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Review

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A review of the physical and physiological demands associated with cricket fast and spin bowlers

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Abstract

Understanding the demands associated with cricket match-play is essential for the development and implementation of training programs to improve the conditioning status of players. With the recent expansion of playing formats in cricket, particularity Twenty20 cricket, coaching staff must ensure that training programs are specific to each playing position and also give consideration to each match format. The current literature collectively highlights that the physical and physiological demands associated with cricket vary considerably across playing positions and match formats. Further, there is a growing body of research detailing the physical and physiological responses of cricket bowlers during training and match-play. Thus, this review provides an overview of the current literature examining the physical and physiological demands of fast and spin bowlers during competitive match-play, training and simulation protocols. Unsurprisingly, the current research suggests that the physical and physiological demands associated with fast bowling differ considerably to spin bowlers. However, the current research also indicates that the use of game-based activities rather than the traditional, net-based training may more closely replicate the demands of match-play. Based on this information, coaches may be able to develop tailored conditioning programs for cricket players specific to match formats. Greater research into the physical and physiological demands elicited during cricket training and match-play may further improve knowledge on the efficacy and validity of current training techniques used in cricket.

Keywords

Game-based training, global positioning system, match demands, rating of perceived exertion, small-sided games, training demands

Introduction

Bowlers are an integral part of any cricket team[1] and the volume of literature pertaining to cricket reflects this.[2–17] All bowlers aim to dismiss the batsmen on the opposing team while restricting the amount of runs scored by the opposing batsmen, with different bowlers relying on various types of deliveries: fast bowlers using a variety of deliveries involving swing and seam movement of the ball. Regardless of the playing format (multi-day [MD], one-day [OD] or Twenty20 [T20]), recent research has focused more on bowlers, and in particular fast bowlers[18–21] as opposed to other playing positions. For the purposes of this review, research referring to medium, medium-fast, fast-medium and fast bowlers were collated under the term fast bowlers. In addition, cricket teams typically also include spin bowlers who deliver the ball at slower speeds and place rotation on the ball prior to release for deviation off the pitch to increase shot difficulty by the batsman. Depending on the direction the ball is spun from the hand, spin bowlers are classified as either leg- or off-spin bowlers. Due to their role within a cricket team,[1] much of the previous and current research has centred around the biomechanics of the bowling

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technique[3,19,22,23] and injury surveillance[3,5,18,21,24–27] with a particular focus on male fast bowlers.

Novel lines of inquiry have also focused on understanding the physical, physiological and perceptual demands associated with cricket bowlers during match-play, training sessions, and simulation protocols in a variety of playing groups.[20,28–30] The recent increase in research has coincided with a more congested playing schedule which has resulted from an increase in the variants of match formats. Past data have shown that different playing formats impose different physical and physiological demands between fast and spin bowlers[29] and as such, coaching staff should develop training sessions to specifically prepare for each match format and bowling position.[31]

Historically, there are two main training formats that are used to replicate the demands of match play for bowlers. The more traditional format is termed net-based training, whereby a group of bowlers continuously bowl to a batsman enclosed within a net on a pitch consisting of a natural or artificial surface. In more recent times, game-based training sessions or small-sided games have been employed to concurrently improve physiological capacities and technical abilities,[32–34] whereby players are placed in an environment more replicable of match-play. Such game-based training may include centre-wicket (CW) practice sessions, whereby bowlers perform as they would during a (typical) match but within a controlled setting with coaches able to implement a variety of changes to the playing conditions or rules.[35] Another example of this form of training are cricket-specific small-sided games which in some cases are referred to as 'The Battle Zone' (cSSG),[33] and much like small-sided games in other sports changes the demands experienced by players using a variety of constraints within match scenarios. A large focus within recent literature has been the management of bowling workload particularly during various training formats. In an elite setting, the number of deliveries completed by each bowler is determined and limited by the coaching staff, to regulate player workload and limit injury risk.[5] This workload management is also coupled with a range of non-cricket specific training activities in order to allow players to cope with the demands of match-play and improve their resilience to injury.[23] Although the implications of these strength and conditioning programs specific for fast bowlers have been discussed in the literature,[23,36] the existing work has only provided a brief account of the general qualities and training plans for preparing fast bowlers.

Despite the increasing literature associated with cricket match-play and training, previous reviews regarding cricket bowlers have not provided a comprehensive account of the information available.[20,31] To rectify this gap in the literature, this review aimed to provide a detailed synthesis of the current literature relating to the physical and physiological demands experienced by cricket bowlers during training and match-play. In addition to this, this review will be useful for cricket coaches seeking to provide more match-specific and individualised training programs for their players

Physical demands of bowlers

Contemporary research reporting on the physical demands of cricket players refutes the suggestion that cricket is a low-intensity activity, demonstrating that cricket is played at a considerably high physical intensity, especially given the extended duration of matches.[29] The introduction of global positioning system (GPS) technology has increased the capacity to quantify the physical demands experienced by players during cricket match-play. The increased use of these devices, particularly within high performance sport has allowed practitioners and coaches to determine the movement patterns and characteristics of bowlers typically encompassing distance and speed data during different match formats as well as during training. This technological advancement has in turn permitted training techniques to be modified to provide adequate workloads relative to player position and match/training format.

Physical demands of fast bowlers during a match

Numerous studies have reported on the physical demands of elite and amateur fast bowlers during match-play in recent years with the collective conclusion revealing fast bowlers are required to perform at the highest intensity of all cricket positions.[28,29,35,37–41] Petersen et al.[29,37,38,40] as well as Vickery et al.[35] observed fast bowlers to maintain the greatest match intensities when compared with other playing positions (batsman, spin bowler, wicketkeeper), irrespective of match format. A fast bowler typically performs a large percentage of low-intensity activity (<3.51 m s^{-1}) (76–86%; Table 1) interspersed with high-intensity bouts largely reflective of the run-up before a delivery during match-play. Petersen et al.[29] reported that there is a similar match profile regardless of format, although the shorter the match format (T20 < OD < MD), the higher the relative distance covered and number of high-intensity efforts performed by a fast bowler.[29,35] The shorter match formats are also characterised by shorter recovery times between each high-intensity effort ($>3.5\,m{\cdot}s^{-1}$) (Table 1). This is an important

Table 1. Physical demands of fast bowlers during various match formats (mean ± SD) .

Study	Match format	Total distance ($m \cdot h^{-1}$)	Low-intensity distance ($m \cdot h^{-1}$)	High-intensity distance ($m \cdot h^{-1}$)	Mean speed ($m \cdot min^{-1}$)	Recovery ratio (1:x)	# High-intensity efforts (h^{-1})
Petersen et al.[37]	T20	6367 ± 1120	4862 ± 1131	1505 ± 506	106 ± 19	32 ± 10	122 ± 33
Petersen et al.[38]	OD	4544 ± 729	3441 ± 24	150 ± 25	76 ± 12	68 ± 12	55 ± 9
Petersen et al.[29]	T20	4171 ± 971	3352 ± 455	819 ± 427	70 ± 17	25 ± 18	61 ± 25
	OD	3831 ± 839	3183 ± 579	693 ± 260	64 ± 14	25 ± 7	54 ± 14
	Multi-day	3774 ± 802	3126 ± 341	648 ± 371	63 ± 13	38 ± 31	56 ± 29
Petersen et al.[40]	OD	4279 ± 677	3584 ± 759	694 ± 168	71 ± 11	73 ± 21	52 ± 11
Vickery et al.[35]	OD	4653 ± 1743	3733 ± 1152	977 ± 527	77 ± 28	19 ± 6	114 ± 46
Vickery et al.[41]	OD	3389 ± 1038	2927 ± 935	441 ± 121	54 ± 15	13 ± 6	62 ± 17

OD: one-day; T20: Twenty20.

consideration for coaches when developing annual training plans for fast bowlers, as they will need to ensure that the workloads and the physical intensities at which fast bowlers train replicate that of the upcoming matches across the season.

In addition to differences between match formats, the existing literature has also highlighted variations in the physical demands experienced between playing levels. Amateur fast bowlers perform at lower match intensities compared to their elite counterparts, despite shorter recovery ratios and a similar number of high-intensity efforts.[41] It is possible that these shorter recovery times somewhat explain the overall lower match intensities at which amateur fast bowlers perform in comparison to elite players. This difference highlights that high-intensity activity could be a determining factor between elite and amateur performance within fast bowlers and, needs to be a consideration in the development of training programs by coaching staff.

It should be noted, however, that the current research detailing the physical demands imposed on fast bowlers does not provide separate accounts of the movements performed while bowling and those that are completed when these players are not bowling (i.e. in the field). This gap in the available data makes it difficult for coaches who may seek to develop a training session which only focuses on the movement patterns and characteristics typical of fast bowling within a match. However, given that fast bowlers must remain on the field during the entire innings and can be called upon to bowl at any point during a match, the physical demands which occur between bowling spells (i.e. those times during an innings when a bowler is not performing the bowling action and is fielding) are just as vital to performance as the bowling-specific movement demands and should be considered when developing a training program.

Physical demands of fast bowlers during training and simulation protocols

There is a growing body of evidence that has reported on the physical demands of fast bowlers in a variety of environments. The training activities used by cricket coaches can typically be classified by training form and playing form.[42] Firstly, training form is defined as those activities practised in isolation or in small groups lacking competitive aspects, such as net-based batting and bowling as well as fielding drills.[42] Information regarding the physical demands of fast bowlers during training form activities such as net-based bowling is surprisingly limited despite this being the most common method for cricket training. Despite this, it has been demonstrated that amateur fast bowlers covered a greater distance during net-based training sessions when compared to the other playing positions with 32% of training time completed at a high intensity.[41] When compared to OD match-play, amateur fast bowlers covered an extra 278 m and 69 high-intensity efforts per hour during a net bowling session[43] suggesting that physical demands of these net-based sessions do provide a match-specific stimulus. However, they exceed the physical demands of a typical OD match which if not properly managed by coaching staff may predispose bowlers to overtraining.

More recently though, it has been reported that the total distance covered by elite fast bowlers during training varies depending on the training format, which is typical of the second way that training can be classified, that being playing form.[44] Playing form refers to those activities which replicate the competitive structure of a match.[42] While the net-based format is the more common cricket training session adapted, Vickery et al.[35] highlighted that the high-intensity demands of elite fast bowlers during game-based training more closely replicated the relative high-intensity distance (net-session: 32%, game-based: 20%, OD match: 21%) (refer to Tables 1 and 2) covered during match-play. Additionally, greater physical demands were also imposed during cSSG when compared to an OD match. Specifically, amateur fast bowlers covered a greater high-intensity distance (1.1 ± 0.5 km) compared to OD match-play (0.4 ± 0.1 km), mainly due to the more frequent high-intensity efforts performed (219 ± 59 $\# \cdot h^{-1}$ vs. 62 ± 17 $\# \cdot h^{-1}$) (Table 2). In the same study,[41] amateur fast bowlers covered a total of 5.0 ± 1.7 km at a mean speed of $93 \pm 29\,m \cdot min^{-1}$. A significantly ($P < 0.05$) greater distance was completed at a high intensity (1.1 ± 0.4 km) as well as more high-intensity efforts (184 ± 61 $\# \cdot h^{-1}$) than during OD match-play. Vickery et al.[45] demonstrated that the physical demands of amateur fast bowlers during cSSG training could also be altered through the manipulation of rule constraints and the physical environment. Different cSSG resulted in the total distance and high-intensity efforts still replicating or in some cases exceeding that of a typical OD match[45] (Table 2). Although it was stated that no specific constraints led to a greater physical demand during cSSG training, is was apparent that the physical demands imposed on these players[45] increased compared to the original scenario used within an earlier study.[34] Importantly for those looking to develop conditioning sessions alongside typical match training activities (i.e. bowling), it appears that this can be completed with the manipulation of the playing rules and the environment such as changes to the run up for bowlers between deliveries which limited the rest period between each ball bowled. These studies suggest that with the use of playing form activities, fast bowlers are likely to provide physical demands that replicate or exceed that of match-play.

Prior to GPS devices being used in a competitive match, simulation protocols were used to determine the physical demands of fast bowlers. Duffield et al.[46] had an elite fast bowling cohort complete two 6-over spells which were separated by low-intensity activity designed to replicate match movement patterns. In this study, Duffield et al.[33] reported that elite fast bowlers covered 6546 ± 885 m, with 77% of this distance covered at low intensities. Further, Minett et al.[47,48] had fast bowlers undertake 6- (amateur) and 10-over (elite) bowling spells which also included varied other sport-specific activities designed to simulate fielding movements. During this protocol, fast bowlers completed 4328 ± 707 m and 8676 ± 1295 m during the 6- and 10-over bowling spells, respectively. When compared to Duffield et al.[46] and match data (Table 1), Minett et al.[47,48] reported a lower percentage of distance was covered at a low intensity (59–61%); however, this variance could have resulted from the different classification of low-intensity activities (low-intensity activity: Duffield et al.[46]: $< 14\,km \cdot h^{-1}$; Minett et al.[47,48]: $< 7\,km \cdot h^{-1}$). As noted previously,[49,50] this lack of consistency at classifying velocity zones and high-intensity efforts makes the transference of information difficult for practitioners wishing to use this information for the development of individualised training programs. Furthermore, it is unclear whether the protocols used by Duffield et al.[46] and Minett et al.[47,48] were based on the physical demands of either elite or amateur fast bowlers as determined from movement analysis studies as information from GPS devices was not available and therefore may limit the ecological validity of the results. The current literature provides sufficient information regarding the differing physical demands associated with fast bowling levels although coaches should ensure they recognise the benefits and limitations associated with different training formats. Collectively though, existing literature surrounding the physical demands of fast bowlers during training suggests that coaching staff should recognise there is a range of training activities that can be used in the development of cricket fast bowlers.

Table 2. Physical demands of fast bowlers during net-based training and game-based sessions (mean ± SD).

Study	Training format	Total distance ($m \cdot h^{-1}$)	Low-intensity distance ($m \cdot h^{-1}$)	High-intensity distance ($m \cdot h^{-1}$)	Mean speed ($m \cdot min^{-1}$)	Recovery ratio (1:x)	# High-intensity efforts (h^{-1})
Vickery et al.[34a]	cSSG	3673 ± 833	3157 ± 693	500 ± 203	60 ± 10	46 ± 29	83 ± 37
Vickery et al.[41]	Net-based	4249 ± 1125	3128 ± 934	1090 ± 459	71 ± 19	23 ± 31	219 ± 59
	cSSG	4970 ± 1735	3837 ± 1437	1053 ± 397	93 ± 29	21 ± 33	184 ± 61
Vickery et al.[35]	Net-based	4931 ± 788		1573 ± 370			11 ± 3
	CW	3854 ± 795		771 ± 385			28 ± 15

[a]Adapted to relative time based on duration provided within the study.

Note: The study of Duffield[46] and Minett et al.[48] did not provide duration of simulation protocol and Minett et al.[47] only included an approximate duration therefore relative distances could not be calculated.

CW: centre-wicket.

Physical demands of spin bowlers during a match

When compared to fast bowlers, less data are available that details the physical demands of spin bowlers during match-play, which may be due to the fewer spin bowlers typically selected onto a cricket team. To date, only Petersen et al.[29,37] and Vickery et al.[35,41] have reported on the movement patterns and characteristics of elite or amateur spin bowlers. Petersen et al.[37] first reported that the physical demands of elite spin bowlers during T20 matches were more intensive than the longer match formats, with the relative high-intensity distance observed between 9 and 14% and 7 and 9% for T20 and OD matches, respectively. This observation differs to elite fast bowlers, most likely as a result of differences in the bowling run-up length and intensity. Spin bowlers are less likely to reach high running speeds during their pre-delivery run-up as they use a shorter route performed at a slower speed than fast bowlers. It has also been demonstrated that the physical demand placed upon amateur spin bowlers are considerably less than elite spin bowlers (Table 3). As with elite spin bowlers, amateur spin bowlers have also been observed to complete a small percentage of total distance during limited overs cricket (OD and T20) at a high intensity (Table 3). Within the current scientific literature, no information currently exists which highlights the movement patterns of spin bowlers during MD matches. Therefore, it is difficult for coaches to develop training approaches based on match data to stress the physical demands of spin bowlers adequately; however, it is apparent that spin bowlers perform at considerably lower physical intensities than fast bowlers.

Physical demands of spin bowlers during training and simulation protocols

To date, only Vickery et al.[35,41] has reported on the physical demands of elite and amateur spin bowlers during either typical net-based training, game-based training scenarios, or simulation protocols. Compared to OD matches, game-based (CW) sessions provided elite spin bowlers with the closest physical demands as demonstrated by the greater proportion of high-intensity distance (Table 4).[35] Furthermore, playing form activities such as CW training provides elite spin bowlers with greater physical demands than net-based training formats (Tables 3 and 4), suggesting that playing form training sessions may better develop the fitness capacities needed to perform high-intensity movements during match-play. However, the information regarding physical demands of amateur spin bowlers is limited.[41] The results from this study showed the physical demands of net- and game-based (cSSG) sessions exceeded that of

Table 3. Physical demands of spin bowlers during various match formats (mean ± SD).

Study	Match format	Total Distance ($m{\cdot}h^{-1}$)	Low-intensity distance ($m{\cdot}h^{-1}$)	High-intensity distance ($m{\cdot}h^{-1}$)	Mean speed ($m{\cdot}min^{-1}$)	Recovery ratio (1:x)	# High-intensity efforts (h^{-1})
Petersen et al.[37]	T20	6403 ± 1176	4753 ± 1111	457 ± 504	107 ± 20		42 ± 26
Petersen et al.[29]	T20	3292 ± 640	2995 ± 492	297 ± 148	55 ± 11	63 ± 36	5 ± 4
	OD	3166 ± 536	2872 ± 393	294 ± 143	53 ± 9	54 ± 16	4 ± 1
Vickery et al.[35]	OD	3486 ± 1248	2974 ± 834	499 ± 420	61 ± 25	55 ± 38	59 ± 49
Vickery et al.[41]	OD	1749 ± 338	1689 ± 324	57 ± 16	30 ± 5	92 ± 150	7 ± 2

OD: one-day; T20: Twenty20.

Table 4. Physical demands of spin bowlers during net-based training and game-based sessions (mean ± SD).

Study	Training format	Total distance ($m{\cdot}h^{-1}$)	Low-intensity distance ($m{\cdot}h^{-1}$)	High-intensity distance ($m{\cdot}h^{-1}$)	Mean speed ($m{\cdot}min^{-1}$)	Recovery ratio (1:x)	# High-intensity efforts (h^{-1})
Vickery et al.[34a]	cSSG	2677 ± 607	2447 ± 537	227 ± 113	43 ± 2	84 ± 42	37 ± 13
Vickery et al.[41]	Net-based	3419 ± 951	3196 ± 861	209 ± 332	61 ± 7	231 ± 278	135 ± 53
	cSSG	3172 ± 658	2900 ± 500	261 ± 226	53 ± 11	109 ± 81	40 ± 41
Vickery et al.[35]	Net-based	2975 ± 619	2904 ± 589	64 ± 163	50 ± 10	725 ± 549	72 ± 73
	CW	3075 ± 747	2801 ± 654	262 ± 141	51 ± 12	79 ± 47	42 ± 25

[a]Adapted to relative time based on duration provided within the study.
CW: centre-wicket.

a OD match (Tables 3 and 4). As with fast bowlers, despite the benefits of the game-based training at replicating the physical demands of match-play, this needs to be correctly managed by coaching staff to limit the chance of these bowlers from overtraining or becoming fatigued. This, however, may not be of importance due to the lower intensity at which spin bowlers perform in comparison to their fast bowling counterparts. Further to this, Vickery et al.[45] failed to examine the influence of different game-based scenarios on the physical demands encountered by amateur spin bowlers. While no differences were reported between scenarios, it was suggested that game-based training sessions replicate the physical demands of match-play and should be frequently used to simulate game-based scenarios during training.[45] Unfortunately, as previously stated, the current information regarding the physical demands of spin bowlers is limited due to the small number of spin bowlers typically on a cricket team. This limited number of spin bowling positions on a team limits the quantity of data that can be collected during a series of matches. Therefore, more research should continue to investigate the physical demands of spin bowling to better understand the demands imposed on this position during training and match-play for the development of position-specific physical conditioning programs.

Physiological and perceptual responses of bowlers

Little information regarding the physiological intensity of cricket match-play existed when the most recent review by Johnstone et al.[20] was published. Since this time, several studies have reported on the physiological responses of cricket players during matches, training sessions and simulation protocols, although the majority of research has been limited to investigating the heart rate (HR) responses of bowlers. Previous attempts to review this information have not provided sufficient detail for practitioners.[31,51] The following sections provide a detailed overview of the literature pertaining to the physiological responses associated with cricket bowling during match-play and training which will be useful for coaches looking to develop match-specific training programs for their bowlers.

Physiological and perceptual responses of fast bowlers during a match

In one of the only studies to quantify and examine the of fast bowling to date using current technology, which examines both the physical and physiological demands associated with elite fast bowling during match-play, Petersen et al.[29] reported average mean and maximum heart rates of $133 \pm 12\,\text{b}\cdot\text{min}^{-1}$ and $181 \pm 10\,\text{b}\cdot\text{min}^{-1}$, respectively, during an elite T20 match. Unfortunately, the limited sample size used in this study restricts a complete understanding of the physiological demands associated with each format for elite fast bowlers. In more recent research though, higher mean heart rates (HR_{mean}) have been reported in elite ($148 \pm 9\,\text{b}\cdot\text{min}^{-1}$) and amateur ($142 \pm 5\,\text{b}\cdot\text{min}^{-1}$) fast bowlers during OD matches, which may be a result of the greater high-intensity activity performed by elite fast bowlers.[35,41] In both of these studies, the majority of playing time was spent between 50 and 75% of each player's maximum heart rate (HR_{max}).[35,41] Elite fast bowlers spent a greater percentage of time above 75%HR_{max} ($41 \pm 20\%$)[35] compared to amateur fast bowlers ($33 \pm 20\%$),[41] suggesting that higher performance levels evoke greater physiological intensities. Regardless of the format or playing level, however, the varied HR response of bowlers appears is likely to reflect the intermittent physical demands of bowling that has been previously highlighted. This intermittent nature of fast bowling should be replicated where possible within any future training programs which are implemented by coaches to ensure that match-specific intensities and energy metabolism are provided within the training of fast bowlers.

Despite the association between HR and rating of perceived exertion (RPE) during exercise,[52–54] limited information on the perceptual responses of fast bowlers during match-play currently exists. Furthermore, the importance of perceptual measures in cricket, such as RPE, is highlighted by its continued use as a workload monitoring tool for fast bowlers.[44,46,55] The limited information available suggests that both elite and amateur fast bowlers perceive their activities during OD matches to range from hard to very hard,[35,41] although it should be noted that these data represent responses across an entire innings which involves fielding and therefore may not be solely based on fast bowling performance. When comparing differing playing levels, the perceived intensities of fast bowling during a OD match was higher in amateurs (7.4 ± 0.9) compared to elite players (6.1 ± 1.0).[35,41] Therefore, the greater cardiovascular response in elite fast bowlers as noted previously appeared to not result in higher perceptions of exertion. However, it is possible the superior fitness of the elite fast bowlers due to their greater training workload may change the relationship between the HR and RPE. However, given the multifactorial nature of the RPE response, other physiological mediators (e.g. hormone concentrations, neurotransmitter levels)[56] as well as situational factors (e.g. attentional focus)[57] and trait characteristics (e.g. self-efficacy, extraversion)[58] may also underpin variations in RPE data reported between elite and sub-elite bowlers, Previously, Gore et al.[59] examined the impact of environmental factors on the physiological state of amateur fast bowlers during actual and simulated match-play. As expected, there was an increased thermoregulatory stress reported during the warmer playing conditions than cool, with the sweat rate of amateur fast bowlers significantly ($P < 0.05$) increasing relative to temperature (cool: $0.50\,kg \cdot h^{-1}$, warm: $0.70\,kg \cdot h^{-1}$, hot: $1.37\,kg \cdot h^{-1}$). These data coincided with greater levels of dehydration in warmer conditions.[59] Although it should be noted that players only performed once during actual match conditions (hot scenario: $\geq$38°C), whereas a match simulation which does not appear to be based on match-specific movement data was used for the cooler environments (warm: 30°C; cool: 22°C), limiting the ecological validity of the results. Moderate levels of dehydration have been shown to negatively impact fast bowling performance albeit during a simulated match protocol.[60] Soo and Naughton[61] attempted to further understand the impact of hydration within elite female cricket players during a four-day tournament. These authors reported that changes in body mass ($-0.38 \pm 0.74\%$) and sweat rate ($-0.27 \pm 0.25\,L{\cdot}h^{-1}$) occurred as a result of cricket match-play, although the environmental conditions and variability in activity levels may have led to modest results. Despite these results, the lack of consistency between playing and training conditions in each study suggest further research is still required to determine how fast bowlers respond when playing in all match formats across varying environmental conditions. This knowledge is of high importance for those coaching within countries that experience excessively high outdoor temperatures to ensure that workloads and performance in fast bowlers are managed to limit the risk of heat-related injuries and fatigue.

Physiological and perceptual responses of fast bowlers during training and simulation protocols

Although match data exist, the majority of data has reported on the HR responses of fast bowlers during training activities and simulation protocols. In line with the physical demands, any increases in HR are sporadic[4,,46,62] and are representative of the intermittent nature of fast bowling (Table 5). CW practice requires elite fast bowlers to maintain a HR_{mean} of $148 \pm 16\,b{\cdot}min^{-1}$ with a considerable proportion of time ($54 \pm 29\%$) spent working in a high-intensity HR zone ($>75\%HR_{max}$).[35] Compared to CW practice, elite fast bowlers perform at lower physiological intensities during net-based training ($128 \pm 17\,b{\cdot}min^{-1}$; $>75\%$ HR_{max}: $28 \pm 15\%$ time). Further, during cSSG training ($152 \pm 32\,b{\cdot}min^{-1}$; $>75\%HR_{max}$: $63 \pm 24\%$), amateur fast bowlers were able to maintain physiological intensities above that of OD matches ($>75\%HR_{max}$: $33 \pm 12\%$).[41] Unlike the more generic cSSG scenario, changes to the playing rules and environment led to a cardiovascular response that was more representative of match-play as it was observed that the time spent performing $>75\%HR_{max}$ ranged between 32 and 42%.[45] When compared to studies examining net-based training protocols HR_{mean} varied considerably which includes the studies of Duffield et el.[46] who included low-intensity activity between two 6-over spells ($162 \pm 11\,b{\cdot}min^{-1}$), as well the typical net-based training protocols without the inclusion of fielding activities ($171 \pm 10\,b{\cdot}min^{-1}$, $153 \pm 10\,b{\cdot}min^{-1}$) used by Burnett et al.[4] and Stretch and Lambert.[62] In these studies, no information pertaining to the time spent in different HR intensity zones was provided limiting the comparisons able to be made with other methods of cricket training. Therefore, while these net-based training protocols were designed to replicate the physiological responses of a match, the HR_{mean} of these elite fast bowlers achieved during playing form training such as cSSG may be more beneficial for developing the conditioning status of fast bowlers than the traditional net-based sessions as they more closely replicate the HR response of T20[29] and OD matches.[35]

Another physiological response monitored in elite fast bowlers was measured by Burnett et al.[4] where it was reported that blood lactate concentrations ([BLa$^-$]) ranged between 4.4 and $5.1\,mmol{\cdot}L^{-1}$ throughout a simulated 12-over fast bowling spell. Similar values have also been reported when a similar bowling spell was divided into two spells of six overs

Table 5. Heart rate of senior fast bowlers during net-based bowling protocols (mean ± SD).

	Over number												
Study	1	2	3	4	5	6	7	8	9	10	11	12	Mean ± SD
Burnett et al.[4]	163 ± 11	170 ± 8	174 ± 11	175 ± 13	175 ± 12	176 ± 12	166 ± 8	172 ± 10	173 ± 8	169 ± 9	170 ± 10	172 ± 8	171 ± 10
Stretch and Lambert[62]	149 ± 11	152 ± 10	153 ± 10	155 ± 10	155 ± 78	156 ± 78							153 ± 10
Duffield et al.[46]	160 ± 13	160 ± 13	160 ± 13	160 ± 13	160 ± 13	160 ± 13	159 ± 13	159 ± 13	159 ± 13	159 ± 13	159 ± 13	159 ± 13	160 ± 13

(4.7–5.0 $mmol \cdot L^{-1}$).[46] However, amateur fast bowlers possessed a significantly ($P < 0.05$) lower [BLa$^-$] during net-based sessions (1.8 ± 0.6 $mmol \cdot L^{-1}$) when compared to game-based training (2.7 ± 1.5 $mmol \cdot L^{-1}$). Moreover, when the playing environment and rule constraints were manipulated to include a pair of bowlers rotating between deliveries, [BLa$^-$] decreased to 1.6 ± 0.7 $mmol \cdot L^{-1}$.[45] This lower [BLa$^-$] during cSSG was attributed to the periods of low-intensity activity completed between each over. While bowlers perform a high-intensity run-up (5.7 ± 0.5 $m \cdot s^{-1}$) prior to each delivery, there is an active recovery period of between 20 and 30 s where they walk back to their starting position following each delivery that allows for lactate oxidation.[4] Duffield et al.[46] however, reported that bowlers with a faster run-up speed recorded a higher [BLa$^-$], which most likely is due to the higher anaerobic metabolic recruitment of more sprint capable athletes. Further information regarding other biochemical markers which result from fast bowling performance has at this point only been reported within the studies of Minett et al.,[47,48] whereby biochemical markers of muscle damage and inflammation were measured during fast bowling simulations and in the following recovery period in hot conditions (30.4–31.9°C). Alongside the considerable physical load that occurs during a fast bowling spell, Minett et al.[47,48] reported increases in creatine kinase or C-reactive protein (although no significant differences were reported) following a 6- (229-389 $U \cdot L^{-1}$; 3.0–3.5 $U \cdot L^{-1}$) or 10-over bowling spell, respectively. It should be noted that exact values were not reported for biochemical measures within Minett et al.[48] However, following a 10-over spell, a significant ($p < 0.05$) rise in creatine kinase was reported suggesting that muscle damage caused by fast bowling may not appear immediately following performance and appropriate recovery strategies to limit this damage such as pre-cooling of the muscles should be considered.[47,48] Noakes and Durandt[63] have suggested muscle damage may be due to repeated eccentric muscle contractions, particularly in the lower limbs in the case of fast bowlers, which occur during a typical bowling delivery however this is still yet to be investigated.

Lastly, the RPE of elite fast bowlers following a two 6-over simulation protocol was 6.5 ± 0.8,[46] which was higher than that reported for net-based training (5.2 ± 1.2) and similar to cSSG training (6.2 ± 1.4). During sessions in which the playing environment and rules were manipulated, similar perceptual responses were also reported (4.7–6.0). Therefore, the increased physical demands of fast bowlers during these playing form sessions due to the inclusion of fielding during the bowling spell, most likely accounts for this increased RPE in comparison to net-based training sessions. Collectively, these data demonstrate that specific physiological responses are easily modifiable with the integration of various training methods.

Physiological and perceptual responses of spin bowlers during a match

Despite the smaller number of studies which have focused on spin bowlers, understanding the physiological responses during match-play of these players is no less important due to their integral part in the cricket team. Initially, Petersen et al.[29] reported the HR response of elite T20 spin bowlers (HR_{mean}: ~135 $b \cdot min^{-1}$; HR_{max}: ~175 $b \cdot min^{-1}$). More recently, Vickery et al.[35,41] reported a HR_{mean} of 125 ± 18 $b \cdot min^{-1}$ during OD matches, with only 5 ± 6% of this being > 75%HR_{max} which is considerably less than that of fast bowlers from the same study. This discrepancy is likely to reflect the significantly ($P < 0.05$) greater high-intensity workload of elite fast bowlers related to the high-speed runner involved in their run up.[35] A similar HR_{mean} (121 ± 19 b min^{-1}) was reported in amateur spin bowlers; however, a significantly ($P < 0.05$) greater time was spent performing > 75%HR_{max} (24 ± 28%)[41] when compared to that of their elite counterparts. This research remains the only information currently available regarding the HR responses of spin bowlers during match-play. Further to this, no data are available that details the [BLa$^-$] responses of spin bowlers throughout any competition level or match format. Vickery et al.,[41] however, did report RPE values of 4.9 ± 1.0 and 4.8 ± 2.1 in elite and amateur spin bowlers during OD matches, respectively which is lower than that reported for the fast bowlers and mirrors the decreased intensity shown in the heart rate responses. The lower intensity demand (in comparison to fast bowlers) likely accounts for the decreased physiological responses of spin bowlers, suggesting that conditioning programs designed for spin bowlers need to differ to those used for fast bowlers and other playing positions.

Physiological and perceptual responses of spin bowlers during training and simulation protocols

As with the provided match data, limited data exist; however, recent research has quantified the HR responses of spin bowlers during net-based training and playing form activities.[41,44] The HR_{mean} of elite spin bowlers of net-based training was 130 ± 14 $b \cdot min^{-1}$, with 91 ± 19% of the total duration spent performing at ≤ 75%HR_{max}. Similar values were reported during CW simulations (130 ± 22 $b \cdot min^{-1}$), although slightly less time was spent working at $\leq 75\%HR_{max}$ ($84 \pm 58\%$).[35] Interestingly, a higher HR_{mean} was reported while bowling in the nets by amateur spin bowlers (143 ± 16 b·min^{-1}), which was combined with less time performing at $< 75\%HR_{max}$ ($64 \pm 33\%$). Of particular note, game-based training evoked the highest reported HR_{mean} (152 ± 19 b·min^{-1}) for spin bowlers with less time spent working at $\leq 75\%HR_{max}$ ($41 \pm 43\%$).[41] Further, manipulating the environment and rule constraints of cSSG resulted in large fluctuations in the HR_{mean} of amateur spin bowlers (131–162 b·min^{-1}), although the majority of time was still spent performing at a heart rate $\leq 75\%HR_{max}$ (90–91%) when the number of players was reduced and changes to the playing rules including continuous bowling between a pair of bowlers were made.[45]

A lack of information exists regarding the [BLa$^-$] of spin bowlers making it difficult to determine the anaerobic requirements of spin bowlers during training and whether this adequately replicates match-play. Vickery et al.[41] reported that during net-based sessions, the [BLa$^-$] of amateur spin bowlers was 1.3 ± 0.4 mmol·L^{-1}, and slightly higher during cSSG (1.4–1.9 mmol·L^{-1}).[34,41] Furthermore, changing the constraints of the session had limited impact on [BLa$^-$] (1.0–1.9 mmol·L^{-1}).[45] Based on this information, the role of a spin bowler during training activities may not be physiologically demanding due to a limited reliance on anaerobic glycolysis for energy provision.

Separately, the RPE of amateur spin bowlers was 5.2 ± 1.4 following net-based training, which is considerably higher than elite spin bowlers (3.6 ± 0.8) for similar training application.[41] Elite spin bowlers reported a higher RPE (4.1 ± 1.0) during CW practice[35] which was similar to the RPE of amateur spin bowlers during cSSG training (4.2 ± 1.4).[41] In line with other physiological measures, amateur spin bowlers displayed wide variance in their perceived intensity of cSSG training (RPE: 3.0–5.5) when the training scenario was manipulated (changes to playing rules and environment).[45] Despite showing some overlap between the physiological intensities encountered between training and match-play, the available research suggests that the physiological demands of spin bowlers during any form of training does not consistently replicate that of a OD match. Due to the limited number of studies which have reported on the physiological intensities of spin bowlers, any further comparison to match-play is difficult. It could be suggested that the more traditional cricket training methods (i.e. net-based training) may not allow spin bowlers to train at match intensity which in turn may not provide these players with sufficient match conditioning. Vickery et al.[35] proposed that the inclusion of the fielding component of playing form activities such as CW and cSSG allowed these protocols to most closely replicate match-play.

Future research

With the increased use of monitoring technology in high performance sport there exists an opportunity for a more detailed examination of the physical demands of bowlers to be completed. For example, microtechnologies currently have the capacity to provide information on the directional and technical movements completed by players amongst other measures. As such, researchers should look to increase the amount of information available for coaching staff in order to develop more specific training programs for their bowlers by reporting on aspects of movement such as the accelerations and decelerations experienced by bowlers during match-play and training as well as the differing movement demands associated with the bowling action and fielding. A lack of consistency also currently exists in the measures used to quantify and examine the movement characteristics and patterns with particular reference to velocity-based criteria used to determine speed. As has been suggested previously in this review and within other sports,[49,50] future research should look to standardise the velocity zones and high-intensity efforts within the sport of cricket to provide greater consistency for practitioners which will lead to a more position specific training programs to be developed.

As noted earlier, much of the research has been conducted on the prevalence of injuries in cricket players,[5,10,64–69] with the majority of studies reporting that these injuries are linked to a player's bowling technique and overuse.[5,24,70–72] Previous research has demonstrated a lower incidence of training injuries during game-based training compared to traditional conditioning activities in other team sports, such as rugby league.[73] However, no information exists detailing the correlation between playing form activities and the likelihood of incurring cricket-related injuries. Additionally, it still remains unknown if the use of these playing form methods which aim to concurrently develop physical conditioning and technical ability in bowlers provide a physical stimulus which replicates that achieved during more traditional conditioning methods. Future research therefore must continue to further understand the game-based scenarios such as cSSG that are becoming more popular.

A notable underrepresentation from the current research is the examination of the physical or physiological demands of female cricket bowlers. Given the differences in the playing schedules, physiological capacities and match formats of each gender, it is likely the demands associated with each will differ. Therefore, coaches and researchers should investigate match responses and explore specific conditioning programs and specific training responses in female cricket players.

Conclusion

There is an increasing amount of literature which has become available in recent times which quantifies the playing demands placed upon cricket players and specifically bowlers. Presently, it is known that the physical and physiological demands of bowlers vary greatly across the different match and training formats. Typically, a shorter match format leads to a greater physical and physiological response, particularly amongst fast bowlers. Spin bowlers by comparison tend to perform at much lower physical and physiological intensities than fast bowlers most likely due to the lower speeds reached and difference in the associated movement patterns. Training programs developed by coaches as such must endeavour to transfer this knowledge into practice to ensure that their bowlers are more likely to train in a match-replicable environment. It can also be suggested that the current training methods used in cricket may not best replicate the demands of match-play. Current research supports the use of a more game-based approach than traditional net-based training in isolation. Regardless of the type of bowler, game-based activities appear to provide an environment for a bowler which replicates more closely the physical and physiological demands associated with match-play. It should be noted that due to the considerable differences in physical demands and physiological responses experienced by fast and spin bowlers, training programs developed by coaches must be specific to playing position.

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