ABSTRACT

Purpose: To examine the relationship between session Rating of Perceived Exertion (sRPE) and measures of internal and external training load (TL) within cricket batsmen and medium-fast bowlers during net-based training sessions. ***Methods:*** The internal (heart rate), external (movement demands, Player Load™) and technical (cricket-specific skills) loads of thirty, male cricket players (age: 21.2 ± 3.8 y, height: 1.82 ± 0.07 m, body mass: 79.0 ± 8.7 kg) were determined from net-based cricket training sessions (n = 118). The relationships between sRPE and measures of TL were quantified using Pearson's product moment correlations, respective to playing position. Stepwise multiple regression techniques provided key internal and external load determinants of sRPE in cricket players. ***Results:*** Significant correlations were evident (r = -0.34 – 0.87, $P < 0.05$) between internal and external measures of TL and sRPE, with the strongest correlations ($r \geq 0.62$) existing for GPS-derived measures for both playing positions. In batsmen, stepwise multiple regression analysis revealed that 67.8% of the adjusted variance in sRPE could be explained by Player Load™ and high-intensity distance (y = 27.43 + 0.81 Player Load™ + 0.29 high-intensity distance). For medium-fast bowlers, 76.3% of the adjusted variance could be explained by total distance and mean heart rate (y = 101.82 + total distance 0.05 + HR_{mean} -0.48). ***Conclusion:*** These results suggest that sRPE is a valid method of reporting TL amongst cricket batsmen and medium-fast bowlers. Position specific responses are evident, and should be considered when monitoring the TL of cricket players.

KEY WORDS: batsman, bowler, internal training load, external training load, GPS

INTRODUCTION

Within the confines of the high performance team sport environment, as a result of training load monitoring practices, it is common to prescribe more individualised player training programs specific to their respective match demands[1]. As reviewed previously [2, 3] there are numerous methods currently available for monitoring an individual's training load (TL), though these are generally classified as either internal or external in nature[4]. Internal-TL, particularly via Rating of Perceived Exertion (RPE) using Borg's Category Ratio 10 [CR-10] scale, is calculated by multiplying an individual's RPE by the duration of a training session (in minutes) [5]. Research has demonstrated the sRPE method to be a valid indicator of TL when compared to other internal measures across an array of sports and activities [6-10]. In addition to this, the advancements in micro-technology that allow global positioning system (GPS) and accelerometer devices to measure external-TL mean that it is now ubiquitous in many sports. Furthermore, recent studies show evidence of strong relationships between measures of external-TL and sRPE, particularly within field-based team sports [4, 11, 12].

Training programs are traditionally prescribed on external-TL, as is determined by the work performed by the athlete (ie. distance/speed from GPS devices), while the internal-TL represents the psycho-physiological stress imposed on individual athletes [13]. As noted by Impellizzeri and colleagues [14], the internal load experienced by an athlete is associated with the extent of the external load placed upon them during training or match-play. Recent evidence suggests a system that combines internal- and external-TL measures may be the most appropriate method to holistically quantify TL [11, 15]. By comparison however, the activity profile of cricket players during either training or match-play differs to that of other field based team sports, as typically the durations are much longer and a larger proportion of time is spent performing low-intensity activities (<3.5 $m \cdot s^{-1}$ and <75% maximum heart rate

[HR_{max}]) [16]. As such it is unclear whether measures of external-TL would be useful when prescribing training sessions based on TL for cricket players, especially given such unique and subtle movement characteristics of the sport and varying positions.

Given the high technical load specific to cricket and the various playing positions within a single team, the use of external measures based on the technical demands of a specific sport may be one way in which the TL's of athletes could be monitored. Few studies have examined the relationship between sRPE and technical measures of a specific sport, despite the large number of studies which have compared the sRPE derived TL's to common internal (HR) and external (GPS) measures. Recently however, both Lovell et al. [11] and Weaving et al. [15] have reported significant correlations between rugby league specific GPS-derived technical measures, i.e. body load and number of impacts and sRPE during skills-specific ($r > 0.24$) and skills-conditioning ($r > 0.43$) training sessions. Each respective study provided evidence that the sport specific technical load measures in combination with other internal and external measures of TL accounted for a predominance of the variance in sRPE. Additionally, Murphy et al. [17] recently used shot count and the number of unforced errors as a measure of reporting load amongst tennis players to determine player's concepts of what constitutes sRPE following a training session. Despite suggesting the use of external-TL measures such as shot count may be useful when prescribing unsupervised practice; these same measures were unable to explain the variance in sRPE within junior tennis players.

Collectively, the above research findings appear to suggest that the use of more sport specific external measures of TL may be unique to each individual sport. In cricket, the training dose of a net-based session is typically dictated by the restrictions of medium-fast bowlers, as evidenced by a number of national organisations limiting the number of deliveries a medium-fast bowler can perform in training [18, 19]. As such, coaching staff are more likely to develop training programs based on this measure of TL load as opposed to internal HR-based or external GPS-derived measures. Accordingly, the purpose of this study was to determine the association between sRPE and previously established measures of internal- and external-TL in cricket, and secondly, to determine what internal and external load markers are determinants of position specific RPE responses in batsmen and medium-fast bowlers during net-based training.

METHODS

Subjects

Thirty elite, male cricket players (age: 21.2 ± 3.8 y, height: 1.82 ± 0.07 m, body mass: 79.0 ± 8.7 kg; batsmen n =10; medium-fast bowlers n = 9) currently all playing at a minimum standard of first-class cricket and with a minimum of 10 years playing experience volunteered to participate in the study. All players provided verbal and written informed consent prior to the commencement of the study. Players were familiarised with Borg's CR-10 RPE scale [20] and the exact procedures of the study prior to data collection. The Ethics Committee of the University of Newcastle granted approval for the study (H-2010-1288).

Study Design

Whilst attending a pre-season training camp at the Australian National Cricket Centre the internal- and external-TLs of batsmen and medium-fast bowlers were measured over a period of 12 weeks during typical training sessions. During this time a total of 27 net-based training sessions were completed, with 118 individual sessions being used for analysis. A typical net-based training session was similar to that previously reported in the studies of Vickery et al. [21] and Petersen et al. [22], whereby batsmen batted against medium-fast bowlers (n = 2-3 bowlers per net) who rotated between deliveries as opposed to completing 6 ball overs on a turf cricket pitch, which was surrounded by netting. Batsmen batted in pairs and were instructed to rotate the strike by completing a single as typical of match-play, as often as possible during their allotted batting period. When rotating the strike batsmen were encouraged to perform this at typical match intensity. Training sessions were designed to allow players to practice isolated technical aspects of cricket match-play [22]. Players were instructed to train as per the instructions of their coaching staff.

Measures of Internal Training Load

Heart Rate

Heart rate (HR) was collected simultaneously from each player using heart rate monitors (Polar Team[2] System, Polar Electro Oy, Kemple, Finland) that sampled at 5 s intervals throughout each training session. Due to limitations with the number of HR devices available and restrictions made by coaching staff, the number of participants who wore HR devices varied from 4-10 each session. Heart rate data was stored within the GPS device worn by the player and download using Logan Plus 4.6 software (Catapult Innovations, Scoresby, Australia) following each training session for analysis. As in previous studies [4, 12, 14] mean HR (HR_{mean}), HR_{max} and the amount of time spent above 75% HR_{max} were determined during analysis [17]. Additionally, Edwards TRIMP method [23] for quantifying internal-TL was determined as:

$$\text{Internal-TL} = (\text{Zone 1 duration x 1}) + (\text{Zone 2 duration x 2}) + (\text{Zone 3 duration x 3}) + (\text{Zone 4 duration x 4}) + (\text{Zone 5 duration x 5})$$

where Zone 1 = 50-60% HR_{max}, Zone 2 = 60-70% HR_{max}, Zone 3 = 70-80% HR_{max}, Zone 4 = 80-90% HR_{max} and Zone 5 = 90-100% HR_{max}.

Each individual's HR_{max} was determined from the HR_{max} achieved prior to exhaustion from the performance of a Yo-Yo Intermittent Recovery Test Level 1 that was completed at the commencement of the training camp.

Session-RPE

The perceived intensity of each specific training session was quantified using Borg's CR-10 RPE scale [20] for each player following a training session as has been used previously [6, 8, 10, 24] . Player's provided separate RPE scores for each of the separate training session sections ie. Batting and bowling. Training load was then calculated by multiplying each player's RPE by the duration (min) of each specific part (i.e. batting and/or bowling) training session [5]. To ensure that consistent ratings of perceived intensity were recorded, as previously reported [24] sRPE scores were recorded 30 min following the conclusion of each separate section of the training session (eg. 30 min following net batting, 30 min following net bowling) to minimise any bias from the final stages of the session. Although as is typical of net-based cricket training, each player was allowed to continue training if they completed their batting and/or bowling session before other players which may have been led to some limitations with regards to data analysis.

Measures of External Training Load

Global Positioning Systems

Similar to recent research [4, 12, 15] the movement patterns of each player during all training sessions were recorded simultaneously via MinimaxX GPS devices (v6.65, Catapult Innovations, Scoresby, Australia) sampling at a frequency of 10 Hz to determine the external-TL of players. As with HR, limitations due to equipment availability and coaching restrictions meant the number of players wearing a GPS device varied from 4-10 per session. Each GPS unit was situated between the shoulder blades of each player using a specially designed harness. Following each training session, data was downloaded to determine measures of external-TL (distance covered [which included distance at a low-intensity:<3.5 $m \cdot s^{-1}$ and high-intensity: ≥ 3.5 $m \cdot s^{-1}$] [21], movement characteristics and Player Load™) using Logan Plus 4.6 software (Catapult Innovations, Scoresby, Australia). To limit inter-unit variability, each player was fitted with the same GPS device (where possible) during each training session. To ensure spurious information was not included, data was removed when a horizontal dilution of position value of greater than 5 was indicated, or when the number of connected satellites was less than 5 [25].

Technical Skill

Recent evidence [17] suggests sports-specific technical skills are associated with athlete's perception of effort (r = 0.63), and hence may be an avenue for exploration in cricket environments to determine TL. Consequently, during each net-based training session a fixed video camera (HDV 1080i/mini DV Handycam, Sony, Japan) was placed behind the batsmen (opposite end to where the ball was delivered by bowlers) to record the technical skills of batsmen and bowlers during each net-based training session. Following data collection, the footage was viewed by the lead researcher and notational analysis was used to quantify the volume of the technical skills performed by batsmen (number of balls faced, number of balls hit, number of defensive shots, number of attacking shots) and medium-fast bowlers (number of balls bowled).

Statistical Analyses

Pearson's product moment correlation was used to calculate the association between measures of internal- and external-TL. Only those correlations that were statistically significant ($P<0.05$) were reported. Similar to previous research [12] ratio measures for 90% limits of agreement were also calculated using a customised spreadsheet [26]. Correlation coefficients categories were to quantify the strength of the association based on Hopkins [27] (trivial= 0-0.1, small= 0.1-0.3, moderate= 0.3-0.5, large= 0.5-0.7, very large= 0.7-0.9, almost perfect= 0.9-1). Using both internal and external measures of TL, stepwise multiple regression was used to determine a predictive equation for sRPE. Additionally, for each playing position, partial correlations, standardized coefficients, and level of significance were reported for sRPE. Collinearity tolerance statistics established correlations between predictor variables, where values <.10 were considered beyond an acceptable tolerance level and removed from the model. All statistical analyses were completed using SPSS (v. 22, IBM Corporation, Somers, New York, USA) with the level of statistical significance set at $P<0.05$. As in Scott et al. [4] the amount of data available from individual players was a limitation of the study design and as such the following correlation coefficients reflect the relationship between measures of TL from the pooled data, rather than the mean of intra-subject correlations.

RESULTS

Measures of internal- and external-TL are presented in Table 1. Mean and 90% confidence intervals of correlation coefficients between the measures of internal- and external-TL and sRPE shown in Figure 1 for (a) batsmen and (b) medium-fast bowlers, respectively. Mean duration of individual batting sessions was 21 ± 10 min (range: 13 - 61 min), whereas mean duration for medium-fast bowling sessions was 28 ± 13 min (range: 13 – 72 min). Across each of the playing positions, the mean sRPE TL for individual sessions were: batsmen 82 ± 39 Arbitrary Units (AU) (range: 43 – 179 AU) and medium-fast bowlers 124 ± 57 AU (range: 44 - 279 AU) (Table 1). Heart rate based internal measures of TL within batsmen showed a small negative correlation with sRPE (r = -0.28 - -0.24, $P < 0.05$); whereas, moderate correlations between external-TL and sRPE within batsmen were evident (r = -0.34 – 0.47, $P < 0.02$) (Figure 1a). Specifically, measures of external-TL associated with physical demands (distance covered, number of efforts, player load) demonstrated large to very large correlations with sRPE (r = 0.60 – 0.74, $P < 0.01$) (Figure 1a). Alternatively, technical skill (number of balls faced, hit and defensive shots played) displayed moderate negative correlations with sRPE (r = -0.34 - -0.33, $P < 0.02$) (Figure 1a). In regards to medium-fast bowlers, a small negative correlation existed between HR_{mean} and sRPE ($r = -0.29$, $P < 0.02$), with all other measures of internal-TL not significantly associated ($P > 0.05$) (Figure 1b). Moderate to very large correlations (r = -0.54 – 0.87, $P < 0.01$) were evident between all measures of external-TL and sRPE (Figure 1b). Notably a moderate negative correlation was seen between work-to-rest ratio and sRPE (, $r = -0.54$, $P < 0.01$). Additionally, the number of balls bowled demonstrated a strong association with sRPE ($r = 0.68$, $P < 0.01$,) (Figure 1b).

*****INSERT TABLE 1 AROUND HERE*****

*****INSERT FIGURE 1AROUND HERE*****

The results of the stepwise multiple regression analysis are presented in Table 2. A total of 67.8% of the adjusted variance in batsmen's sRPE could be explained by Player Load™ and the total distance covered performing at a high-intensity (y = 27.43 + 0.81 Player Load™ + 0.29 High-intensity distance; adjusted R^2 = 0.68; F = 54.76; P < 0.001). The collinearity of this equation was acceptable for both variables with tolerance levels of 0.530. In regards to the medium-fast bowlers, total distance and HR_{mean} accounted for 76.3% of adjusted variance in sRPE (y = 101.82 + Total distance 0.05 + HR_{mean} -0.48; adjusted R^2 = 0.76; F = 100.97; P < 0.001). Similar to batsmen, the collinearity of this equation was acceptable for both variables with a tolerance level of 0.979.

*****INSERT TABLE 2 AROUND HERE*****

DISCUSSION

This study aimed to determine the relationship between measures of internal- and external-TL and sRPE amongst cricket batsmen and medium-fast bowlers. As in recent previous research in tennis as well as field based team sports such as rugby and football [11, 14, 17, 24, 28], the current research reported strong relationships between GPS-derived measures of load and sRPE within both playing positions. However, HR-based measures of internal-TL typically demonstrated weaker relationships with sRPE within both playing groups in the current study. Also unique to this study was the use of cricket-specific skills as a measure of external-TL, which indicated a moderate to strong relationship with sRPE dependent upon playing position. The findings suggest that a collective of TL measures best explains sRPE amongst cricket players, and it was interesting that cricket-specific skills were not included.

With the exception of HR_{mean} (batsmen: r = -0.28; medium-fast bowlers: r = -0.29), the present results showed no significant correlation between any measures of HR and sRPE (HR_{max}, percentage time >75%HR_{max} and Edwards' TRIMP) for either playing position. As stated above, this contrasts with previous research that has reported strong relationships between HR measures and sRPE in field based team sports [1, 12, 28]. For example, Impellizeri and colleagues [14] found large to very large correlations (r = 0.50 – 0.85) between sRPE and measures of HR amongst young soccer players when performing a soccer-specific training program. More recently, Lovell et al. [11] reported moderate to large correlations (r = 0.45 – 0.75) between sRPE as a measure of TL and Banister's TRIMP across a range of rugby league training activities amongst professional players. The weak correlation between sRPE and HR-based measures of load in the present study may be explained by the unique nature of cricket training, especially given such large proportions of time are spent performing low-intensity activities, particularly compared to the more likely higher-intensity sessions undertaken by the football codes [21, 29]. Previous research within cricket [21, 30, 31] highlights that despite the intermittent nature of net-based training, a large percentage of time is spent at an intensity below 75%HR_{max} during net-based cricket training sessions (batsmen: 43 ± 38%; medium-fast bowlers: 48 ± 37%). Given Edwards' TRIMP method places a greater weighting on more intense activity when calculating internal-TL, this may explain the lower correlation when compared to other team sports requiring longer periods at higher intensities [32, 33]. Surprisingly though, the current results demonstrated a negative correlation for HR_{mean} and sRPE for both playing positions. As sRPE includes the duration of the training session it is possible that the considerable portion of time spent at low-intensities invokes low cardiovascular load, yet can amplify the calculated TL. This suggests that coaches who develop net-based training sessions which are designed based around internal measures of TL may need to consider this information regarding the cardiovascular responses of cricket players. The limited relationship which exists between internal-TL and sRPE amongst cricket batsmen and medium-fast bowlers suggests that external measures may possibly have a stronger relationship with sRPE.

Similar to recent studies [4, 11, 12] strong correlations were present between sRPE and measures of external-TL. Specifically for batsmen, large correlations existed between sRPE and total distance (r = 0.74), total low-intensity distance (r = 0.74) and Player Load™ (r = 0.73). Further, moderate correlations were observed between sRPE with total high-intensity distance (r = 0.62) and the number of high-intensity efforts (r = 0.60). As in previous studies, weaker correlations were reported with an increase in running speed [4, 11], however as in the current study, these correlations were still considered moderate to large ($r \geq 0.43$). Due to the limited movement that occurs when batting in the nets (as highlighted by the proportion of low-intensity activity in Table 2), it is not surprising that the strongest relationship existed between movement performed at low speeds and sRPE within batsmen. A similar result occurred with medium-fast bowlers, with large correlations existing between sRPE and all GPS-derived external measures of load (r = 0.76 – 0.87) apart from work-to-rest ratio (r = -0.58). Although still largely low-intensity activity, the increased proportion of high-intensity activity performed by medium-fast bowlers during net-based training explains the greater correlation to sRPE than when compared to batsmen. In regards to work-to-rest ratio, a high ratio (more time between high- and low-intensity efforts) is likely to result in a lower perceptual response due to the increased recovery time, which likely explains the negative correlation to sRPE. Based on this, coaches may consider decreasing the work-to-rest ratio if wanting to increase the resulting TL of medium-fast bowlers during a net session. Regardless of playing position, GPS-derived external measures appear to correlate to sRPE during cricket training. Unlike that of previous research [12, 15], this study found stronger relationships between external measures of TL and sRPE as opposed to internal-TL measures.

A new finding from this study was the relationships observed between cricket-specific skills and sRPE. Specifically, the number of balls faced and hit by batsmen during a net session demonstrated a moderate but negative correlation (r = -0.34 and -0.33, respectively) with sRPE. Houghton et al. [31] reported a general increase in batsmen's RPE with an increase in the number of balls faced during a simulated batting innings. However, this finding included the physical work that accompanied each shot during the simulation and therefore not unsurprisingly, an increase in physical work was evident alongside in the increase in perceived intensity. In the current study however, it was unclear as to why sRPE and the number of balls faced by batsmen shared a negative association. This conceptually differs to the study of Lovell et al. [11], where a positive relationship was reported between a skill-specific external measure of load (impacts) and sRPE. Within the current study it is possible this negative relationship may reflect that the more balls faced during net-training results in longer sessions and less movement, hence the lower RPE is a by-product of more time in the nets and reduced total and high-intensity movements [34].In regards to medium-fast bowlers, a large correlation (r = 0.68) was reported between the number of balls bowled and sRPE. This is not surprising as completing a greater number of deliveries will lead to greater high-intensity running for the run up of each delivery as well as lengthen the duration of the training session. Consequently, the inverse relationship between technical activity and sRPE may suggest alternate, if not expanded methods of TL monitoring are required. Therefore, although it is common practice for net sessions to be based around the technical load of medium-fast bowlers [18, 19], coaches need to consider the playing position when developing training sessions which are based around the volume of technical skills performed.

Similar to recent studies by Lovell et al. [11] and Murphy et al. [17], the use of a multiple stepwise regression in the current study shows a combination of load and intensity measures may explain more of the variance in sRPE than individual measures of load. Unlike these previous studies, the results of the multiple stepwise regression analysis differed depending on the playing position. For batsmen, Player Load™ and distance covered at a high-intensity contributed to 67.8% of the adjusted variance for sRPE. Although unexpected, the inclusion of distance covered at a high-intensity and Player Load™ to explain the variance in batsmen sRPE suggests that the movement characteristics (e.g. running between the wickets and small movements in various directions whilst batting as opposed to remaining stationary during net-sessions) are influential in the perceived intensity of batsmen.

Meanwhile for the medium-fast bowlers, 76.3% of the variance in sRPE could be explained by total distance and HR_{mean}. These results suggest that within batsmen only external measures of TL account for the variance within sRPE, whereas within medium-fast bowlers it is a combination of internal- and external-TL measures. Interestingly within both playing positions, the external measures of TL specific to technical skill did not account for any variance using this analysis. Therefore, these results would suggest that a combination of internal- (HR-based) and external-TL (GPS-derived and skill-specific) measures account for sRPE within cricket players during net-based training sessions, although this is somewhat position specific. It should be noted that these results are specific to batsmen and medium-fast bowlers during net-based cricket training. Although other methods of training are currently used for skill development and physical conditioning in the sport of cricket such as small-sided games or conditioning based exercises, this study was limited to net-based training sessions due to time and player access restrictions. Future research should consider the training loads of each playing position associated with a variety of training methods which are utilised by current cricket coaches

PRACTICAL APPLICATIONS

- The use of sRPE appears to be a suitable tool for monitoring the TL of cricket batsmen and medium-fast bowlers.
- Coaches may need to reconsider only using of cricket-specific measures of skill volume, such as medium-fast bowler's ball count, in monitoring the TL of cricket players during net-based training sessions. A combination of both internal, GPS derived-external and cricket-specific measures of skill may be more superior to monitor TL.
- The data suggests the GPS-derived (external) information proves the most useful and suitable for coaches for the determining of position specific TL during net-based training sessions. This would minimise the amount of information required and therefore impeding less on player's practice time.
- As sRPE can be explained by varying internal and external measures of TL, coaches need to consider playing position when deciding upon which TL measure to use when developing net-based training sessions and monitoring cricket players. This would allow for more specific information to be gathered by coaches which in turn would help in the development of more individualised net-based training programs.

CONCLUSION

This study supports the use of sRPE as a measure of TL as it was demonstrated that sRPE is highly correlated with external-TL measures, particularly those derived from GPS devices in cricket batsmen and fast-bowlers. However, this was not the case with HR-derived internal-TL measures, which is likely explained by the intermittent nature and greater proportion of low-intensity activity of cricket players during training activities. It was also evident that technical skill external measures of TL were correlated to sRPE to varying levels depending on playing position. Additionally, this study also showed that a number of factors could be used to predict sRPE as opposed to only relying on one internal or external measure of TL, although these factors differ between playing position. Overall the results of this study provide cricket coaches with information regarding the use of load monitoring during net-based cricket training sessions.

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