Journal of Science in Sport and Exercise
https://doi.org/10.1007/s42978-024-00287-8

ORIGINAL ARTICLE

Physiological and Perceptual Demands During a Simulated "The Hundred" Batting Work-Bout in Female Cricketers

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Received: 22 November 2023 / Accepted: 15 April 2024

Abstract

Purpose No research has investigated the physiological and perceptual demands of female cricket players at any level or for any format, making this study unique. This is despite the growth in popularity and professionalism of the women's game. Therefore, the purpose of this study was to determine the physiological (heart rate, oxygen consumption) and perceptual (ratings of perceived exertion, body discomfort) demands of female cricketers during a simulated "The Hundred" protocol.

Methods Twenty female cricketers (age: 19 ± 4.53 years, stature: 167.90 ± 7.28 cm; mass: 67.30 ± 13.51 kg) currently playing for a first-class county cricket club were recruited. The protocol consisted of six sets and was designed to mimic the non-powerplay phase of a women's "Hundred" match. Throughout the protocol selected physiological and perceptual responses were recorded.

Results Heart rate responses increased significantly ($P < 0.05$) from the first set (149 ± 14 beats/min) until the end of the third set (167 ± 10 beats/min). A further significant decrease ($P < 0.05$) was observed between set three (167 ± 10 beats/min) and set six (165 ± 12 beats/min). Oxygen uptake responses increased significantly ($P < 0.05$) from set one (22.06 ± 7.82 mL/kg/min) until set three (26.30 ± 7.58 mL/kg/min). A significant difference ($P < 0.05$) was also observed between set three and all the other sets. Central ratings of perceived exertion increased significantly ($P < 0.05$) throughout the protocol (9 ± 1.83–13 ± 3.17). Body discomfort, results indicated that the quadriceps and calves were the areas that felt the most discomfort during the protocol.

Conclusion In conclusion, the design of training programs should mimic the demandsof the women?s format of the game and focus on individualised exercise preparation.

Keywords Cricket · Heart rate · Female · Oxygen consumption · Ratings of perceived exertion

Introduction

Cricket is a global sport and has grown significantly over the last 20 years, particularly due to the newer, more popular, shorter formats of the game [20]. Traditionally it has been a gentleman's game, dominated by male players but in the past few decades, the women's game has expanded and grown around the world [9, 14]. Between 2018 and 2019, the number of female bilateral Twenty20 (T20) matches between Associate Members of the International Cricket Council (ICC) increased by 110%, and there was a 13% growth in female cricket participation in these nations [2]. In England specifically, more than 60 000 females played cricket in 2013, at approximately 600 recreational clubs [2]. However, despite this increase in recognition, there is a paucity of literature regarding the female format of the game, notably compared to that of male cricketers [2]. More specifically, there is a distinct lack of detailed physiological and perceptual data for all formats of the female game.

The first study to examine the physiological demands of cricket was performed during the 1953 Ashes test series; a mean energy cost of 650 kJ/h was observed presuming that the physical demands of the game were unsubstantial [8]. Since then, however, it has been shown that the game is more demanding than traditionally thought [3, 17]. Laboratory-based protocols simulating high scoring One Day

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Published online: 08 May 2024

International (ODI) matches (short duration, high-intensity protocols) have shown heart rate responses between 136 and 159 beats/min, maximal oxygen uptake measures between 26.92 and 27.00 mL/kg/min and energy expenditures between 2536 and 2765 kJ/h, which is significantly higher than conventionally reported [3, 4, 22]. These findings are also accurate when compared to real-time match-play, where heart rate responses of 139–154 beats/min, and 149–167 beats/min have been shown for batters in ODIs and T20 matches respectively [16, 20]. Furthermore, simulated ODI century protocols have also been undertaken in a laboratory setting (focusing on longer duration and lower intensities); these investigations identified heart rate responses between 130 and 144 beats/min and an oxygen consumption of 36.70 mL/kg/min [11, 24].

Similarly, there has been a lack of literature examining the relationship between central ratings of perceived exertion (RPE) and physiological responses in both male and female cricket players [21]. This is even though RPE is related to specific physiological markers such as oxygen consumption, lactate, ventilatory thresholds, and heart rate during exercise [21]. It is well known that RPE rises due to an increase in exercise intensity, but it has also been shown, specifically in cricket-related research, that these measures increase as a function of exercise intensity and duration [22]. Furthermore, research has demonstrated a strong, positive correlation ($R = 0.94$) between central ratings of perceived exertion and heart rate responses during a simulated, high-scoring ODI match on males [22]. No studies have looked at the relationship between these variables in T20 matches, or the shorter formats of the game.

Most of the literature investigating the physiological and perceptual responses of batting has focused primarily on ODIs and T20 matches. To the authors' knowledge, no research of this kind (for males or females) has been conducted on the shortest format of the game to date, "The Hundred" competition. This format, professionally introduced in the United Kingdom in 2021, is one of the key drivers in developing the women's game 'through increased visibility, investment, and exposure [15]. Compared to the more traditional formats, a typical "Hundred" match lasts approximately two and a half hours where each team faces 100 deliveries [15]. Furthermore, a single bowler can deliver a maximum of 20 deliveries in five or ten consecutive deliveries, known as sets, compared to the traditional overs (one set = five deliveries) [15]. Ultimately, the match outcome is decided by the team that scores the most runs [15].

No research has examined the physiological and perceptual responses of female batters in any format, or at any level. Furthermore, no literature has examined the demands of a typical innings in "The Hundred" competition, for male or female players. Therefore, the main aim of this investigation was to quantify these responses while performing a simulated "Hundred" protocol. This is important so that scientifically based training protocols can be implemented that closely mimic actual match-play, improve overall physical performance, and potentially reduce the risk of injury.

Materials and Methods

Participants

Twenty female cricketers (age: 19 ± 4.53 years, stature: 167.90 ± 7.28 cm; mass: 67.30 ± 13.51 kg) currently playing for a first-class county cricket club were recruited for the study (the sample was one of convenience). Ethical approval was granted by the *blinded for peer review*, and all players were volunteers.

Simulated Batting Protocol

The simulated batting work-bout was based on the analysis performed by Nicholls et al. [15] and was designed to mimic the demands of the non-powerplay phase of a women's "Hundred" game. The non-powerplay phase was chosen as the running requirements during this period of play are higher than required during the powerplay, thus placing a greater physiological load on the batters. The premise was to understand the most demanding aspects of the game. Analysis showed a mean time of 29.2 s between deliveries and 62.5 s between sets. As a result, the batters were required to face six sets (30 deliveries) with a 29 s break between deliveries (to simulate the bowler returning to the top of their run-up) and a 63 s break between sets (to simulate the changeover between sets). Within each set participants were required to complete certain running requirements on a 17.68 m pitch (Table 1). These running requirements were based on the analyses of 31 matches (6073 deliveries) in the women's "Hundred" competition during the 2021 season [15]. On average a wicket falls every four sets in the non-powerplay phase however, six sets were chosen as this would elicit maximum physiologic response from the batters.

Procedures

Players were required to attend one testing session. Prior to this, players were sent an information sheet explaining the details, risks, and benefits of the investigation, and were required to give consent to participate. This was also to familiarise individuals with the protocol and the equipment that would be used, and any questions were answered before the commencement of testing. Players were also requested

Table 1 Running requirements for the simulated women's "Hundred" batting protocol

Sets	Ball 1	Ball 2	Ball 3	Ball 4	Ball 5
Set 1	2 (all-out sprint)	0	1 (jog through)	0	1 (all-out sprint)
Set 2	1 (jog through)	1 (all-out sprint)	0	4 (run half-way down the pitch)	1 (all-out sprint)
Set 3	2 (all-out sprint)	0	1 (jog through)	0	1 (all-out sprint)
Set 4	1 (jog through)	1 (all-out sprint)	0	4 (run half-way down the pitch)	1 (all-out sprint)
Set 5	2 (all-out sprint)	0	1 (jog through)	0	1 (all-out sprint)
Set 6	1 (jog through)	1 (all-out sprint)	0	4 (run half-way down the pitch)	1 (all-out sprint)

to not consume any alcohol or participate in any strenuous physical activity for 24 h prior to the main experimentation session. Testing took place in the indoor performance suite at the *blinded for peer review*, on an indoor running track where creases were marked at distances of 17.68 m (the length of a standard cricket pitch). Before the protocol, players were taken through a warmup consisting of 5 min of cycling on a stationary bicycle, followed by dynamic stretching of the lower limbs to warm them up before the high-intensity work bout. As players were accustomed to this type of play it was not anything unusual for them. Players were then required to perform the batting work-bout in full cricket attire including pads, gloves, and thigh pads. Due to equipment constraints, no helmet was required. Each ball was bowled overarm by the primary investigator; tennis balls were used to prevent impact injuries and protect equipment. Players were instructed to play any shot based on the delivery thrown. At the end of each set the primary investigator recorded the necessary physiological (heart rate and oxygen consumption) and perceptual measures (central ratings of perceived exertion and body discomfort). Once the protocol had been completed, players were debriefed, and any additional questions were answered.

Physiological Measures

Oxygen consumption (VO_2) was measured throughout the protocol using a portable VO_2 breathe-by-breathe analyser (VO_2 Master, Canada). Prior to each testing session, the flow sensor was calibrated to zero by leaving the VO_2 master undisturbed for 10–45 s. It was further calibrated using a 3 L flow calibration syringe to calibrate for respiratory variables, as per the manufacturer's instructions. Heart rate responses were monitored using a Polar Accurex Plus Heart rate strap (Polar Electro, Finland).

Throughout the protocol live oxygen consumption and heart rate data were sent to the VO_2 Master Manager Application which also stored the data for further analyses. A manual heart rate reading was also taken by the primary investigator at the end of each set to ensure accuracy.

Perceptual Measures

Central ratings of perceived exertion were rated using Borg's [1] Rating of Perceived Exertion scale (20-point scale) at the end of each set. The 20-point scale was used for ease of comparison to studies done on male batters. Body discomfort was also measured at the end of each set using a rating system for pain [13]. Players were habituated to both scales prior to the commencement of the testing session.

Statistical Analysis

All data was analysed using the IBM SPSS Statistics package (version 28) and presented as mean (±SD) where appropriate. Prior to analysis, normality assumptions were checked using the Shapiro-Wilk test. A Kruskal-Wallis test was used to determine whether there was significance for responses over time (between sets) and a Dunn's post-hoc test (adjusted using the Bonferroni correction) was used to indicate specific pairwise differences. Statistical significance was set at $P < 0.05$ (confidence interval of 95%). The effect size statistic was used to characterise the magnitude of the difference between the different sets. The criteria for interpreting effect sizes were: < 0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and > 2.0 very large [10]. Only large effect sizes were reported. A bivariate Pearson's correlation coefficient analysis was used to determine the association between heart rate and ratings of perceived exertion.

Results

Heart rate responses increased significantly ($P < 0.05$) from the first set (149 ± 14 beats/min) until the end of the third set (167 ± 10 beats/min), which was the highest heart rate measured during the protocol (Fig. 1). A further significant decrease ($P < 0.05$) was observed between set three (167 ± 10 beats/min) and set six (165 ± 12 beats/min). Lastly, large effect sizes were shown between set one and set three, four, five, and six respectively (ES = 1.41, 1.42, 1.33, 1.26). The coefficient of variation (*CV*) ranged between 6.94% and 11.32% with an overall *CV* of 8.60%.

As with heart rate, oxygen uptake responses increased significantly ($P < 0.05$) from set one (22.06 ± 7.82 mL/kg/min) until set three (26.30 ± 7.58 mL/kg/min), which was

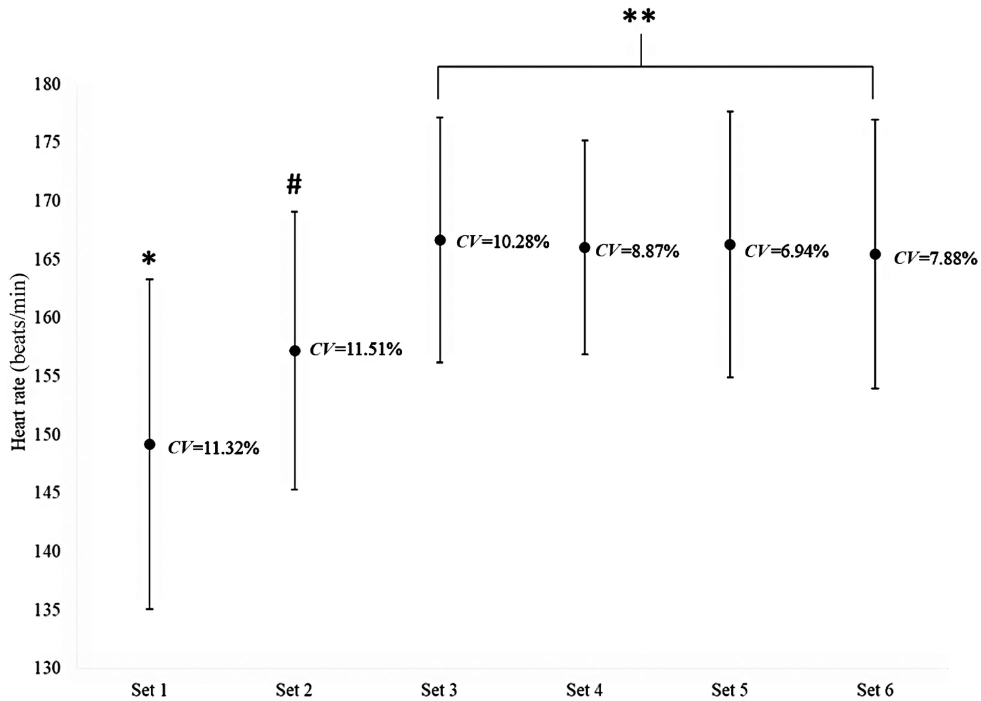

Fig. 1 Mean (±SD) changes in heart rate responses overtime during the simulated batting protocol. Where: *significant difference ($P<0.05$) between set one and the remaining sets, #significant difference ($P<0.05$) between set two and remaining sets, **significant difference ($P<0.05$) between set three and six. *CV* refers to the coefficient of variation

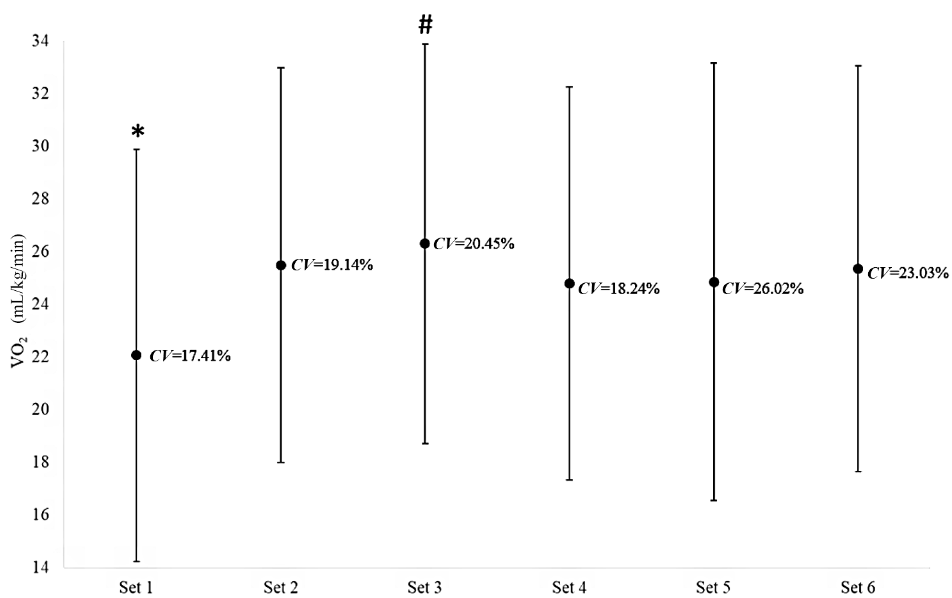

Fig. 2 Mean (±SD) changes in oxygen consumption responses over time during the simulated batting protocol. Where: *significant difference ($P<0.05$) between set one and all remaining sets, #significant difference ($P<0.05$) between set three and all remaining sets. *CV* coefficient of variation

the highest oxygen consumption measured throughout the protocol (Fig. 2). A significant difference ($P<0.05$) was also observed between set three and all the other sets. No large effect sizes were observed between any of the sets. The coefficient of variation (*CV*) ranged between 17.41 and 26.02% with an overall *CV* of 23.42%.

Central ratings of perceived exertion increased throughout the protocol and significant increases ($P<0.05$) were observed between set one (9 ± 1.83) and sets five (12 ± 2.85; ES = 1.25) and six (13 ± 3.17; ES = 1.55). A large effect size was also shown between set one and set four (ES: 1.35). A significantly large ($P<0.05$), positive correlation ($R^2=0.85$) was detected between heart rate and central ratings of perceived exertion. For body discomfort, results indicated that regions 42 and 43 (quadriceps) as well as regions 17 and 18 (calves), were the areas that felt the most discomfort during the protocol.

Discussion

This is the first study to investigate the physiological and perceptual responses of female cricketers, not only in "The Hundred" competition but in all formats of the game. Heart rate (HR) and oxygen consumption (VO_2) responses increased significantly ($P < 0.05$) from the first set (HR: 149 ± 14 beats/min; VO_2: 22.06 ± 7.82 mL/kg/min) until the end of the third set (HR: 167 ± 10 beats/min; VO_2: 26.30 ± 7.58 mL/kg/min) which were the highest responses recorded throughout the protocol. A significant decrease ($P < 0.05$) was also observed between set three (167 ± 10 beats/min) and set six (165 ± 12 beats/min) for heart rate responses. These are similar to the physiological responses (HR = 136–159 beats/min, VO_2 = 26.92–27.00 mL/kg/min) recorded in male batters for high scoring, high intensity, ODI and T20 simulated batting protocols [3, 14, 22]. This is despite the current protocol (2–3 high intensity sprints per set) being lower in intensity than the aforementioned work-bouts (4–6 high intensity sprints per over). However, this was to be expected because of the physiological differences between males and females. Typically, males tend to be larger, have more muscle mass, and less body fat percentage compared to females [27, 28]. Therefore, females require greater cardiac work requirements to meet the same external workloads as their male counterparts [6, 27, 28], which is potentially why the physiological responses between the separate protocols are similar, despite differences in intensity [26]. These physiological differences would also impact measures such as peak running speed, aerobic capacity, and anaerobic speed reserve, which have been shown to be crucial when estimating player tolerance at high-intensity exercise [27]. This is important when designing training programs for female players rather than male players; exercise prescriptions should be individualised to achieve optimal performance and reflect these physiological differences [28].

When compared to real match play, heart rate responses in the current investigation were also like those shown in actual ODI and T20 matches (139–167 beats/min) [16, 20]. However, although the absolute responses are similar, relative values suggest a greater intensity of work for female players in the "Hundred" competition compared to their male counterparts in ODI and T20 match play. This is supported by the fact that more runs are scored by hitting boundaries in the men's game and hence there is reduced running between the wickets [16]. The similarity in responses could also be attributed to the design of the "Hundred" competition where the rules are intended to encourage quicker play and may have an impact on the physiological cost or because the current investigation was designed to simulate the high-intensity, non-powerplay phase of the game compared to the whole match. The differences in laboratory and field-based testing also need to be considered when disseminating these results; more variables can be controlled for in the laboratory, but this may impact the ecological validity. For example, it needs to be recognised that factors such as player and competition dynamics, (e.g., scoreboard pressure and importance of match) were not considered in this investigation which may have impacted results [24]. This is an area that could be looked at in more detail in future research. Lastly, the calibre of the player also needs to be considered; the training status of players needs to be reflected when comparing club cricketers to elite or professional players.

Central ratings of perceived exertion (RPE) increased progressively over time (Set 1 = 9 ± 1.83; Set 6 = 13 ± 3.17) as a function of exercise duration; the same trend was shown in previous cricket research when simulating high-scoring ODI matches [3, 22]. This is an important finding as it indicates that the RPE scale can be used as an indicator of both exercise intensity and duration [5, 18]. However, this can only happen when the endpoint of exercise is known which could be a limitation to fixed duration protocols such as the current investigation [22]. It has been suggested that when the endpoint of a work-bout is known, the brain uses this information to regulate exercise and prevent catastrophic failure of the organs [22]. This is something that should be considered for future research; typically, batters do not know how long they will be at the crease for real match play, which would impact RPE as an indicator of exercise duration [5]. Lastly, a significantly strong ($P < 0.05$), positive correlation ($R^2 = 0.85$) between HR and RPE was noted, an observation that was also shown during a high-intensity ODI simulated work-bout [22, 25]. These are the only two studies to date that have examined the relationship between physiological and perceptual responses in cricket batters.

Participants in the current investigation indicated the highest amount of body discomfort in the lower limb musculature, more specifically the calves and quadriceps. The lower extremities are a common source of discomfort in both fast bowlers and batters [19, 23] and tend to be the area where most soft tissue injuries occur [7, 12]. For batters, this is most likely due to the eccentric muscle demands because of the repeated high-intensity efforts, requiring numerous accelerations and decelerations when running between the wickets [23]. This suggests that trainers and coaches should focus on the lower limb musculature when designing programs that reduce fatigue and as a result, the risk of strains or sprains. However, this is the only study to date that has examined body discomfort in female batters, which could potentially differ from areas of discomfort in male players; this is an area that should be considered in future simulated batting protocols.

Conclusion

The current investigation was important as it was the first study to quantify the physiological responses of female cricket batters in any setting or format. Physiological responses were like those shown in simulated high scoring work-bouts for male batters in ODI and T20 matches as well as real time match-play for the same formats. This is an important finding highlighting that female batters work at a greater relative intensity compared to their male counterparts, which is mostly due to the physiological differences between the different sexes. As a result of this, strength and conditioning programs should reflect these distinctions when prescribing exercise intensities for individuals. These programs should also mimic the demands of the women's format of the game and focus on individualised exercise preparation. Furthermore, the highest amount of body discomfort was shown in the lower limb musculature, which has been shown previously in male batters and bowlers. Therefore, trainers should focus on the lower limbs when implementing training and injury prevention programs. A strong correlation was observed between heart rate and RPE which has been shown in previous studies in male cricketers, suggesting that RPE can be used as an indicator of exercise duration and intensity. However, for cricket activity, this should be interpreted with caution as typically batters do not know the end point of the exercise (how long they will be at the crease).

Practical Applications

The findings of this investigation are key for informing future research in both female and male cricketers; the following highlights should be considered:

- This is the first investigation ever to quantify the physiological and perceptual responses of female batters for any format of the game.
- Female batters work at higher relative intensities compared to their male counterparts; strength and conditioning coaches should reflect these differences when designing training programs, particularly when prescribing anaerobic and aerobic based training.
- Body discomfort was highest in the lower limb musculature which is important to consider when prescribing training and injury prevention practices. The use of acceleration and deceleration drills as well as eccentric strengthening of the lower limbs could aid in preventing these types of injuries from occurring.
- Central ratings of perceived exertion can be used as an indicator of exercise intensity and duration, but this is difficult for actual cricket match play where the end-point of exercise is not known.

Acknowledgements Not applicable.

Author Contributions LP, SN, and AS contributed significantly to the conception ad design of the manuscript. LP, AS contributed to the acquisition of data, and LP, AS, SN, JK, CC were involved in the analysis and interpretation of the data. All authors participated in the drafting of the manuscript, with LP and CC critically revising each draft. All authors read and approved the final version of the manuscript.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data Availability Available on request.

Declarations

Ethical Approval Ethical approval was granted by the University of Derby College of Science and Engineering Research Ethics Committee [ETH2223-1523].

Consent to Participate and Publish Informed Consent was obtained from all participants prior to the collection of any data.

Competing Interests The authors have no relevant financial or non-financial interests to disclose.

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