A review of the internal and external physiological demands associated with batting in cricket

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Aaron T. Scanlan,[1,2] Daniel M. Berkelmans,[1] William M. Vickery,[3] and Crystal O. Kean[1]

[1]School of Medical and Applied Sciences, Building 81, Central Queensland University, Bruce Highway, Rockhampton, Australia.
[2]Human Exercise and Training Laboratory, Building 81, Central Queensland University, Bruce Highway, Rockhampton, Australia.
[3]Department of Sport, Exercise and Rehabilitation, Northumberland Building, Northumbria University, Newcastle Upon Tyne, United Kingdom.

✉ Dr Aaron T Scanlan
Human Exercise and Training Laboratory Director
Central Queensland University
Bruce Highway
Rockhampton, Queensland, 4702
Australia
Phone (international): +61 7 4923 2538
Fax (international): +61 7 4930 6781
Email: a.scanlan@cqu.edu.au

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ABSTRACT

Cricket is a popular, international team sport with various game formats ranging from long duration multi-day tests to short duration Twenty20 game-play. The role of batsmen is critical to all game formats with differing physiological demands imposed during each format. Investigation of the physiological demands imposed during cricket batting has historically been neglected with much of the research focusing on bowling responses and batting technique. A greater understanding of the physiological demands of the batting role in cricket is required to assist strength and conditioning professionals and coaches with the design of training plans, recovery protocols, and player management strategies. This brief review provides an updated synthesis of the literature examining the internal (e.g. metabolic demands, heart rate) and external (e.g. activity work rates) physiological responses to batting in the various game formats as well as simulated play and small-sided games training. While few studies in this area exist, the summary of data provides important insight regarding physiological responses to batting, and highlights that more research on this topic is required. Future research is recommended to combine internal and external measures during actual game-play as well as comparing different game formats and playing levels. In addition, understanding the relationship between batting technique and physiological responses is warranted to gain a more holistic understanding of batting in cricket as well as develop appropriate coaching and training strategies.

Key Words: batsmen; heart rate; lactate; RPE; GPS; time-motion analysis.

INTRODUCTION

Cricket is an international team sport with 105 member countries recognized by the International Cricket Council, spanning Africa, the Americas, Asia, East-Asia-Pacific, and Europe.[1] Modern cricket involves two teams of 11 players and is played on a field containing a pitch with a set of three wooden stumps at each end.[2] The focal point of cricket is the contest between bat and ball, with three primary functional roles being identified: batting, bowling, and fielding. The objective when bowling and fielding is to dismiss 10 batsmen (10 wickets) while minimizing the amount of runs scored. Conversely, the batting team aims to strike the ball through or over the field, scoring runs if the ball reaches the boundary (4 or 6 runs) or if the batsmen run the length of the pitch (individual runs given per length completed). Ultimately, the batting team attempts to accumulate more runs than the opposing team. Batsmen can be dismissed by various means including being bowled, caught, stumped, run out, leg before wicket (stumps), and hitting the stumps.

In recent times there has been an increase in the volume of cricket played across the annual season, as well as enhanced commercialization of the sport. This evolvement has promoted a more professional, structured approach to travelling, training, game preparation, and recovery using scientific concepts. Consequently, greater research attention is being given to various aspects of cricket to better understand the demands placed on players during games, simulated play, and training.[3-12] Researchers have primarily focused on examination of bowling and fielding in cricket, resulting in numerous focused reviews in this area.[13-17] Although less inquiry is available regarding batting in cricket, a greater understanding of the physiological responses and technical attributes associated with this role has emerged in the literature across several examinations in the past decade. Consequently, there is a need for a contemporary synthesis of the literature regarding batting responses in cricket, with the only available review examining physiological responses conducted in 2000.[18] In turn, a more recent review focusing on batting technique and biomechanics was conducted in 2012.[19] As very little biomechanical research related to cricket batting has been conducted since the review by Penn and Spratford,[19] the aim of this review is to focus on synthesizing the literature related to internal and external physiological responses to batting in cricket.

SEARCH STRATEGY

A comprehensive search of the online library databases provided by Central Queensland University, as well as Google Scholar and PubMed was conducted to locate potential sources for this review. No time restrictions were set and the following combination of terms were entered: ‘cricket’, ‘batting’, 'batsmen', 'responses', 'physiology', 'heart rate', 'metabolic', 'perceptual', and 'activity'. Reference lists of identified publications were searched to locate additional sources. The quality of retrieved publications were assessed using various items from the critical review form for quantitative studies developed by Law et al.[20] Given the observational nature of the included studies, aspects related to study design, intervention, and drop-outs contained in the original critical review form were excluded in our evaluation. Evaluations for each publication are presented in Table 1, with study limitations provided in further detail. Almost all of the retrieved publications (89%) scored $\geq$7 out of 10 in the evaluation.

INSERT TABLE 1 AROUND HERE

GAME FORMAT

Various factors can alter the physiological responses to batting in cricket, the most prominent being game format. The traditional game format in cricket involves multi-day competition with up to 5 days (90 overs per day) for each team to bat and bowl across two separate innings. A winning outcome is achieved if a team dismisses 20 batsmen (2 innings x 10 wickets) for a lower aggregate run total. A shift toward shorter games emerged in the 1970s with the game outcome produced in a single day.[21] The One-Day format adopts a similar approach to multi-day competition, but each team only bats and bowls across a single innings (1 innings x 10 wickets) and games are limited to 50 overs per team. The trend of producing shorter game formats continued with Twenty20 cricket being developed in 2003. Twenty20 cricket is played across 20 overs per team, with each game lasting approximately 3 hours.

Player requirements in cricket can be altered across the different game formats.[8,9,22] For instance, batting performance during a Twenty20 game necessitates a higher rate of scoring strokes compared to a multi-day game where less time restrictions are encountered.[23] In turn, these temporal constraints promote a higher urgency for attacking play and running between wickets to score runs during shorter game formats. Thus when gathering evidence regarding batting responses from the available literature, readers should be aware of the game format being investigated as each format is likely to impose unique requirements upon players. We have included all game formats in this review.

PHYSIOLOGICAL RESPONSES TO BATTING IN CRICKET

Understanding the physiological requirements of team sports forms the basis of designing conditioning programs which promote adaptation in players to optimize physical preparedness for competition.[8] With the growing application of sport science and evolvement of advanced measurement techniques, increased research has been conducted examining the physiological responses to batting in cricket. The primary measures examined in the literature can be broadly categorized as internal and external responses.

Internal Responses

Measurement of internal responses to game-play and training provide important insight into the physiological stress imposed upon athletes across various body systems.[24] To date, a range of internal responses to batting in cricket have been reported in the literature. Specifically, internal measures primarily examined include metabolic responses, heart rate (HR), blood lactate concentration ($[BLa^-]$), and rating of perceived exertion (RPE). A summary of the internal physiological responses observed during batting in cricket studies is presented in Table 2.

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Metabolic Responses

Early research reporting on the physiological responses to batting utilized portable calorimetry during batting tasks during practice to estimate the energy expenditure during actual game-play.[25] Fletcher[25] estimated energy expenditure to be 648 $kJ \cdot h^{-1}$ for batsmen based upon running between wickets for 26.6 runs per hour during international multi-day cricket. The primary limitations of this research were the inclusion of drink breaks, lunch breaks, and time spent waiting to bat in calculations. These limitations, likely underestimating the requirements of competition and this notion is substantiated by more a recent investigation which shows a higher energy expenditure during batting in cricket.[3]

To analyze the physiological responses to batting, Christie et al.[3] utilized a single 7-over bout, with 30-s and 1-min rest periods between deliveries and overs respectively. A live bowler was used and batsmen completed 2 runs every 3 balls (28 runs across the protocol).[3] This configuration was based on observations made during One-Day international games, and allowed a more definitive metabolic assessment of batting to be conducted with direct use of a portable metabolic analyzer during batting. Accordingly, an energy expenditure of 2,536 $kJ \cdot h^{-1}$ was recorded in first team university batsmen during the protocol.[3] Furthermore, a mean oxygen uptake (VO_2) of 26.7 ± 1.4 $mL \cdot kg^{-1} \cdot min^{-1}$ and respiratory exchange ratio (RER) of 1.05 ± 0.05 were also observed.[3] While these data suggest a predominant recruitment of aerobic metabolic pathways (mean VO_2 ≈50% VO_{2max}) during batting, the increase in RER to 1.09 ± 0.05 following the four sprints in the first over (out of 7 overs) indicates anaerobic energy systems are also important during the short high-intensity running bouts and likely contribute to sustained elevated physiological responses thereafter. Furthermore, given RER was consistently >1 following the first over, Christie et al.[3] concluded that carbohydrates were the preferred source of energy substrate during batting tasks.

The discrepancies in metabolic responses observed in early research compared with more recent data are likely due to temporal changes in game demands and/or greater physiological stress being imposed upon batsmen during shorter game formats.[8] Nevertheless, the collective research emphasizes the lack of metabolic data representative of batting tasks in cricket, particularly during game-play. This lack of inquiry is likely due to the logistical limitations associated with administering metabolic measurement techniques using bulky and costly equipment during actual batting tasks. Consequently, many researchers have opted to use telemetric heart rate (HR) devices to estimate the metabolic demands experienced by batsmen during games and training given the greater practical utility and indirect indication of aerobic energy system recruitment accompanying HR monitoring.[26,27]

Heart Rate

HR measurement has emerged as the most popular approach to monitor the internal responses of batsmen in cricket. Researchers have provided HR measurements for batsmen across actual games, simulated play, and training scenarios. Specifically, mean absolute HR of 149 ± 17 beats·min^{-1} have been observed during Twenty20 games in second-tier international batsmen,[8] while responses of 144 ± 13 beats·min^{-1} and 159 ± 12 beats·min^{-1} were reported in second-tier international[8] and first team club batsmen[28] during One-Day games, respectively. The reported HR data also demonstrate some important time-course responses with spikes in HR showing players reach 97% of HR_{max} and spend considerable proportions of batting time (63%) working above an intensity of 75% HR_{max}.[28] Thus, while the overall mean HR in batsmen might be considered *hard* (73-78% of age-predicted HR_{max}),[29] periodic bursts of high-intensity efforts are required which suggests phosphocreatine (PCr) stores and the glycolytic energy system are relied upon for energy provision, placing the body into an oxygen deficient state and producing metabolic by-products.[30] Consequently, the oxidative energy system likely plays major roles not only in adenosine triphosphate re-synthesis, but also in PCr restoration and lactate oxidation during lower-intensity activity.[31] Moreover, comparisons across studies indicate that game format, playing level, and competition locality are likely to influence the energetic demands of batting as evidenced by varied HR responses.

While limited HR data exist representative of actual game-play, a wider scope of studies have used simulated play and training scenarios to measure the internal responses of batsmen.[3,5,6,28,32,33] Novel approaches such as BATEX[5,6,32] and The Battlezone[28,33] have been developed to replicate batting requirements during game-play. BATEX is a simulated batting innings consisting of 6 x 21-min stages with embedded rest periods, producing a performance duration indicative of scoring 100 runs in a One-Day international game.[5] Each stage consists of 5 overs in a net-based practice setting.[5] Timings of ball deliveries are based on archived game data, with each stage containing different running requirements to represent typical distributions at different game stages.[5] In contrast, The Battlezone is a small-sided game (SSG) whereby batsmen complete pre-determined frequencies of 6 bouts of 8 overs separated by 5 min of rest.[33] The Battlezone is representative of play in close proximity to the pitch within the inner circle (27.4-m diameter).[33] A net encloses the inner circle which contains two batsmen, three fielders, two bowlers (who alternate between overs), and a wicket-keeper.[33] Generally, the aim for batsmen during The Battlezone is to score as many runs as possible with encouragement to hit the ball along the ground and not over the net[33]; however coaches have the option to alter this approach to suit session objectives.

Reported HR across each of these approaches, as well as the simulated 7-over bout developed by Christie et al.[3] have been shown to vary across studies (BATEX: 130-144 beats·min^{-1}; The Battlezone: 164 ± 12 beats·min^{-1}; 7-over bout: 145 ± 11 beats·min^{-1}).[3,5,6,28,32,33] Furthermore, HR during BATEX and 7-over bout increased with protocol progression, reaching 147-159 beats·min^{-1} by the final stage/over.[3,5,6,32] Subsequently, these simulated protocols appear to invoke comparable or greater HR than those evident during Twenty20 and One-Day game-play.[8,28] Thus, the established simulation and SSG approaches in the literature may be particularly useful as training stimuli for batsmen to optimize cardiovascular adaptation in preparation for game-play. However, these observations should be treated with caution given the existing data during simulated play and SSG training are indicative of club players (first to fourth teams),[3,5,6,28,32,33] while findings during actual game-play are representative of club (first and second teams) and international players.[8,28] The higher level players likely possessed superior levels of training experience and fitness which might have influenced the HR results observed.[27] Indeed, Houghton et al.[32] showed lower-level club players (third and fourth teams) to produce greater HR responses (4-8 beats·min^{-1}) across all stages of BATEX than higher-level club players (first and second teams).

Blood Lactate Concentration

While metabolic and HR data permit assumptions to be made regarding the reliance on anaerobic metabolic pathways during batting in cricket, [BLa^-] is a more direct indicator of energy production from anaerobic glycolysis.[34] Subsequently, research reporting on [BLa^-] highlights the variable recruitment of anaerobic metabolism during batting across simulated play and SSG training. More precisely, Houghton et al.[32] observed comparable [BLa^-] in first and second team club batsmen (3.2 ± 1.6 to 4.5 ± 1.6 $mmol \cdot L^{-1}$) and third and fourth team club batsmen (3.0 ± 0.9 to 4.1 ± 1.2 $mmol \cdot L^{-1}$) during BATEX. The range of responses indicate that during BATEX, batsmen work at intensities above those associated with anaerobic threshold using fixed [BLa^-] (3-4 $mmol \cdot L^{-1}$).[35] These responses were also higher than those evident during SSG training (The Battlezone) in first and second team club batsmen (1.8 ± 0.7 to 3.2 ± 1.4 $mmol \cdot L^{-1}$).[28,33] Collectively, these data contradict the higher cardiovascular intensities (HR responses) during The Battlezone, as the [BLa^-] results indicate that batsmen do not reach intensities concomitant with anaerobic threshold as readily during The Battlezone compared to BATEX. These variations might be due to the protocols adopted across studies. The Battlezone bouts lasted between 14-18 min and batting performance was self-determined, with running between wickets conducted in an ad-hoc manner during live game scenarios.[36,37] In contrast, BATEX bouts were performed across 6 x 21-min stages with included recovery periods (total = 2 h 20 min) and increased running demands periodically elicited at maximum exertion with protocol progression.[5] Alternatively, the lower playing levels of participants examined during BATEX (club-level from first to fourth team) might have possessed inferior aerobic fitness compared with those completing The Battlezone (club-level first and second teams). In turn, this would promote recruitment of anaerobic metabolic pathways for energy provision at lower relative HR intensities in participants completing BATEX, leading to greater lactate accumulation. However, this postulation remains speculative as aerobic fitness measures were not provided in these studies.[28,32,33]

Rating of Perceived Exertion

The reported HR and [BLa^-] data provide useful insight regarding aerobic and anaerobic metabolic recruitment respectively. In turn, RPE has been suggested to be a global indicator of exercise demands encompassing both of these measures during intermittent activity.[38] RPE responses have been recorded in batsmen using 1-10 and 6-20 Borg Scales. Reported RPE scores of 4-5 (1-10 scale) and 10-17 (6-20 scale) have been observed across The Battlezone[28,33] and BATEX protocols,[5,6,32] respectively. Furthermore, RPE of 5 ± 2 (1-10 scale) has been reported during One-Day game-play in first team club batsmen.[28] These observations reflect *fairly light* to *very hard* intensities, which tend to overlap and/or exceed the descriptive intensity zones observed for HR responses,[29] adding credence to the combined anaerobic and aerobic contribution to perceived exertion in cricket.[38] Time-course comparisons across BATEX in first and second team club batsmen suggested that RPE increased as a function of duration rather than intensity, given greater increases in perceptions of effort were observed than other internal and external markers of intensity.[6] Moreover, non-significant differences in RPE between One-Day game-play and SSG training (The Battlezone) were reported by Vickery et al.[28] suggesting batting stimuli presented during each of these formats exert similar perceptual demands. Given the practical benefits in gathering and interpreting RPE scores,[39] it is apparent more research is needed to establish the utility of this approach in representing the internal demands associated with batting in cricket, particularly during games across various formats.

External responses

The added measurement of activity demands gives detail about the external responses to batting, from which further physiological inferences can be made. Technological advancements in video-based approaches and the development of micro-technologies, such as global positioning system (GPS) units, permit reliable and valid measurement of activity responses in cricket.[22,40,41] These approaches are becoming more routinely used to monitor the external physiological responses of players and thus an increasing number of researchers have reported these data for batsmen during cricket games, simulated play, and training scenarios. Activities performed are typically categorized according to intensity, whereby most studies adopt the following criteria: standing/walking = $\leq$2 m·s^{-1}; jogging = 2.01-3.5 m·s^{-1}; running = 3.51-4 m·s^{-1}; striding = 4.01-5 m·s^{-1}; and sprinting = >5 m·s^{-1}.[5,8,28,33,42] In turn, insight regarding activity frequencies, durations, and distances within these categories has been provided for batsmen. A summary of the external physiological responses observed during batting in cricket studies is presented in Table 3.

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Activity Frequencies

Using video-based time-motion analyses, Duffield and Drinkwater[22] examined the external responses of batsmen across 50-, 80- and 100-run innings during One-Day and multi-day international games. The comparative analyses showed consistent jogging, striding, and sprinting frequencies across game formats for each innings category. Furthermore, significantly greater standing, and walking frequencies were observed for multi-day compared to One-Day game-play for each innings category. Similarly, Petersen et al.[8] showed greater frequency of high intensity (running, striding and sprinting) during Twenty20 compared to One-Day and multi-day game-play as well as One-Day compared to multi-day game-play but did not report frequency of low-intensity activities (standing, walking, or jogging). With regards to the simulated game play and SSG (The Battlezone), Vickery et al.[28,33] reported The Battlezone has higher frequency of sprinting and high-intensity activities compared to One-Day game-play, with the frequency of sprinting comparable to that noted by Petersen et al.[8,42] during Twenty20 (Table 3). However, the frequency of high-intensity activities during The Battlezone is greater than that presented in actual game-play studies (Table 3).

Duffield and Drinkwater[22] also showed an increase in shot frequency during the multi-day versus One-Day game-play for the 80- and 100-run innings (80 runs: 95 ± 17 vs. 122 ± 23; 100 runs: 105 ± 18 vs. 151 ± 22), indicating that a greater number of shots are required to reach pre-determined scores during longer duration multi-day than One-Day games. Limited information regarding the frequency of attacking and defensive shots exists with only Vickery et al.[28] noting that during One-Day game-play the frequency of attacking shots was 21 ± 4 $\cdot h^{-1}$ compared to 12 ± 5 $\cdot h^{-1}$ defensive shots. To date, no studies have compared shot type frequency between different game formats.

Based on the present research it appears batting during multi-day games has a greater contribution from low-intensity activity than shorter games (One-Day or Twenty20). The current research also shows a greater frequency of recovery activities around high-intensity bouts during multi-day cricket, reflecting the more attacking style of play through an augmented shot frequency in shorter game formats. However, data regarding activity frequencies for batting during Twenty20 cricket is limited with only Petersen et al.[8,42] reporting the frequency of sprinting and high intensity efforts (Table 3). Further research comparing the influence of game formats and shot types on activity frequencies during batting is warranted to improve the understanding in this area.

Activity Durations

Duration data provide useful information regarding the proportions of game-play or training spent working at different intensities. The durations spent performing different activities during batting have been provided across all game formats and concur with the findings for activity frequencies. Petersen et al.[42] utilized GPS technology to measure the activity demands imposed upon state-level batsmen scaled to 30 min of activity during Twenty20 games. Activity categories were grouped as low- and high-intensity, with players spending more time engaged in walking and jogging (low-intensity activity) than running, striding, and sprinting (high-intensity activity). Across longer game formats, Duffield and Drinkwater[22] reported activity durations for 50-, 80- and 100-run innings during international One-Day and multi-day games. Consistent jogging, striding, and sprinting durations were apparent across game formats for each run innings category. For 50-run innings there was also consistency in walking and shot (0.9 ± 0.2 vs 1.1 ± 0.4 min) durations between game formats. In contrast, there was significantly greater walking durations between game formats for the 80- and 100- run innings categories and shot durations (80 runs: 95 ± 17 vs. 122 ± 23 min; 100 runs: 105 ± 18 vs. 151 ± 22 min). In addition, significantly greater standing durations were evident between game formats for each run innings category (Table 3). Overall, innings durations during One-Day games were significantly shorter than multi-day games for 50- and 100-run innings (50 runs: 84.5 ± 17.7 vs 108.9 ± 26.6 min; 100 runs: 135.5 ± 21.4 vs 213.4 ± 31.9 min).[22]

The literature indicates that the majority of batting time is spent engaged in low-intensity activity. When grouped according to low- and high-intensity, 95.5%, 97.7%, and 98.6% of batting time were spent engaged in low-intensity activity during Twenty20, One-Day, and multi-day cricket respectively.[22,42] While the volume of high-intensity activity during batting is comparable across One-Day and multi-day game formats (2.2 vs. 2.1 min in 50-run innings), greater standing and walking activity were apparent during multi-day games predisposing to larger work:rest ratios in batsmen during this format (One-Day: 1:47 s; multi-day: 1:67 s).[22] Furthermore, batting during Twenty20 cricket invoked an even lower work:rest ratio (1:24 s) than both One-Day and multi-day formats.[42] Separately, Petersen et al.[8] observed comparable work:rest ratios across One-Day (1:50 s) and multi-day (1:61 s) games to those reported in international batsmen by Duffield and Drinkwater[22] with a considerably higher work:rest ratio evident during Twenty20 game-play (1:38 s). Likewise, Vickery et al.[28] observed a higher work:rest ratio in One-Day games (1:66 s) than those reported in other studies. Discrepancies across studies might be related to playing level of the batsmen investigated as second-tier international,[8] state-level,[42] and club-level[28] players have been examined.

Nevertheless, the available evidence suggests as the duration of the game decreases, external physiological intensity increases primarily through a reduction in recovery time between high-intensity efforts. Given that PCr depletion has been proposed as a prominent fatigue mechanism during intermittent exercise, longer recovery periods would promote greater PCr restoration between high-intensity bouts to optimize performance maintenance.[43] Consequently, other fatigue mediators such as glycogen depletion, dehydration, or neural mechanisms might be more influential during longer game formats.[22]

Activity Distances

Distance data have also been provided in all game formats across varied playing levels for batsmen in cricket. During state-level Twenty20 games, Petersen et al.[42] recorded various distances for different activities when scaled to 30 min of batting with a greater distance covered during walking activities than jogging, running, striding, or sprinting. Following this study, Petersen et al.[8] compared the activity demands imposed upon second-tier international batsmen during Twenty20, One-Day, and multi-day game formats. Activity distances were scaled and presented as $m \cdot h^{-1}$ to provide comparable data across game formats. Batsmen completed greater (*moderate* to *large*) relative distances jogging, running, striding, and sprinting during Twenty20 than multi-day games. Furthermore, batsmen covered greater (*moderate*) relative distances jogging, striding, and sprinting during One-Day than multi-day games. Analogous overall relative distances were also observed between Twenty20 and One-Day games, with lower measures recorded during multi-day games (Table 3).[8] Following a similar approach using GPS technology, Vickery et al.[28] reported lower overall relative distances for club-level batsmen during One-Day games than across all formats observed by Petersen et al..[8,42] Overall distance was further analyzed according to low- and high-intensity activity and again showed the majority of distance covered was covered while engaged in low-intensity activity [28].

Together, the distance data reported during actual game-play shows that shorter game formats (Twenty20 and One-Day) carry higher work rates ($m \cdot h^{-1}$) than longer formats (multi-day).[8,28,42] Interestingly, examinations of Twenty20 cricket showed wide variation in activity distances, with 1.6-2.4 times the work rate evident across activities during state-level[42] compared to second-tier international[8] game-play. These differences highlight that the external physiological demands imposed upon batsmen during Twenty20 cricket might be highly variable. Furthermore, across separate studies, work rate decreased with the playing level investigated. Specifically, second-tier international players demonstrated the highest work rates (≈2.6 $km \cdot h^{-1}$) during Twenty20 and One-Day games,[8] followed by state-level batsmen (2.4 $km \cdot h^{-1}$) during Twenty20,[42] and club-level batsmen (1.9 $km \cdot h^{-1}$) during One-Day games.[28]

In addition to observations made during game-play, distance data have also been provided using GPS units for simulated play and SSG training in batsmen.[5,28,33] Comparable total work rates were evident across BATEX in club-level players (2.2 ± 0.2 km·h^{-1}) compared with One-Day (1.9-2.5 km·h^{-1}) and multi-day (2.1 ± 0.6 km·h^{-1}) game-play.[5,8,28] However, the work rates during BATEX were lower than those reported for Twenty20 (2.4-4.9 km·h^{-1}).[8,42] Analyzed further, BATEX imposed lower relative distances during low-intensity activities (standing, walking, and jogging) and consistent or greater high-intensity demands (running, striding, and sprinting) than all game formats (Table 3).[5,8,28,42] Thus, BATEX appears to match the overall work rates and exceed the high-intensity demands reported for batsmen during One-Day and multi-day game-play, while also matching the high-intensity work rates seen during Twenty20 cricket. Consequently, BATEX might hold useful utility across all game formats as an assessment tool to gauge the preparedness of batsmen for different competitions as well as a training stimulus to adequately prepare batsmen for game demands. Conversely, batting during SSG training has been shown to elicit considerably higher work rates across all activity categories than BATEX in club-level batsmen.[28,33]

Vickery et al.[28,33] reported batsmen to cover between 3.8-3.9 km·h^{-1} across 14-18-min bouts of The Battlezone, including 3.3-3.4 km·h^{-1} and 0.6-0.7 km·h^{-1} performing low- and high-intensity activity, respectively. These work rates are greater than those reported during BATEX[5] and game-play[8,28] (Table 3). It has been proposed that the fewer number of fielders in the game-play scenarios encountered during The Battlezone might have permitted batsmen to score more freely and the protocol objectives might promote an attacking mind-set to secure as many runs as possible across the short playing durations by executing frequent high-intensity sprints.[33] Comparisons with game-play across studies confirm the practical usefulness of SSG training to elicit elevated work rates and provide a beneficial training stimulus for batsmen in preparation for all game formats.

CONCLUSIONS

Findings pertaining to the internal and external physiological responses during batting in cricket vary between game format, as well as simulated play and SSG training. The collective works in this area provide important insight regarding player responses to batting, and highlight the need for more research on this topic, particularly combining internal and external measures during actual game-play, comparing different game formats and playing levels. Investigation of fatigue-mediating mechanisms during batting across games are also encouraged as well as studies examining responses to different shot types (attacking vs defensive). The physiological demands of batting should be considered in combination with other responses, as the importance of technique to batting performance has been reiterated across various sources[19,23,28,44-46] and was not covered in the present review. Future studies should examine the physiological responses to batting and biomechanical attributes of batting technique to provide greater insight into the relationship of these variables and overall performance. Further, given much of the available data (Table 1) has been provided during simulation and games training scenarios, more research examining player responses during actual game-play is required.

PRACTICAL APPLICATIONS

The data synthesized in this review provide a useful reference for internal and external physiological stimuli relative to game format as well as simulation/training protocol for strength and conditioning professionals and coaches to use when developing training plans, recovery protocols, and player management strategies to best prepare players for competition. Specifically, work:rest ratio data highlight physiological intensity is heightened across shorter game durations through a reduction in recovery time between high-intensity efforts. Thus player conditioning plans should account for these metabolic variations and be adjusted to best prepare players for specific game formats across the season. In addition, variations in work rates across playing levels suggest that training and assessment approaches relative to playing level are warranted. Conditioning drills might incorporate batting exercise simulation (BATEX) and SSG training (The Battlezone), which appear to provide adequate physiological overload to prepare for the batting demands associated with all game formats.

REFERENCES

1. International Cricket Council. *Members overview*. Available at http://www.icc-cricket.com/about/96/icc-members/overview, Accessed November 1 2015.
2. Scalmer S. Cricket, imperialism and class domination. *WorkingUSA*. 2007;10(4):431-442.
3. Christie C, Todd A, King G. Selected physiological responses during batting in a simulated cricket work bout: A pilot study. *J Sci Med Sport*. 2008;11(6):581-584.
4. Elliott B, Baker J, Foster D. The kinematics and kinetics of the off-drive and on-drive in cricket. *Aus J Sci Med Sport*. 1993;25(2):48-54.
5. Houghton L, Dawson B, Rubenson J, Tobin M. Movement patterns and physical strain during a novel, simulated cricket batting innings (BATEX). *J Sports Sci*. 2011;29(8):801-809.
6. Pote L, Christie C. Selected physiological and perceptual responses during a simulated limited overs century in non-elite batsmen. *Eur J Sport Sci*. In press.

7. Petersen C, Pyne D, Dawson B, Kellett A, Portus M. Comparison of training and game demands of national level cricketers. *J Strength Cond Res.* 2011;25(5):1306-1311.
8. Petersen C, Pyne D, Dawson B, Portus M, Kellett A. Movement patterns in cricket vary by both position and game format. *J Sports Sci.* 2010;28(1):45-52.
9. Petersen C, Pyne D, Portus M, Dawson B. Comparison of player movement patterns between 1-day and test cricket. *J Strength Cond Res.* 2011;25(5):1368-1373.
10. McNamara D, Gabbett T, Chapman P, Naughton G, Farhart P. Variability of PlayerLoad, bowling velocity, and performance execution in fast bowlers across repeated bowling spells. *Int J Sports Physiol Perform.* 2015;10(8):1009-1014.
11. Orchard J, Blanch P, Paoloni J, Kountouris A, Sims K, Orchard J, Brukner P. Fast bowling match workloads over 5–26 days and risk of injury in the following month. *J Sci Med Sport.* 2015;18(1):26-30.
12. Peterson C, Pyne D, Portus M, Karppinen M, Dawson B. Variability in movement patterns during one day internationals by a cricket fast bowler. *Int J Sports Physiol Perform.* 2009;4(2):278-281.
13. MacDonald D, Cronin J, Mills J, McGuigan M, Stretch R. A review of cricket fielding requirements. *S Afr J Sports Med.* 2013;25(3):87-92.
14. Bartlett R, Stockill N, Elliott B, Burnett A. The biomechanics of fast bowling in men's cricket: A review. *J Sports Sci.* 1996;14(5):403-424.
15. Johnstone J, Mitchell A, Hughes G, Watson T, Ford P, Garrett A. The athletic profile of fast bowling in cricket: A review. *J Strength Cond Res.* 2014;28(5):1465-1473.
16. Stronach B, Cronin J, Portus M. Part 1: Biomechanics, injury surveillance, and predictors of injury for cricket fast bowlers. *Strength Cond J.* 2014;36(4):65-72.
17. Stronach B, Cronin J, Portus M. Part 2: Mechanical and anthropometric factors of fast bowling for cricket, and implications for strength and conditioning. *Strength Cond J.* 2014;36(5):53-60.
18. Stretch R, Bartlett R, Davids K. A review of batting in men's cricket. *J Sports Sci.* 2000;18(12):931-949.
19. Penn M, Spratford W. Are current coaching recommendations for cricket batting technique supported by biomechanical research? *Sports Biomech.* 2012;11(3):311-323.
20. Law M, Stewart D, Pollock N, Letts L, Bosch J, Westmorland M. *Critical review form - quantitative studies*. Hamilton: MacMaster University; 1998.
21. Cashman R. Crisis in contemporary cricket. In: Cashman R, Mckernan M, eds. *Sport: Money, Morality and the*

Media. Kensington, NSW: New South Wales University Press Limited; 1981:305-312.

22. Duffield R, Drinkwater. Time-motion analysis of Test and One-Day international cricket centuries. *J Sports Sci*. 2008;26(5):457-464.
23. Portus M, Farrow D. Enhancing cricket batting skill: Implications for biomechanics and skill acquisition research and practice. *Sports Biomech.* 2011;10(4):294-305.
24 Scanlan A, Wen N, Tucker P, Dalbo V. The relationships between internal and external training load models during basketball training. *J Strength Cond Res.* 2014;28(9):2397-2405.
25. Fletcher A. Calories and cricket. *Lancet.* 1955;268(6875):1165-1166.
26. Bot S, Hollander A. The relationship between heart rate and oxygen uptake during non-steady state exercise. *Ergonomics.* 2000;43(10):1578-1592.
27. Alexandre D, da Silva C, Hill-Haas S, del Wong P, Natali A, De Lima J, Bara Filho M, Marins J, Garcia E, Karim C. Heart rate monitoring in soccer: Interest and limits during competitive match play and training, practical application. *J Strength Cond Res.* 2012;26(10):2890-2906.
28. Vickery W, Dascombe B, Duffield R. Physiological, movement and technical demands of centre-wicket Battlezone, traditional net-based training and one-day cricket matches: A comparative study of sub-elite cricket players. *J Sports Sci.* 2014;32(8):722-737.
29. Balady G, Chaitman B, Driscoll D, Foster C, Froelicher E, Gordon N, Pate R, Rippe J, Bazzarre T. AHA/ACSM joint position statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. *Med Sci Sports Exerc*. 1998;30(6):1009-1018.
30. Noakes T, Durandt J. Physiological requirements of cricket. *J Sports Sci.* 2000;18(12):919-929.
31. Dupont G, Blondel N, Berthoin S. Performance for short intermittent runs: active recovery vs. passive recovery. *Eur J Appl Physiol.* 2003;89(6):548-554.
32. Houghton L, Dawson B, Rubenson J. Performance in a simulated cricket batting innings (BATEX): Reliability and discrimination between playing standards. *J Sports Sci.* 2011;29(10):1097-1103.
33. Vickery W, Dascombe B, Duffield R, Kellett A, Portus M. Battlezone: An examination of the physiological responses, movement demands and reproducibility of small-sided cricket games. *J Sports Sci.* 2012;31(1):77-86.
34. Matthew D, Delextrat A. Heart rate, blood lactate concentration, and time-motion analysis of female

basketball players during competition. *J Sports Sci.* 2009;27(8):813-821.

35. Garcia-Tabar I, Llodio I, Sánchez-Medina L, Ruesta M, Ibañez J, Gorostiaga E. Heart rate–based prediction of fixed blood lactate thresholds in professional team-sport players. *J Strength Cond Res.* 2015;29(10):2794-2801.
36. Austin D, Kelly S. Positional differences in professional rugby league match play through the use of global positioning systems. *J Strength Cond Res.* 2013;27(1):14-19.
37. Scanlan A, Dascombe B, Reaburn P, Dalbo V. The physiological and activity demands experienced by Australian female basketball players during competition. *J Sci Med Sport.* 2012;15(4):341-347.
38. Coutts A, Rampinini E, Marcora S, Castagna C, Impellizzeri F. Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. *J Sci Med Sport.* 2009;12(1):79-84.
39. Scanlan A, Wen N, Tucker P, Borges N, Dalbo V. Training mode's influence on the relationships between training-load models during basketball conditioning. *Int J Sports Physiol Perform.* 2014;9(5):853-859.
40. Petersen C, Pyne D, Portus M, Dawson B. Validity and reliability of GPS units to monitor cricket-specific movement patterns. *Int J Sports Physiol Perform.* 2009;4(3):381-393.
41. Vickery W, Dascombe B, Baker J, Higham D, Spratford W, Duffield R. Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *J Strength Cond Res.* 2014;28(6):1697-1705.
42. Petersen C, Portus D, Dawson M. Quantifying positional movement patterns in Twenty20 cricket. *Int J Perform Anal Sport.* 2009;9(2):165-170.
43. Padulo J, Tabben M, Ardigo L, Ionel M, Popa C, Gevat C, Zagatto A, Dello Iacono A. Repeated sprint ability related to recovery time in young soccer players. *Res Sports Med.* 2015;23(4):412-423.
44. Stretch R, Buys F, Toit E, Viljoen G. Kinematics and kinetics of the drive off the front foot in cricket batting. *J Sports Sci.* 1998;16(8):711-720.
45. Stuelcken M, Portus M, Mason B. Off-side front foot drives in men's high performance cricket. *Sports Biomech.* 2005;4(1):17-35.
46. Taliep M, Galal U, Vaughan C. The position of the head and centre of mass during the front foot off-drive in skilled and less-skilled cricket batsmen. *Sports Biomech.* 2007;6(3):345-360.

TABLE LEGEND

Table 1. Quality evaluation for each retrieved publication.

Table 2. Summary of studies reporting on the internal physiological responses to batting in cricket during games and training.

Table 3. Summary of studies reporting on the external physiological responses to batting in cricket during games and training.

Table 1. Quality evaluation for each retrieved publication.

Study	Purpose	Literature	Participants	Reliability	Validity	Results	Analysis	Clinical	Conclusions	Practical	Study limitations	Score
Christie et al.[3]	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	Simulated batting bout used. Single live bowler used.	**5**
Duffield and Drinkwater[22]	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Coding approach likely lowered mean durations of high-intensity bouts.	**7**
Houghton et al.[32]	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Simulated batting bout used. Bowling machine used.	**7**
Houghton et al.[5]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Simulated batting bout used. Single live bowler used.	**8**
Petersen et al.[42]	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Data were scaled to a 30-min innings. Positional analyses conducted limiting focus on batsmen.	**8**
Petersen et al.[8]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Only one 3-day game analyzed for multi-day data. Positional analyses conducted limiting focus on batsmen.	**9**
Pote and Christie[6]	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Simulated batting bout used. Bowling machine used.	**7**
Vickery et al.[28]	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Small-sided games training bout used. Positional analyses conducted limiting focus on batsmen.	**7**
Vickery et al.[33]	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Small-sided games training bout used. Positional analyses conducted limiting focus on batsmen.	**7**

Note: Quality evaluation adapted from Law et al.[20] Purpose = was the purpose stated clearly; Literature = was relevant background literature reviewed; Participants = was the sample described in detail; Reliability = were the outcome measures reliable; Validity = were the outcome measures valid; Results = were the results reported in terms of statistical significance; Analysis = were the analysis method(s) appropriate; Clinical = was clinical importance reported; Conclusions = were the conclusions appropriate given study methods and results; Practical = were the implications of the results to practice provided. Total score is summed across each item where: Yes = 1; No = 0.

Table 2. Summary of studies reporting on the internal physiological responses to batting in cricket.

Study	Participants	Playing level	Format/protocol	Mean metabolic responses	Mean HR ($b \cdot min^{-1}$)	[BLa^-] ($mmol \cdot L^{-1}$)	RPE (AU)
Christie et al.[3]	n = 10 22 ± 3 years	University (first team)	Simulated batting bout (7 overs)	Energy: 2,536 ± 302 $kJ \cdot h^{-1}$ V_E: 65.1 ± 7.9 $L \cdot min^{-1}$ VO_2: 26.7 ± 1.4 $mL \cdot kg^{-1} \cdot min^{-1}$ RER: 1.05 ± 0.05	145 ± 11	–	–
Houghton et al.[32]	n = 11 21 ± 2 years	Club (first and second teams)	BATEX	–	137 ± 11	3.2-4.5 across stages	10-17 across stages (6-20 scale)
	n = 11 19 ± 1 years	Club (third and fourth teams)	BATEX	–	143 ± 14	3.0-4.1 across stages	10-17 across stages (6-20 scale)
Houghton et al.[5]	n = 9 20 ± 3 years	Club (first to fourth teams)	BATEX	–	130 ± 16	–	13 ± 3 (6-20 scale)
Petersen et al.[8]	n = 16 22 ± 3 years	Second-tier international	Twenty20	–	149 ± 17	–	–
	n = 5		One Day	–	144 ± 13	–	–
Pote and Christie[6]	n = 17 23 ± 2 years	Club (first and second teams)	BATEX	–	144 ± 15	–	12 ± 3 9-16 across stages (6-20 scale)
Vickery et al.[28]	n = 11 22 ± 3 years	Club (first team)	Battlezone	–	164 ± 12	3.2 ± 1.4	5 ± 2 (1-10 scale)
	n = 10	Club (first team)	One Day	–	159 ± 12	–	5 ± 2 (1-10 scale)
Vickery et al.[33]	n = 13 23 ± 4 years	Club (first and second teams)	Battlezone	–	–	1.8 ± 0.7	4 ± 1 (1-10 scale)

Note: HR = heart rate; RPE = rating of perceived exertion presented as mean or range; AU = arbitrary units; [BLa^-] = blood lactate concentration presented as mean or range; BATEX = batting exercise simulation protocol consisting of 6 x 21-min stages typical of a One Day International-level score of 100 runs; Battlezone = small-sided cricket game-play consisting of 6-8-over bouts; Energy = energy expenditure; V_E = minute ventilation; VO_2 = oxygen uptake; RER = respiratory exchange ratio.

Table 3. Summary of studies reporting on the external physiological responses to batting in cricket.

Study	Format/protocol	Standing	Walking	Jogging	Running	Striding	Sprinting	Total
Activity frequencies								
Duffield and Drinkwater[22]	One Day							
	50-run innings	190 ± 40	216 ± 49	86 ± 34	–	50 ± 18	22 ± 10	–
	80-run innings	285 ± 53	332 ± 69	143 ± 49	–	81 ± 31	34 ± 14	–
	100-run innings	315 ± 70	367 ± 93	156 ± 43	–	95 ± 44	43 ± 32	–
	Multi-day							
	50-run innings	264 ± 66	267 ± 647	68 ± 17	–	41 ± 11	19 ± 6	–
	80-run innings	438 ± 80	438 ± 74	107 ± 13	–	65 ± 9	35 ± 12	–
	100-run innings	527 ± 111	526 ± 96	139 ± 14	–	83 ± 9	39 ± 12	–
Petersen et al.[42#]	Twenty20	–	–	–	–	-	12 ± 5	–
						38 ± 17 (high-intensity)		
Petersen et al.[8]	Twenty20	–	–	–	–	–	15 ± 9·h^{-1}	–
						45 ± 16 ·h^{-1} (high-intensity)		
	One Day	–	–	–	–	–	13 ± 9·h^{-1}	–
						39 ± 16 ·h^{-1} (high-intensity)		
	Multi-day	–	–	–	–	–	8 ± 3·h^{-1}	–
						28 ± 6 ·h^{-1} (high-intensity)		
Vickery et al.[28]	The Battlezone	–	–	–	–	–	23 ± 19·h^{-1}	–
						224 ± 73 ·h^{-1} (high-intensity)		
	One Day	–	–	–	–	–	8 ± 8·h^{-1}	–
						50 ± 21 ·h^{-1} (high-intensity)		
Vickery et al.[33*]	The Battlezone	–	–	–	–	–	3 ± 3	–
						39 ± 20 (high-intensity)		
Activity durations								
Duffield and Drinkwater[22]	One Day							
	50-run innings	50.8 ± 11.5 min	29.3+6.6 min	3.0 ± 1.3 min	–	1.4 ± 0.5 min	0.8 ± 0.3 min	–
	80-run innings	74.5 ± 13.7 min	41.4 ±7.1 min	5.0 ± 1.7 min	–	2.3 ± 0.8 min	1.0 ± 0.5 min	–
	100-run innings	79.1 ± 12.1 min	45.5 ± 9.3 min	5.1 ± 1.3 min	–	2.6 ± 1.1 min	1.2 ± 0.9 min	–

	Multi-day							
	50-run innings	68.6 ± 20.3 min	35.1 ± 8.2 min	2.6 ± 0.8 min	–	1.1 ± 0.3 min	0.6 ± 0.2 min	–
	80-run innings	113.9 ± 22.0 min	55.6 ± 11.8 min	3.9 ± 0.8 min	–	1.7 ± 0.3 min	1.1 ± 0.4 min	–
	100-run innings	133.2 ± 29.5 min	65.1 ± 13.0 min	5.4 ± 1.0 min	–	2.3 ± 0.4 min	1.3 ± 0.5 min	–
Petersen et al.[42#]	Twenty20	–	28.43 ± 0.78 min (low-intensity)		1.35 ± 0.72 min (high-intensity)			–
Activity distances								
Houghton et al.[5]	BATEX	–	1,359 ± 157 $m·h^{-1}$	233 ± 33 $m·h^{-1}$	99 ± 10 $m·h^{-1}$	217 ± 31 $m·h^{-1}$	261 ± 58 $m·h^{-1}$	2,171 ± 157 $m·h^{-1}$
Petersen et al.[42#]	Twenty20	–	1,644 ± 507 m	395 ± 114 m	80 ± 34 m	153 ± 91 m	161 ± 83 m	2,433 ± 450 m
Petersen et al.[8]	Twenty20	–	1,638 ± 352 $m·h^{-1}$	332 ± 103 $m·h^{-1}$	97 ± 35 $m·h^{-1}$	187 ± 70 $m·h^{-1}$	175 ± 97 $m·h^{-1}$	2,429 ± 606 $m·h^{-1}$
	One Day		1,808 ± 400 $m·h^{-1}$	279 ± 119 $m·h^{-1}$	86 ± 37 $m·h^{-1}$	154 ± 70 $m·h^{-1}$	149 ± 94 $m·h^{-1}$	2,476 ± 631 $m·h^{-1}$
	Multi-day		1,604 ± 438 $m·h^{-1}$	200 ± 90 $m·h^{-1}$	67 ± 18 $m·h^{-1}$	107 ± 33 $m·h^{-1}$	86 ± 28 $m·h^{-1}$	2,064 ± 630 $m·h^{-1}$
Vickery et al.[28]	The Battlezone	–	2619 ± 1173 $m·h^{-1}$ (low-intensity)		1235 ± 422 $m·h^{-1}$ (high-intensity)			3,895 ± 1,236 $m·h^{-1}$
	One Day		1632 ± 794 $m·h^{-1}$ (low-intensity)		271 ± 12 $m·h^{-1}$ (high-intensity)			1,919 ± 793 $m·h^{-1}$
Vickery et al.[33]*	The Battlezone	–	566 ± 55 m	351 ± 46 m	104 ± 31 m	99 ± 67 m	21 ± 27 m	1,147 ± 175 m

Note: Activity intensities typically calculated as walking = ≤2 $m·s^{-1}$, jogging = 2.01-3.5 $m·s^{-1}$, running = 3.51-4 $m·s^{-1}$, striding = 4.01-5 $m·s^{-1}$, sprinting = >5 $m·s^{-1}$; [#] indicates data scaled to a 30 min inning; * indicates data collected across mean bout length of 18 ± 2 min; BATEX = batting exercise simulation protocol consisting of 6 x 21-min stages typical of a One Day International-level score of 100 runs; Battlezone = small-sided cricket game-play consisting of 6 bouts of 8-overs.