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Physiological requirements of cricket

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Despite its long history and global appeal, relatively little is known about the physiological and other requirements of cricket. It has been suggested that the physiological demands of cricket are relatively mild, except in fast bowlers during prolonged bowling spells in warm conditions. However, the physiological demands of cricket may be underestimated because of the intermittent nature of the activity and the generally inadequate understanding of the physiological demands of intermittent activity. Here, we review published studies of the physiology of cricket. We propose that no current model used to analyse the nature of exercise fatigue (i.e. the cardiovascular–anaerobic model, the energy supply–energy depletion model, the muscle power–muscle recruitment model) can adequately explain the fatigue experienced during cricket.

A study of players in the South African national cricket team competing in the 1999 Cricket World Cup revealed that, in a variety of measures of explosive ('anaerobic') power and aerobic endurance capacity, they were as 'fit' as South African national rugby players competing in the 1999 Rugby World Cup. Yet, outwardly, the physiological demands of rugby would seem to be far greater than those of cricket. This poses the question: 'Why are these international cricketers so fit if the physiological demands of cricket are apparently so mild?' One possibility is that this specific group of athletes are unusually proficient in a variety of sports; many achieved high standards of performance in other sports, including rugby, before choosing to specialize in cricket. Hence their apparently high fitness may simply reflect a superior genetic physical endowment, necessary to achieve success in modern international sports, including cricket. Alternatively, it could be hypothesized that superior power and endurance fitness may be required to cope with the repeated eccentric muscle contractions required in turning and in bowling and which may account for fatigue and risk of injury in cricket. If this is the case, the fitness of cricketers may be increased and their risk of injury reduced by more specific eccentric exercise training programmes.

Keywords: aerobic capacity, anaerobic capacity, cricket, eccentric exercise, exercise models, strength training.

Introduction

Although cricket is one of the oldest organized sports, there is a relative lack of scientific research of the sport or its players. There are, for example, very few studies of the physiological demands of cricket or of the specific physiological, biochemical or anthopometric attributes of top-class cricketers. Perhaps this reflects the innate conservatism of either the game or the scientists who study it.

International cricket is undergoing a phase of rapid change as it competes to attract a more global audience. As a result, modern international cricketers are now exposed to greater physical and psychological demands. These expanded demands include more five- and one-day matches per season, a longer season without a real winter break, more frequent tours and less time spent at home each season. For example, during the 1998–99 cricket season, which began on 2 October 1998 and ended on 31 March 1999, the South African national cricket team played 8 five-day test matches, 17 one-day internationals and were eligible to play in 8 four-day and 10 one-day provincial (county) cricket matches. Thus the total number of days on which they could have played representative cricket was 99.

In contrast, in 1970, the South African national cricket team played 4 five-day Test matches and no one-day international matches. Players were also eligible to play 4 three-day and 3 one-day provincial matches during the season, giving a possible total for the season

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of 35 days of cricket. Hence, between 1970 and 1999, the demands on international South African cricketers has increased by approximately 280%.

Now expected to perform under these more trying conditions, it is probable that only the best prepared cricketers will perform better, more consistently, with fewer injuries and, as a result, will enjoy longer careers. Thus there is a real need to understand better the physiological demands of modern cricket, initially for the benefit of individual players and teams, but eventually for the survival and growth of the game itself.

Early studies of the physiological demands of cricket

Perhaps the earliest study to attempt a physiological analysis of the demands of international five-day Test match cricket was that of Fletcher (1955). He collected data during the 1953 Ashes Test series between England and Australia and tried to predict the average energy expenditure of the international cricketers involved in that competition. He calculated that, of the 150 h allocated for the five Test matches, 46 h were lost to English 'summer' weather and a further 4 h when the ball was 'out of play'. Although it is not immediately clear what constituted the ball being 'out of play', Fletcher considered 100 h of actual play took place. He further calculated that, during those 100 h of play, 4363 runs were scored from a total of 1833 overs. This meant that 43.6 runs were scored per hour with 26.6 of those runs being run, rather than resulting from hits to the boundary. If batters ran 20 m per run, each would have run less than 500 $m \cdot h^{-1}$ when batting.

Bowling analysis revealed that the mean duration of each over was 3 min and 20 s and that the average bowler bowled approximately 12 overs per day. A total of 11,026 deliveries were bowled; 8099 of these were fielded by fielders other than the wicket-keeper. As a result, a 'typical' fielder would have fielded 8.1 balls per hour.

From these data, Fletcher (1955) calculated that the mean daily physical activity for an 'idealized' player during the 1953 five-match Test series was as follows: batting for 38.5 min and scoring 14 runs; bowling for 14 min for a total of 4.2 overs; fielding for 116 min, during which 16 balls were fielded; and resting in the pavilion for 191.5 min. As a result, the mean rate of energy expenditure was 86.4 $kcal \cdot m^{-2} \cdot h^{-1}$. For an average cricketer with a body surface area of 1.8 m^2, this corresponds to an energy expenditure of approximately 650 $kJ \cdot h^{-1}$.

These calculations, together with data recorded using indirect calorimetry to predict the energy expenditure of cricketers practising in the nets, produced Fig. 1, which shows the energy expenditure during different cricketing activities. The mean energy expenditure for the average Test cricketer was just slightly more than the mean energy expenditure achieved when standing. Although mean energy expenditures when batting or bowling were somewhat higher, they were still lower than that required to walk at 6 $km \cdot h^{-1}$. Only when bowling or batting in the nets did the mean energy expenditure exceed that achieved when playing tennis according to the style of play that was then popular (Fig. 1).

This study may have confirmed the perception that cricket is a physically undemanding sport. This attitude may explain why, when the MCC toured Australia and

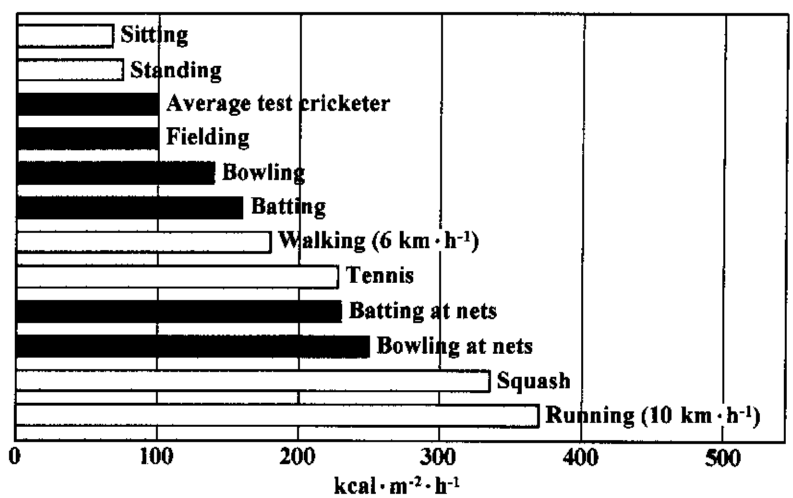

Fig 1. Energy demands of different cricketing activities, including batting, bowling and fielding, compared with other sports. To convert to $kJ \cdot h^{-1}$, multiply $kcal \cdot m^{-2} \cdot h^{-1}$ by 7.6, assuming an average body surface area of 1.8 m^2. Redrawn from Fletcher (1955).

New Zealand the following year, the fitness guidelines of the captain, Sir Leonard Hutton, were as follows: Each player is responsible for his own fitness. He must stay well rested and must not overstrain in practices. He should exercise only very mildly on 'off' days, during which he may swim or play tennis or golf in the early mornings only; and he must stay out of the midday sun (Woolmer, 1999).

It would appear that Sir Leonard's advice that cricketers should train with circumspection, emphasizing adequate rest, was still the standard 30 years later. The 1986 Edition of *The Lord's Taverners Cricket Clinic* included the following recommendations for fitness training for cricket:

- To develop stamina, cricketers were advised to run, skip or cycle for 10–20 min in the session.
- To develop strength, the players were encouraged to do push-ups, sit-ups and 'swing the cricket bat'.
- To enhance their mobility, cricketers were advised to perform wide stride sitting, toe touching and head and shoulder circling (*The Lord's Taverners Cricket Clinic*, 1986).

In the section on fitness training there is a picture of one of the greatest English and world cricketers of all time, Ian Botham, performing what appears to be a physiological fitness test. In the picture, Botham is shown walking on a motorized treadmill, fully clothed and without any clear indication that any particular physiological measurements are being taken. It is not immediately apparent what exactly is the point of either the test or indeed of the photograph. But perhaps the hidden meaning of the photograph is to show that, even without definitive input from any of the exercise sciences, Botham achieved legendary status as one of the greatest all-rounders the game has known. It would perhaps be understandable if Botham, and other exceptional cricketers of the past, concluded that science has little to offer the modern cricketer. This is perhaps analogous to the observation that, despite the astonishing success of Kenyan runners in world competition, there are essentially no professional exercise physiologists in Kenya. But this does not mean that Botham, or even the Kenyan runners, might not have been even better if they had had access to appropriately trained exercise scientists, a point that is easily overlooked.

Models for understanding the physiological demands of cricket

Although exercise physiologists have perhaps yet to embrace the concept fully, it is clear that much of what is written about the different physiological limitations to exercise can only be interpreted according to specific models that have evolved about the nature of the physiological factors that limit exercise performance (Noakes, 1997, 2000). These models – the classic cardiovascular–anaerobic model, the energy supply–energy depletion model, the muscle power–muscle recruitment model, the biomechanical model – have been described elsewhere and will be used here to evaluate further the physiological factors that determine physical performance in cricket. It should be understood, however, that cricket is, above all else, a game requiring inordinate physical skills and mental aptitude, including the ability to concentrate intensely for very prolonged periods, and for which high physical fitness cannot, on its own, fully compensate. However, we are of the opinion that modern cricketers will benefit from superior physical fitness, regardless of their skill. Thus we argue that, for cricketers of equal skill, physiological factors determining their fitness will ultimately predict their success and longevity in the sport.

The classic cardiovascular–anaerobic model of exercise physiology

The classic model holds that there is an exercise intensity or workload above which the output of the heart reaches a limiting maximum, so that any activity above that exercise intensity must be undertaken in the presence of an inadequate oxygen and blood supply to the active skeletal muscles. Faced with an inadequate blood and oxygen supply, the active muscles must contract 'anaerobically', that is with an inadequate oxygen supply. This model further holds that anaerobic energy production produces metabolic by-products, the accumulation of which inhibit both energy production and muscle contractile activity, leading to fatigue and the termination of exercise. The historical basis for this work are the original studies of A.V. Hill and his colleagues in the 1920s (Hill and Lupton, 1923; Hill *et al.*, 1924a,b).

A popular interpretation of this model is that of Webster (1948): 'First the sprinter very quickly creates what is termed an "oxygen debt"; and secondly, the valuable glycogen inside the muscle fibres is turned into poisonous lactic acid, the muscles become tired and stiff, dwindle in power, and finally refuse to function until the lactic acid has been turned back to glycogen during the recuperative processes of rest'. Accordingly, this concept gives rise to the idea that energy metabolism during exercise can either be classified as anaerobic (oxygen-independent) or aerobic (oxygen-dependent). The point, however, is that performance in this type of exercise is considered to be limited by the rate of energy supply by the active skeletal muscles, rather than by any other physiological or metabolic factors. Thus, it is argued that, if one knows the duration for which any activity is undertaken and the metabolic pathways that provide fuel during activity of that intensity and duration, then one can predict the metabolic factors that are likely to limit performance in activities of any duration or intensity. This knowledge is then used to determine the most appropriate training methods, according to the metabolic pathways that are activated and, presumably, trained by the different exercise intensities and durations used in training.

Figure 2 shows the relative contribution of the different energy systems during exercise of different durations. Thus, according to this model, performance during maximal exercise lasting 6 s or less is limited by the capacities of the phosphagens (ATP and PCr) and oxygen-independent glycolysis to provide fuels sufficiently rapidly for muscle contraction. Similarly, maximal activity that produces fatigue within 120 s maximizes energy use from aerobic glycolysis, which is the oxygen-dependent breakdown of glycogen to carbon dioxide and water, with approximately 35% of the energy derived from oxygen-independent or anaerobic glycolysis with the production of lactate. Activity of this maximal intensity and duration is also considered to be limited by the inability of these two pathways to provide energy sufficiently rapidly in the active muscles. Alternatively, accumulation of the by-products of rapid glycolysis, including hydrogen ions and perhaps phosphate, may inhibit muscle contraction. Conversely, exercise of 60 min or longer is considered to be limited by depletion of the body energy, especially carbohydrate, reserves. This gives rise to the energy-depletion model described below.

There is a body of evidence to suggest that the cardiovascular–anaerobic (energy supply) model is relatively simplistic (Noakes, 1997, 1998, 2000). For example, it has yet to be shown that skeletal muscle becomes anaerobic during high-intensity exercise. Rather, all the published evidence indicates that the partial pressure of oxygen in the exercising skeletal muscles does not change during exercise, despite large changes in external workload (Richardson *et al.*, 1996, 1998; Hogan *et al.*, 1998; Hochachka, 1999). Nor is there any evidence that performance during exercise of these specified durations is principally limited by an inability of these different pathways to provide energy at the appropriate rates. More revealing, perhaps, is the argument that, according to the classic cardiovascular–anaerobic model of Hill, it is the heart not the exercising skeletal muscles that is at the greatest risk of developing ischaemia or anaerobiosis (Noakes, 1997, 1998, 2000). Hence for 75 years we may have focused on the incorrect organ as the limiting determinant of exercise performance, especially during high-intensity exercise of short duration. In addition, the role of the central nervous system, in particular in determining skeletal muscle recruitment patterns, has been consistently ignored (Noakes, 1998).

Regardless of this ongoing debate, there is little relevance of these models to cricket physiology, as most activities in cricket are of relatively short duration, lasting perhaps at most 10 s, and are seldom of a maximal all-out nature. Exercise of this short duration is fuelled mainly by phosphagen breakdown (Fig. 2) with restoration of the phosphagen stores during recovery from effort. Phosphagen resynthesis occurs

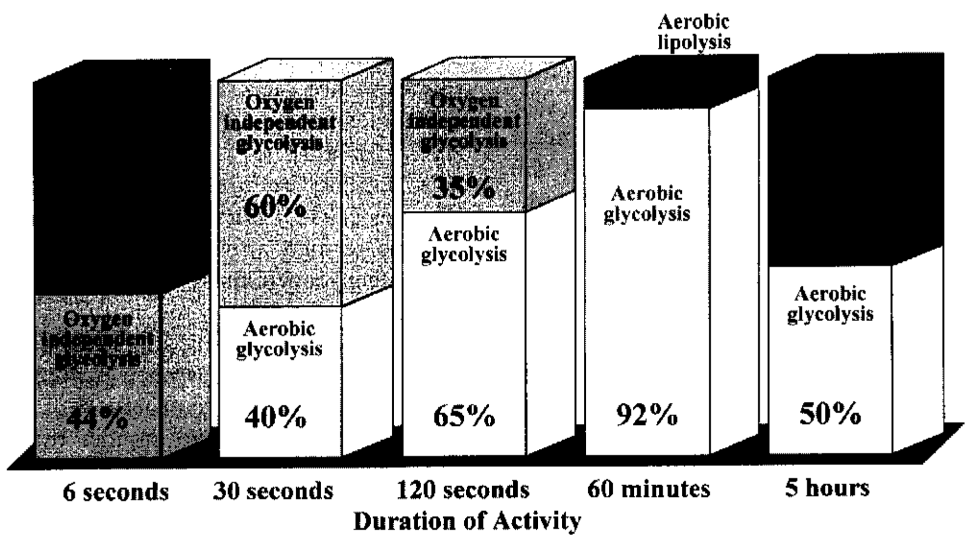

Fig. 2. Postulated contributions (% of total energy) from the different metabolic energy systems used during activities lasting different durations. Note the predominant contribution from oxygen-independent glycolysis and the phosphagens in activities of short duration (less than 40 s) typical of cricket.

from oxidative metabolism in the mitochondria of the active muscles. As even the most vigorous activities in cricket would not induce phosphagen depletion in the active muscles, it is clear that this model has little relevance to an analysis of the physiological limitations in cricket.

The energy supply–energy depletion model

Having suggested that the (anaerobic) energy supply model is of little relevance to the physiology of cricket, an alternative is that whole-body energy depletion could perhaps develop during the course of a cricket match. The energy depletion model is usually used to explain the fatigue that develops during prolonged exercise, like marathon or ultramarathon running, in which high rates of energy expenditure are sustained for periods of at least 2 h. These calculations suggest that it is possible to deplete the body's carbohydrate stores within approximately 2–2.5 h of very vigorous exercise. However, the energy expenditure in cricket is too low (Fig. 1) to suggest that athletes could deplete their body carbohydrate stores during one or more days of cricket.

Indeed, the modest rates of energy expenditure during cricket suggest that fat is the most likely fuel oxidized by cricketers during most of their activity. Accordingly, it is appropriate to question, perhaps in the interests of appropriate humour, whether depletion of body fat stores is likely during a cricket match. Perhaps a speculative analysis of energy metabolism in W.G. Grace would be of interest.

During his cricket career, W.G. Grace scored 54,896 runs, including 126 centuries, and represented England at cricket at age 51. If we estimate that Grace (Fig. 3) weighed 100 kg and had a body fat content of 27%, his 27 kg of body fat would store 1,073,000 kJ of energy. If each hour of cricket play consumes 753 kJ (Fig. 1), this would give Grace the ability to play 1404 h of cricket or 47 Test matches without eating, before he had used up all his body fat stores. At a rate of 10 Test matches a year, Grace's body fat stores would have been sufficient to allow him to play 5 years of Test match cricket before he became energy-depleted. Although the physical demands of cricket have clearly increased in the past 30 years, because of the frequency of international competition, it is equally clear that the only cricketers at risk of developing whole-body energy depletion are those who deliberately choose to do so.

Fig. 3. W.G. Grace at age 51 years when he was still playing international cricket.

The muscle power–muscle recruitment model

It has been proposed that fatigue during prolonged exercise may result from a progressive reduction in skeletal muscle recruitment by the cerebral motor cortex. This postulated form of central fatigue contrasts with the more usual model in which it is assumed that progressive, peripheral skeletal muscle fatigue develops despite a progressive increase in skeletal muscle recruitment by the cerebral motor cortex.

The models for which there is clear evidence of central fatigue or, perhaps, more correctly, a regulated reduction in cerebral motor cortex activity, include the fatigue that develops during exercise at altitude, during exercise-induced hypoglycaemia and probably also during exercise in the heat (Noakes, 1998, 2000). In all these examples, cerebral motor cortical activity is reduced so that exercise terminates not because of peripheral skeletal muscular fatigue but because the cerebral cortex acts as a 'governor' to reduce skeletal muscle recruitment, thereby preventing further exercise that could ultimately lead to whole-body damage.

Accordingly, this governor would prevent the development of myocardial or cerebral hypoxia during exercise at altitude, or neuroglycopenic cerebral insult through hypoglycaemia, or whole-body damage caused by an elevated body temperature in heatstroke (Noakes, 1997, 1998).

Not only are cricketers protected from the risk of developing hypoglycaemia by the fortuitous scheduling of tea or lunch breaks at two-hourly intervals during matches, they are not exposed to the risks of playing at very high altitudes. This is because of the absence of sufficiently large flat playing surfaces at the high altitudes encountered on the Asian subcontinent and for historical reasons, the Tibetans, Nepalese, Peruvians and Colombians do not play cricket. The only likely risk to cricketers is that posed by the development of elevated body temperatures.

In general, the development of heat injury requires both high rates of energy expenditure and severe environmental conditions. Although cricket is occasionally played in severe environmental conditions in Africa, Australia and India, from first principles we would again assume that the rates of energy expenditure during cricket are too low (Fig. 1) to induce hyperthermia.

To the best of our knowledge, there are no publications reporting the rise in body temperature in cricketers during competition. The only study to suggest relatively high rates of heat production in some fast bowlers is that of Gore *et al.* (1993), in which sweat rates of Australian fast bowlers were measured in different environmental conditions, including cool, warm and hot days.

Figure 4 shows that, on the first session of the hot day, the bowlers achieved relatively high sweat rates of 1.5 $l \cdot h^{-1}$, whereas on the warm and cool days, the highest sweat rates were always less than 1 $l \cdot h^{-1}$. Nevertheless, a sweat rate of 1.5 $l \cdot h^{-1}$ is remarkably high and quite unexpected if one assumes that the rates of energy expenditure, even during fast bowling (Fig. 1), are relatively low. Indeed, a sweat rate of 1.5 $l \cdot h^{-1}$ is as high as those reported for athletes competing in marathon or longer races in hot and humid environmental conditions (Noakes, 1993). However, it is unlikely that a cricket fast bowler would be able to sustain his effort for much more than about 1 h; in contrast, marathon runners can sustain these high work rates for 2–3 h, after which time they are at risk of developing heat injury.

It is unlikely, therefore, that high rectal temperatures, which are determined principally by the rate of metabolic heat production, would be sustained for sufficiently long to impact on the performance of cricketers. The only exceptions are fast bowlers bowling for more than 1 h in a hot and humid environment, or batsmen in a one-day international forced to run many singles in the hot and humid conditions that exist during the summer daylight hours on the Asian subcontinent and in Australia.

That bowlers can occasionally achieve such high sweat rates raises the following question: 'What intensity of effort is sustained by the modern cricketer?' Although the measurement of oxygen consumption during exercise provides the most accurate method for determining exercise intensity, this is not possible during cricket. The only means currently available for estimating the exercise intensity during cricket is to measure heart rates during batting and bowling.

Figure 5 is a composite of heart rates measured during marathon running (M. Lambert, personal communication), during 12 overs of fast bowling (Burnett *et al.*, 1995) and during a day's cricket (Gore *et al.*, 1993). It shows that the mean heart rate during a day's

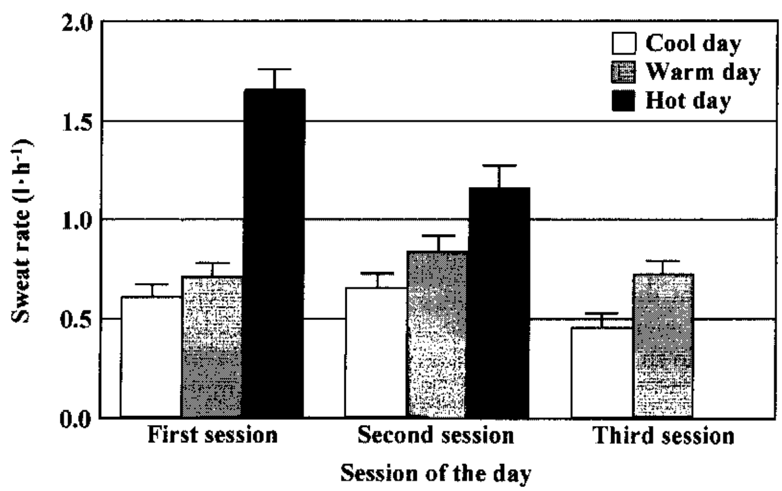

Fig. 4. Sweat rates (mean ± $s_{\bar{x}}$) in fast bowlers during cricket matches played on cool, warm and hot days. Note the very high sweat rates (> 1.5 $l \cdot h^{-1}$) in fast bowlers on hot days. Reproduced from the data of Gore *et al.* (1993).

cricket seldom rises above about 128 beats $\cdot$ min^{-1} in batsmen and fielders, whereas heart rates of the fast bowlers can reach between 180 and 190 beats $\cdot$ min^{-1}, albeit for relatively short periods. In contrast, marathon runners can maintain heart rates of between 170 and 190 beats $\cdot$ min^{-1} for 2 h or more. These data confirm that high rates of energy expenditure, measured as near maximal heart rates, are sustained for relatively short periods and only in fast bowlers. In addition, as shown in Fig. 6, blood lactate concentration, another measure

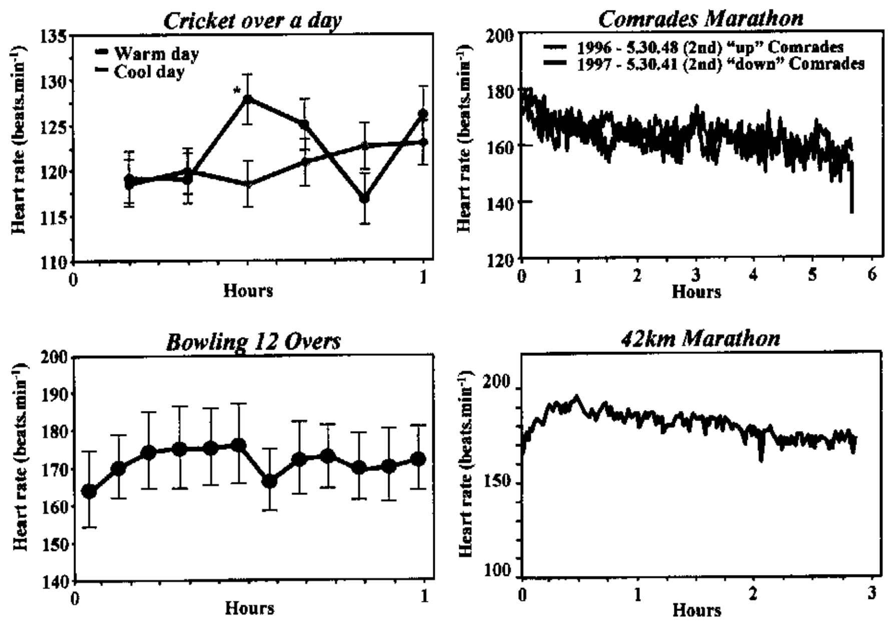

Fig. 5. Heart rates (mean ± $s_{\bar{x}}$) during a day of cricket and during 12 overs of fast bowling (left panels) compared to those in an individual running the 90-km Comrades Marathon or a 42-km standard marathon (right panels). Data are from Gore *et al.* (1993), Burnett *et al.* (1995) and Professor Mike Lambert (personal communication).

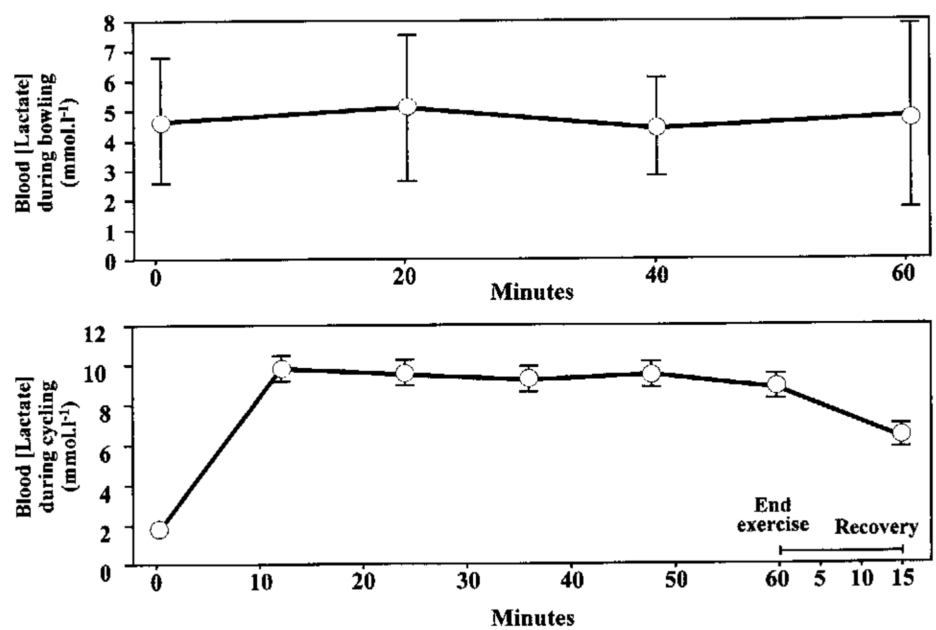

Fig. 6. Blood lactate concentrations (mean ± s) during 12 overs of bowling (approximately 50 min of exercise) and during an equivalent period of high-intensity aerobic exercise (40-km cycling time-trial). Data are from Burnett *et al.* (1995) and Schabort *et al.* (in press). Note that much higher blood lactate concentrations are reached during cycling than during an equivalent period of bowling.

of exercise intensity, seldom exceeds 5 $mmol \cdot l^{-1}$ in fast bowlers (Burnett *et al.*, 1995); in contrast, during high-intensity exercise (e.g. cycling) for up to 1 h, lactate concentrations as high as 10 $mmol \cdot l^{-1}$ have been reported (Schabort *et al.*, in press).

In summary, the early predictions of Fletcher (1955) appear to have been confirmed by more recent studies, all of which have shown that the rates of energy expenditure during cricket are relatively low, with the only possible exception of fast bowlers. Thus, from a physiological point of view, none of the models traditionally used to explain exercise fatigue in athletes appears to be particularly relevant to cricket. All these models suggest that cricketers should be able to play cricket without fatigue for days on end. Although no data are available, it is commonly believed that speed and accuracy decline after 6–8 overs of fast bowling and that batsmen, particularly during a one-day game, can become fatigued in an innings in which they score 100 or more runs. This suggests that our current understanding of the physiology of fatigue is unsatisfactory when applied to such activities as cricket, in which short bouts of high-intensity exercise are interspersed with prolonged periods at much lower exercise intensities. Most research on this topic has focused on repeated bouts of high-intensity exercise repeated at much shorter intervals than typically occur in cricket (Bogdanis *et al.*, 1994, 1996).

The paradox of cricket: Why does one need to be fit to play cricket?

The evidence presented so far indicates that cricket is a relatively gentle game in which the physiological demands are not particularly demanding. There are no data to challenge the original conclusion of Fletcher (1955) that the average energy expenditure during a five-day Test match is little more than that required simply to stand (Fig. 1). It is clear, however, that cricketers do get very tired when playing; this is as much to do with the mental demands of the game as to the physical demands. It is our experience that individual players perform better when they are fitter. But why do cricketers need to be fit? Perhaps the answer can be found in an analysis of the demands imposed by one-day cricket.

An estimate of the physical activity in bowling during one-day cricket suggests that fast bowlers deliver about 64 deliveries (60 legal and 4 wides or no balls) in 40 min. During this time, they are expected to run 1.9 km in about 5.3 min, that is an average speed of 21.6 $km \cdot h^{-1}$. The delivery action would require approximately 64 s of upper body action as well as 64 episodes of lower body deceleration.

Table 1. Estimated peak physical activity for a batsman during a one-day cricket match

Runs scored	Distance run (m)
50×1	1000
20×2	800
10×3	600
20×4	800
Total	3200

Note: Number of decelerations = 110. Overall average running speed = 24 $km \cdot h^{-1}$ (60 runs each of 3 s = 3.2 km covered in 8 min).

Table 1 shows the estimated peak physical activity of a batsman during a one-day cricket match who batted for 100 runs and who batted with other batsmen who also scored 100 runs in the same period. Based on the probable distribution of the numbers of one, two, three and four runs scored, each batsman would run 3.2 km in approximately 8 min. Hence, the overall running speed would be 24 $km \cdot h^{-1}$ and the number of decelerations required to score these runs would be a minimum of 110.

When viewed in this context, it is apparent that the demands of bowling and batting in one-day cricket are not insubstantial. It is clear that elite players in particular need to be athletic to be able to reproduce these performances frequently, especially during a series of one-day international matches, in which they must partake in 3.5 h of frequently vigorous fielding.

Paradox 2: Some cricketers are extremely athletic

We have been privileged to work with the South African cricket team for the past 5 years; in particular, their physical preparation during 1998 and 1999, including the 1999 World Cup, was directed by J.J.D. In 1999, the team, although beaten in a tie in the World Cup semi-final by Australia, was chosen as the International Cricket Team of the Year. One of the players, Jacques Kallis, was named as both the International Cricketer of the Year and the International Young Cricketer of the Year. Table 2 lists the sporting abilities, other than cricket, of the 15 players who represented South Africa in the 1999 Cricket World Cup. What is especially remarkable is that 11 of the 15 players were highly proficient in other sports, in particular rugby. However, most had chosen to specialize as professional international cricketers rather than as rugby players.

Figures 7 and 8 provide a comparison of the aerobic and oxygen-independent (anaerobic) physiological characteristics of the South African batsmen and bowlers in the 1999 national team. Conventional techniques (St. Clair Gibson *et al.*, 1998) were used to measure height, mass, body fat, 20-m shuttle run performance (used to predict maximum oxygen consumption, $\dot{V}O_{2max}$), leg press, bench press and 35-m sprint time.

Table 2. The sporting abilities, other than cricket, of the South African national team in the 1999 Cricket World Cup

Player (arbitrary number)	Proficient in other sports
Batsmen	
1	Provincial rugby (under-19), provincial squash (under-16)
2	SA schools soccer (under-16), SA schools rugby (under-19), provincial rugby (under-21)
3	Provincial squash (under-15), provincial rugby (under-19)
4	School rugby and squash
5	Provincial hockey (senior), national hockey squad (not capped)
All-rounders	
6	Provincial rugby (under-20) (Captain)
7	Provincial rugby trials (under-19)
8	School rugby
9	SA squash (under-19)
10	Provincial hockey (under-19)
11	Provincial rugby (under-19)
12	Provincial rugby (senior)
Bowlers	
13	School rugby and athletics
14	Provincial rugby (under-19), provincial hockey (under-19), provincial tennis (under-19)
15	First division club hockey, school rugby

As we have also had the opportunity to study elite South African rugby players, we compared these data for the South African batsmen and bowlers with data obtained under identical laboratory conditions in the South African loose forwards and back-line players who represented South Africa in the 1999 Rugby World Cup in Wales and England. A comparison of the cricketers to these groups of rugby players, rather than to tight forwards, is made for anthropometric reasons. Cricketers clearly do not have the inborn physical dimensions necessary to be tight forwards and none of this group of South African cricketers had ever played in those positions (Table 2).

The bowlers were taller and heavier with a slightly lower predicted $\dot{V}O_{2max}$, based on performance during the 20-m shuttle run, than the batsmen. Body fat content was the same in both groups and averaged just over 12%. For the 'anaerobic' profiles (Fig. 8), although the batsmen were faster when running a simulated three (runs) and their turn time was also less (data not shown), there was little difference in leg press, bench press or 35-m sprint performances between batsmen and bowlers.

The impression is that the aerobic and 'anaerobic' physiological abilities of the batsmen and bowlers are relatively similar, except that batsmen tend to be smaller and lighter and slightly faster, especially when turning. However, a more interesting finding arises from a comparison of the physiological characteristics of the cricketers and the rugby players. These data show that there are no real physiological differences between these groups, despite the very much greater physical demands of rugby.

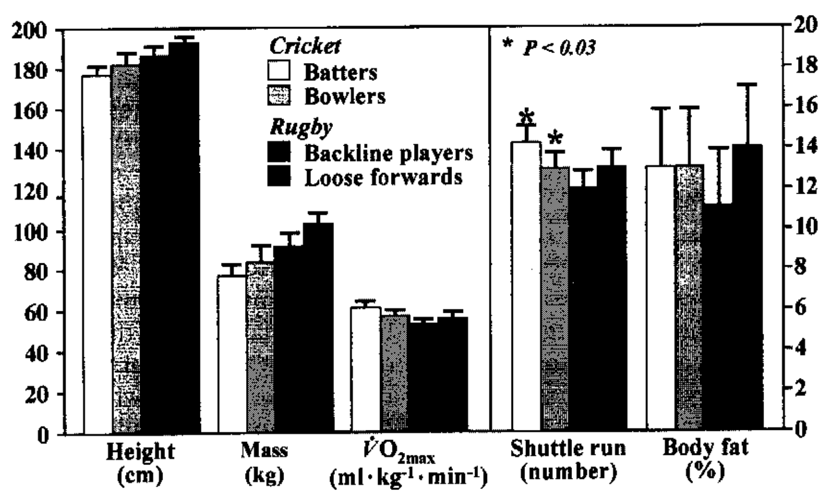

Fig. 7. Comparison of 'aerobic' physiological characteristics of South African international cricketers and rugby players. Note that there are differences in height and weight between batsmen and bowlers and between backline and forward rugby players. Rugby players are heavier and taller than cricketers (mean ± *s*).

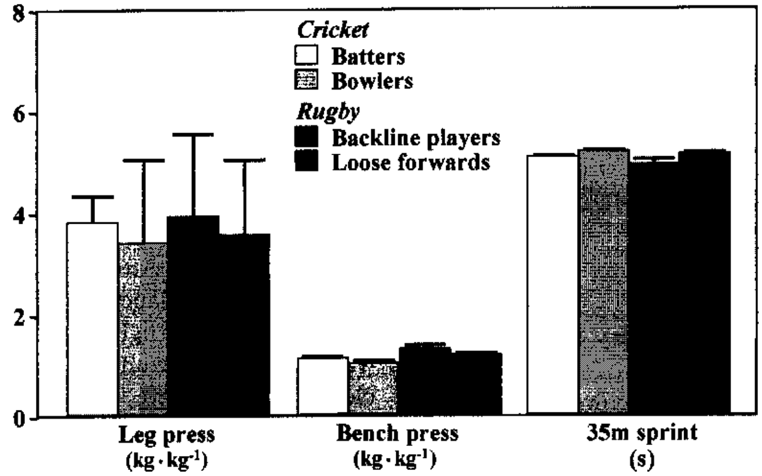

Fig. 8. Comparison of 'anaerobic' physiological characteristics of South African international cricketers and rugby players. Note that there are no significant differences in any of these characteristics between cricketers and rugby players (mean ± *s*).

The first point to note in Fig. 7 is that there is a progressive increase in height from the batsmen to the bowlers to the back-line players to the loose forwards. Thus international cricket players, whether they are batsmen or bowlers, are slightly shorter than international back-line rugby players and loose forwards. Similarly, the body mass of the players follows the same pattern, with the batsmen being lighter than the bowlers, the bowlers being lighter than the back-line rugby players, all of whom are lighter than the rugby loose forwards. Predicted $\dot{V}O_{2max}$ was highest in the batsmen but similar between bowlers, back-line players and loose forwards. Body fat composition was essentially the same in all four groups.

When related to body mass, the leg press and bench press performances of the cricketers were not significantly different from those of the rugby players (Fig. 8). Nor was 35-m sprint speed different between these groups.

These results suggest that, at least in South Africa, cricket bowlers and batsmen are as 'fit' as international rugby players. In addition, they are as strong. The only differentiating physical characteristic between cricketers and rugby players is that the cricketers were lighter and smaller than the rugby players. This raises the question of whether the physical demands of cricket and rugby are more similar than is currently believed. This is an argument that would be difficult to sustain. Alternatively, it is possible that all international sports in which there are repetitive intermittent bouts of exercise select out athletes with similar inherent physical abilities. If this is true, then regardless of the exact physical demands, the physiological characteristics of the elite players in all these sports will be relatively similar. Of course, the physiological requirements of sustained, endurance sports, such as running, cycling and swimming, will select for a different set of physical and physiological characteristics.

A possible solution: The biomechanical model of exercise performance

The work of Nicol *et al.* (1991) has shown that the repeated eccentric muscle contractions of running produce a specific form of fatigue that requires substantial recovery time. Their model proposes that repetitive eccentric muscle contractions produce an altered skeletal muscle function and, in particular, a loss of elastic energy production. This results in increased work during the push-off phase of the running stride or, by analogy, of the upper limb in the fast bowling action. Muscles damaged in this way require a long time to fully recover their function. Nicol *et al.* have shown that abnormal skeletal muscle function is present for at least 2 weeks in athletes who have completed a 42-km marathon foot race.

Perhaps the real stress of cricket results from damage (Morgan and Allen, 1999) caused by repeated eccentric muscle contractions that occur during fast bowling but also in the repeated decelerations that occur when turning during batting or fielding. It is clear that shuttle running, which simulates the acceleration, deceleration and turning required in running between the wickets, is sufficient to induce muscle damage (Thompson *et al.*, 1999). The ability to cope with repeated eccentric muscle contractions may require substantial muscle strength to reduce the extent of muscle damage.

Conclusions

The results presented here show that little is known about the physiological requirements of cricket. However, the South African cricketers assessed by us were as 'fit' as international rugby players, although they were smaller and lighter. This suggests that a sporting selection process may occur in South African sport such that athletes who are physically superior are selected into different sports according to body size (and skill). It would appear that the best South African cricketers have the special skills required of cricketers but, in addition, have a superior physical endowment that, had they been heavier and taller, might have also allowed them to represent South Africa in other sports, especially rugby. Their smaller size precludes them from being as successful in rugby. However, a smaller size might be a selective advantage, especially for batting. In the present study, it was notable that most batsmen were shorter than the other members of the team. This superior genetic endowment may be more important than physical training in determining 'fitness'.

Finally, the very high 'fitness' of these cricketers suggests that cricket is far more demanding physiologically than is presently recognized. The repeated episodes of eccentric muscle contraction could explain this unexpected finding. If this is the case, greater attention should be paid to eccentric muscle strengthening, especially in fast bowlers.

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