been identified as important for badminton performance. This lack of data inhibits the ability to draw strong conclusions as to the optimum physical and physiological characteristics expected for high level badminton performance.

Elite badminton athletes are generally taller and heavier than their non-elite counterparts, with the majority of participants engaged in the sport having low body fat percentages. Approximately 30% of energy production comes from the anaerobic systems which elicits near maximal HR values,[15] whereas blood lactate values remain relatively low. Aerobic metabolism is very important for energy production providing ~70% of energy,[11] meaning badminton athletes have fairly high VO_2max values. Badminton also requires multiple types of strength including muscular power, strength, and endurance.[49]

Muscular endurance is a characteristic highlighted as important to badminton performance,[11] especially in the trunk, as the core muscles are involved in every movement and stroke that happens on a badminton court.[36] However, core strength does not appear to be tested in the literature and so requires the development of valid and reliable tests that are specific to the strength needs of badminton athletes.

Data relating to agility performance are also lacking in the existing literature on badminton athletes. Some of the tests used have been adapted to be badminton-specific, but there is a need for a uniform test of agility for badminton that simulates match play and sport-specific motor patterns, which could be used across studies in order for values to be compared and contrasted with ease. Flexibility is another physiological component where the data pertaining to its impact on performance are scarce. There is some debate as to which parts of the body would benefit most from flexibility development as discussed above. This needs to be further quantified and tested extensively, so clear recommendations can be given to athletes with regards to their flexibility training.

In conclusion, the data collected from studies throughout this review provide a brief insight into the favourable characteristics required by badminton athletes. Additional well-designed studies need to be conducted examining the physical and physiological characteristics of both male and female badminton athletes in order to provide greater guidance for sport scientists, coaches and S&C professionals on the construction of effective training programmes for the individual components of fitness that have been shown to be essential in high level badminton performers.

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AUTHORS' BIOS

DARREN RICHARDSON, BSC

Darren is currently studying for a PhD at Coventry University.

MICHAEL DUNCAN, BA (HONS), PGCERT, MPHIL, PHD, FBASES

Michael is a professor in exercise science and associate head of department at Coventry University; he is also a BASES-accredited sport and exercise scientist. He has over 100 peer reviewed articles in the fields of sport and exercise science and has worked in the area of athlete support for over 10 years.

References

1. Abe, K., Haga, S., Nakatani, T., Ikarugi, H., Ushiyama, Y., Togashi, K. and Ohta, K. The work intensity of a badminton match in Japanese top male players. *Bulletin of Institute of Health and Sport Science*, 13(no issue): 73-80. 1990.
2. Anderson, GS and Rhodes, E.C. A review of blood lactate and ventilatory methods of detecting transition thresholds. *Sports Medicine* (Auckland, N.Z.), 8(1): 43-55. 1989.
3. Astorino, TA, Allen, RP, Roberson, DW and Jurancich, M. Effect of high-intensity interval training on cardiovascular function, VO_2max, and muscular force. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, 26(1): 138-145. 2012.
4. http://www.bwfbadminton.org/page.aspx?id=14914. Accessed 02/10/2014.
5. Baker, D. Comparison of upper-body strength and power between professional and college-aged rugby league players. *Journal of Strength and Conditioning Research* / National Strength & Conditioning Association, 15(1): 30-35. 2001.
6. Brunet, M. Female athlete triad. *Clinics in Sports Medicine*, 24(3): 623-636. 2005.
7. Cabello, D and Lees, A. Temporal and Physiological Characteristics of Elite Womens and Mens Singles Badminton. *International Journal of Applied Sports Sciences* (IJASS), 16(2): 1-12. 2004.
8. Cabello Manrique, D and González-Badillo, JJ. Analysis of the characteristics of competitive badminton. *British Journal of Sports Medicine*, 37(1): 62-66. 2003.
9. Campos, FAD, Daros, LB, Mastrascusa, V., Dourado, AC, Stanganelli, LCR and Campos, FAD. Anthropometric profile and motor performance of junior badminton players. *Brazilian Journal of Medical and Biological Research*, 3(2): 146-151. 2009.
10. Ceesay, SM, Prentice, AM, Day, KC, Murgatroyd, PR, Goldberg, GR, Scott, W and Spurr, GB. The use of heart rate monitoring in the estimation of energy expenditure: a validation study using indirect whole-body calorimetry. *British Journal of Nutrition*, 61(2): 175-186. 1989.
11. Chin, M, Wong, A, So, R, Siu, OT, Steininger, K and Lo, D. Sport specific fitness testing of elite badminton players. *British Journal of Sports Medicine*, 29(3): 153-157. 1995.
12. Cummins, C, Orr, R, O'Connor, H. and West, C. Global positioning systems (GPS) and

microtechnology sensors in team sports: a systematic review. *Sports Medicine* (Auckland, N.Z.), 43(10): 1025-1042. 2013.

13. Daniels, J, Oldridge, N, Nagle, F and White, B. Differences and changes in VO_2 among young runners 10 to 18 years of age. *Medicine and Science in Sports*, 10(3): 200-203. 1978.
14. Epstein, LH, Paluch, RA, Kalakanis, LE, Goldfield, GS, Cerny, FJ and Roemmich, JN. How much activity do youth get? A quantitative review of heart-rate measured activity. *Pediatrics*, 108(3): 1-10. 2001.
15. Faccini, Pand Dai Monte, A. Physiologic demands of badminton match play. *American Journal of Sports Medicine*, 24(6 Suppl): S64-66. 1996.
16. Fahlstrom, M and Soderman, K. Decreased shoulder function and pain common in recreational badminton players. *Scandinavian Journal of Medicine and Science in Sports*, 17(3): 246-251. 2007.
17. Faude, O, Meyer, T, Fries, M and Kindermann, W. Physiological testing in badminton. *Science and Racket Sports*. USA: Spon, 2009 pp 5-13.
18. Faude, O, Meyer, T, Rosenberger, F, Fries, M, Huber, G and Kindermann, W. Physiological characteristics of badminton match play. *European Journal of Applied Physiology*, 100(4): 479-485. 2007.
19. Feliu, J, Ventura, JL, Segura, R, Rodas, G, Riera, J, Estruch, A, Zamora, A and Capdevila, L. Differences between lactate concentration of samples from ear lobe and the finger tip. *Journal of Physiology and Biochemistry*, 55(4): 333-339. 1999.
20. Fernandez-Fernandez, J, de la Aleja Tellez, JG, Moya-Ramon, M, Cabello-Manrique, D and Mendez-Villanueva, A. Gender differences in game responses during badminton match play. *Journal of Strength and Conditioning Research* / National Strength & Conditioning Association, 27(9): 2396-2404. 2013.
21. Gallagher, D, Heymsfield, SB, Heo, M, Jebb, SA, Murgatroyd, PR and Sakamoto, Y. Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. *The American Journal of Clinical Nutrition*, 72(3): 694-701. 2000.
22. Ghosh, AK. Heart rate and blood lactate responses during execution of some specific strokes in badminton drills. International *Journal of Applied Sports Sciences* (IJASS), 20(2): 27-36. 2008.
23. Ghosha, S, Iqbalb, R, Dec, A and Banerjee, D. Relationship of Heart Rate with Oxygen Consumption of adult male workers from Service and Manufacturing Sectors. International *Journal of Physical Education, Fitness and Sports*, 3(3): 26-34. 2014.
24. Girard, O, Chevalier, R, Habrard, M, Sciberras, P, Hot, P and Millet, GP. Game analysis and energy requirements of elite squash. *Journal of Strength and Conditioning Research* / National Strength & Conditioning Association, 21(3): 909-914. 2007.
25. Gucluover, A and Esen, HT. The Comparison of physical and physiological characteristics of elite and amateur female badminton players. *International Journal of Academic Research*, 5(6): 105-109. 2013.
26. Hall, SJ. *Basic Biomechanics*. Sixth edn. New York: McGraw-Hill, 2012 pp 125-133.
27. Heller, J. Physiological profiles of elite badminton players: aspects of age and gender. *British Journal of Sports Medicine*, 44(17): 1-13. 2010.
28. Hughes, MG. Physiological demands of training in elite badminton players. In: *Science and Racket Sports*. London: E & FN Spon, 1995 pp 32.
29. Jeyaraman, R, District, E and Nadu, T. Prediction of playing ability in badminton from selected anthropometrical physical and physiological characteristics among inter collegiate players. *International Journal of Advanced and Innovative Research*, 2(3): 11. 2012.
30. Liddle, S, Murphy, M and Bleakley, W. A comparison of the physiological demands of singles and doubles badminton: a heart rate and time/motion analysis. *Journal of Human Movement Studies*, 30(4): 159-176. 1996.
31. MacRae, HS, Dennis, SC, Bosch, AN and Noakes, TD. Effects of training on lactate production and removal during progressive exercise in humans. *Journal of Applied Physiology* (Bethesda, Md. : 1985), 72(5): 1649-1656. 1992.
32. Mahoney, CA and Sharp, NCC. The physiological profile of elite junior squash players. In: Reilly T, Hughes M, Lees A, editors. *Science and Racket Sports*. London: E and FN Spon., 1995 pp 76-81.
33. Majumdar, P, Khanna, G, Malik, V, Sachdeva, S, Arif, M and Mandal, M. Physiological analysis to quantify training load in badminton. *British Journal of Sports Medicine*, 31(4): 342-345. 1997.
34. Mendez-Villanueva, A, Fernandez-Fernandez, J, Bishop, D, Fernandez-Garcia, B and Terrados, N. Activity patterns, blood lactate concentrations and ratings of perceived exertion during a professional singles tennis tournament. *British Journal of Sports Medicine*, 41(5): 296-300. 2007.
35. Northridge, D.B., Grant, S., Ford, I., Christie, J., McLenachan, J., Connelly, D, McMurray, J, Ray, S, Henderson, E and Dargie, H. Novel exercise protocol suitable for use on a treadmill or a bicycle ergometer. *British Heart Journal*, 64(5): 313-316. 1990.
36. Omosegaard, B. Physical Training for Badminton. Denmark: Malling Beck, 1996 pp 9-123.
37. Ooi, C.H, Tan, A, Ahmad, A, Kwong, KW, Sompong, R, Ghazali, KA, Liew, SL, Chai, WJ and Thompson, MW. Physiological characteristics of elite and sub-elite badminton players. *Journal of Sports Sciences*, 27(14): 1591-1599. 2009.
38. Phomsoupha, M. and Laffaye, G. The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports Medicine* (Auckland, NZ), 45(4): 473-495. 2015.
39. Ramos Álvarez, J, Del Castillo Campos, M, Polo Portes, C, Ramón Rey, M and Bosch Martín, A. Analysis of the physiological parameters of junior Spanish badminton players. *International Journal of Medicine and Science of Physical Activity and Sport. In press*. 2013.
40. Reilly, T. The Racquet Sports. In:Reilly, T, Secher, N, Snell, P and Williams C editors. *Physiology of Sports*. London: E & FN Spon, 1997 pp 337–369.
41. Reilly, T, Secher, N, Snell, P and Williams, C. *Physiology of Sports*. London: E. & F.N. Spon Press, 1990 pp 299-328.
42. Rhodes, J, Mason, B, Perrat, B, Smith, M and Goosey-Tolfrey, V. The validity and reliability of a novel indoor player tracking system for use within wheelchair court sports. *Journal of Sports Sciences*, 32(17): 1639-1647. 2014.
43. Sathyan, T, Shuttleworth, R, Hedley, M and Davids, K. Validity and reliability of a radio positioning system for tracking athletes in indoor and outdoor team sports. *Behavior Research Methods*, 44(4): 1108-1114. 2012.
44. Sheppard, JM and Young, WB. Agility literature review: classifications, training and testing. *Journal of Sports Sciences*, 24(9): 919-932. 2006.
45. Singh, J, Raza, S and Mohammad, A. Physical characteristics and level of performance in badminton: a relationship study. *Journal of Education and Practice*, 2(5): 6-9. 2011.
46. Smekal, G, von Duvillard, SP, Pokan, R, Tschan, H, Baron, R, Hofmann, P, Wonisch, M and Bachl, N. Changes in blood lactate and respiratory gas exchange measures in sports with discontinuous load profiles. *European Journal of Applied Physiology*, 89(5): 489-495. 2003.
47. Subramanian, A. Investigation of the factors predominent to badminton playing ability. *Academic Sports Scholar*, 2(8): 1-6. 2013.
48. Todd, MK and Mahoney, CA. Determination of pre-season physiological characteristics of elite male squash players. In: Reilly T, Hughes M, Lees A, editors. *Science and Racket Sports*. London: E and FN Spon, 1995 pp 81-89.
49. van Lieshout, KA and Lombard, AJ. Fitness profile of elite junior South African badminton players. *African Journal for Physical, Health Education, Recreation and Dance*, 9(3): 114-120. 2004.
50. Wasserman, K, Beaver, WL and Whipp, BJ. Mechanisms and patterns of blood lactate increase during exercise in man. *Medicine and Science in Sports and Exercise*, 18(3): 344-352. 1986.
51. Wonisch, M, Hofmann, P, Schwaberger, G, von Duvillard, SP and Klein, W. Validation of a field test for the non-invasive determination of badminton specific aerobic performance. *British Journal of Sports Medicine*, 37(2): 115-118. 2003.