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The relationship between release speed, heart rate and rate of perceived exertion across maximal and submaximal intensities in fast bowlers

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ABSTRACT

This study investigated potential internal workload measures in fast bowlers by examining the relationship between release speed, heart rate and rate of perceived exertion. It also, examined the agreement between prescribed and measured intensity in fast bowlers. Elite and provincial representative bowlers (n=8) bowled three overs each at 60%, 80% and 100% intensity and repeated this in two sessions, one week apart. Release speed was measured for each ball and rate of perceived exertion (RPE; Borg 6-20) and heart rate was measured across each over. The relationships between variables were examined using Pearson's correlations and equivalence testing. It was found that bowlers were able to scale their effort with prescribed intensities. Examining variables relative to participant maximums resulted in significant correlations between release speed, heart rate and rate of perceived exertion. Consequently, heart rate or rate of perceived exertion could be used to estimate the internal workload of fast bowlers across maximal and submaximal intensities. How these variables changed at sub-maximal intensities did not match the change in prescribed intensity, so these results should be considered in future studies and applied practice.

1. Introduction

Bowling workload has been identified as a risk factor for injury among fast bowlers (Alway, Brooke-Wavell, Langley, King, & Peirce, 2019; Hulin et al., 2013; Warren, Williams, McCaig, & Trewartha, 2018) and can be defined in terms of the external and internal load on the body. External workload, or total bowling volume (Hulin et al., 2013), is often measured as the number of balls bowled over a specified period of time, e.g., match, day, week etc. (Orchard, James, Portus, Kountouris, & Dennis, 2009; Dennis, Farhart, Goumas, & Orchard, 2003) Internal workload refers to the perceived effort or physiological demand of each ball, over or spell of bowling, in terms of the amount of stress that is placed on the internal structures of the body (Hulin et al., 2013), i.e., the greater the stress placed on the body, the higher the internal workload. Being able to effectively estimate and then monitor workload across a period of time should allow spikes in workload to be avoided, thereby reducing the risk of overuse injury in fast bowlers (Hulin et al., 2013).

How best to measure both internal and external workload (and hence estimate total workload) in fast bowlers is currently contentious. Retrospectively examining scorecards can provide an estimate of external workload during matches (Alway et al., 2019; Orchard et al., 2015; Orchard & James, 2003), while subjective recall has been used to estimate external workload during training (Bayne, Elliott, Campbell, & Alderson, 2016; Davies, Du Randt, Venter, & Stretch, 2008; Dennis et al., 2003). More recently, microsensors have also been successful at automatically detecting deliveries in a training setting (Jowitt, Durussel, Brandon, & King, 2020; McGrath, Neville, Stewart, & Cronin, 2019; McNamara, Gabbett, Chapman, Naughton, & Farhart, 2015), which has the potential to improve the measurement of external workload.

Measurement of internal workload in the literature has been reported less than external measures, with heart rate being the most common measure and rate of perceived exertion (RPE) the most common estimate (Duffield, Carney, & Karppinen, 2009; Petersen et al., 2011; Vickery, Dascombe, & Duffield, 2017). Collection of both heart rate and RPE data often appears to be

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employed to view physiological changes that may occur over the course of a spell of bowling that could be attributed to factors such as fatigue (Burnett, Elliott, & Marshall, 1995; Duffield et al., 2009; Stretch & Lambert, 1999). However, the aforementioned measures have been used less commonly to quantify effort. The quantification methods have also differed from study to study. For example, one rating per session has been used in some instances (Hulin et al., 2013; Vickery et al., 2017), while ratings per ball bowled have been used in others (Feros, Young, & O'Brien, 2017). Since fast bowlers are unlikely to work at a consistent intensity over all deliveries in trainings, warm-ups and matches (Petersen et al., 2011), it is reasonable to expect that balls/overs will be performed at submaximal intensities, where bowlers put in less effort and/or bowl slower than they are capable of. As bowling at submaximal intensities becomes more accepted because of its potential to reduce loading (Greig & Child, 2019), there will likely be a greater amount of variability in the intensity balls are bowled at. The greater the variability, the more important an accurate internal workload estimate is, because balls bowled at different intensities will stress the body in different ways (see also, Perrett, Lamb, & Bussey, 2020). If this stress can be quantified and the internal workload estimated better, the calculation of total bowling workload could be improved, as could the quality of workload monitoring and management. Therefore, hopefully reducing the number of overuse injuries seen in fast bowlers.

The purpose of this study was to examine the relationship between release speed, the most commonly accepted intensity measure, and two potential internal workload variables, heart rate and RPE, at both maximal and submaximal intensities. Additionally, this study examined the agreement between prescribed intensity and actual intensity, according to release speed.

2. Methods

2.1. Participants

Elite level and provincial representative bowlers were sought for this study, as they were the most likely to be familiar with the variables of interest, such as prescribed effort and RPE. Eight fast bowlers participated (age: 21 ± 3 years; height: 183 ± 6 cm; weight: 82 ± 9 kg) made up of first-class (n = 2), provincial A (n = 2) and provincial u19 players (n = 4). All participants were free of lumbar stress fractures and disc herniations in the previous 12 months and provided written consent prior to data collection. All procedures were approved by the University Ethics Committee (H19/138).

2.2. Equipment and procedure

This cross-sectional study consisted of two testing sessions, one week apart, performed at an indoor cricket facility with sufficient space for all bowlers to use their full length run-up. In each session participants bowled three overs – one over each at 60%, 80% and 100% intensity; the order of the intensities was randomised prior to each session. Participants were introduced to the Borg RPE scale (6–20), and it was clarified that all ratings should be given relative to the activity of fast bowling.

Once the procedure had been explained to participants, a Polar H10 heart rate monitor (Polar Electro, Kempele, Finland) connected via Bluetooth to a smartphone containing Polar Beat (v.3.4.5), was attached and the bowler performed several practice deliveries to measure the run-up distance to be used at each intensity. Ball release speed was measured using a calibrated Stalker ATSII radar gun (Stalker Radar, TX, USA). This was held at arms-length, parallel to the ground by the experimenter who was standing 3 m behind the stumps at the bowler's end (not at the batters end (McNamara, Gabbett, Blanch, & Kelly, 2018) due to size restrictions in the facility being used). Before the commencement of the first over, baseline heart rate was recorded, and the heart rate recording started. The heart rate recording continued until the completion of the follow through of the sixth ball of that over. Upon completion of each over, participants were provided with the Borg RPE scale and asked to give a rating. Once the participants' heart rates had returned to within 10 bpm of their baseline heart rate, the protocol was repeated for the next intensity until all three overs had been completed. RPEs and heart rate was recorded for all 48 overs and release speed was recorded for all 288 balls bowled. No balls had to be repeated.

2.3. Statistical Approach

Raw heart rate data were extracted along with the release speed and RPE data into MATLAB (R2017b; The MathWorks Inc., Natick, MA) where all analyses were performed. To allow a better comparison between individuals, all variables were also calculated as a percentage of each participant's maximum value across their six overs. One-sample Kolmogorov Smirnov tests evaluated the normality of the release speed, RPE and heart rate data. Equivalence testing at the level of $\alpha = 0.05$ (i.e. 95 % equivalence testing) was used to compare measures between the two sessions, as well as to compare candidate intensity measures (RPE, heart rate) to a more common intensity measure (release speed). Although equivalence testing is relatively new to the field of biomechanics and sports science, the authors believe that it provides an improved description of the relationships between variables by testing for equivalence and rejecting the presence of the smallest effect size of interest (Lakens, Scheel, & Isager, 2018). Pearson's correlations were also calculated between release speed, heart rate and RPE to further describe the relationship between variables (reported as the Pearson correlation coefficient, 95% confidence interval and p-value). The average, absolute residuals from linear regression models were used to quantify the relationship between prescribed intensity and each of, release speed, heart rate and RPE in terms of the goodness of fit.

3. Results

One-sample Kolmogorov Smirnov tests indicate that the residuals from linear regression models fit to prescribed intensity follow a normal distribution for release speed, average and peak heart rate and RPE.

Table 1: Quantitative description of how internal workload variables changed at each of the three intensities relative to participant maximums; mean ± standard deviation (SD), inter-session equivalence ($p < 0.05$ if 90% CI is wholly contained in 95% equivalence range), slope of linear regression model fit to prescribed intensity and goodness of fit of this model (average, absolute residuals).

Variable	Intensity	Mean ± SD (%)	95% equivalence range	90% CI for difference between sessions	Change per 1% increase in prescribed intensity (%)	Average absolute residuals (%)
Average heart rate	60 %	85.0 ± 3.2 [a, b]	[-4.3, 4.3]	[-2.4, 2.6] [c]	0.15	2.26
	80%	87.9 ± 3.7 [b]	[-4.4, 4.4]	[-2.6, 6.1]		2.75
	100%	91.2 ± 3.4	[-4.5, 4.5]	[0.1, 5.9]		2.54
Peak heart rate	60 %	92.4 ± 2.8 [a, b]	[-4.6, 4.6]	[-1.6, 3.6] [c]	0.15	2.02
	80%	94.9 ± 3.5 [b]	[-4.7, 4.7]	[-1.5, 6.2]		2.53
	100%	98.5 ± 2.7	[-4.9, 4.9]	[0.7, 4.6] [c]		1.89
RPE	60 %	64.2 ± 5.6 [a, b]	[-3.1, 3.1]	[-4.1, 4.1]	0.79	4.30
	80%	79.9 ± 4.4 [b]	[-4.0, 4.0]	[-6.9, 3.5]		3.49
	100%	95.9 ± 6.1	[-4.8, 4.8]	[-8.3, 5.9]		5.15
Release speed	60 %	86.8 ± 4.0 [a, b]	[-4.3, 4.3]	[0.7, 2.6] [c]	0.25	3.26
	80%	91.6 ± 3.4 [b]	[-4.6, 4.6]	[0.4, 3.0] [c]		2.78
	100%	96.8 ± 2.1	[-4.8, 4.8]	[0.3, 1.8] [c]		1.69

[a] Significantly lower ($p < 0.05$) than 80% over
[b] Significantly lower ($p < 0.05$) than 100% overs
[c] Null hypothesis of non-equivalence between sessions is rejected

Table 1 shows that the group means of all examined variables positively scaled with intensity (60% < 80% < 100%) when examined relative to participant maximums. RPE scaled most closely (0.79% increase for every 1% increase in prescribed intensity), however the linear regression model had the worst fit at all three intensities. The model for peak heart rate fitted best in the 60% and 80% overs, while release speed fitted best in the 100% overs, and was the only variable to have inter-session equivalence at all three intensities ($p < 0.001$).

Although all participants had mean release speeds that positively scaled with intensity, there was generally an overlap between intensities when considering each ball bowled (Figure 1). Figure 1 also shows that average heart rate positively scaled with intensity in ten of the 16 individual bowling sessions, however there were some inconsistencies between intensities and sessions. For example, P3 had 80% average heart rate values that were lower than the 60% values in both sessions, and also had differences of ~10% between sessions at all intensities.

The continuous heat rate responses for each session and participant are presented in Figure 2. There are two topographical features that are similar across participants. First, the increased slope of the curve from 0-20 s and, second, the nature of the undulating shape of the curve which is apparent in all sessions and intensities for some participants (e.g., P2 and P6) and only some sessions/intensities for others (e.g., P7 and P5). It is also worth noting that the number of local maxima in the undulating curves is often only five, likely because the heart recording was stopped before the final peak.

There is a significant, moderate, positive correlation between average release speed and RPE (r (15) = 0.55 [0.32, 0.72]; $p < 0.001$). Meaning that in general, those bowling faster gave higher ratings of perceived exertion. The correlations between variables are stronger when the percentage of participants' maximum values are used. For example, between release speed and RPE (r (15) = 0.77 [0.63, 0.87]; $p < 0.001$) and between release speed and both peak (r (15) = 0.80 [0.67, 0.88]; $p < 0.001$) and average heart rate (r (15) = 0.68 [0.48, 0.81]; $p < 0.001$).

Equivalence testing with release speed as the "known criterion" measure for intensity (Dixon et al., 2018) allows a further comparison between potential intensity measures when all variables are examined relative to participant maximums. The 95% equivalence range for release speed [-4.59, 4.59] wholly contains the 90% CI for the difference between release speed and peak heart rate [-4.3, -2.8] meaning equivalence between the measures can be supported. Conversely, equivalence cannot be supported between release speed and average heart rate [2.8, 4.61] or RPE [9.2, 14.3]. However, when examined at each intensity, there is equivalence between release speed and average heart rate in the 60% overs (95% equivalence range = [-4.3, 4.3]; 90% CI = [-0.5, 3.9], $p < 0.001$) and between release speed and both RPE and peak heart rate in the 100% overs (95% equivalence range = [-4.8, 4.8]; 90% CI = [-1.6, 3.5], $p < 0.001$; [-2.4, -0.9], $p = 0.02$).

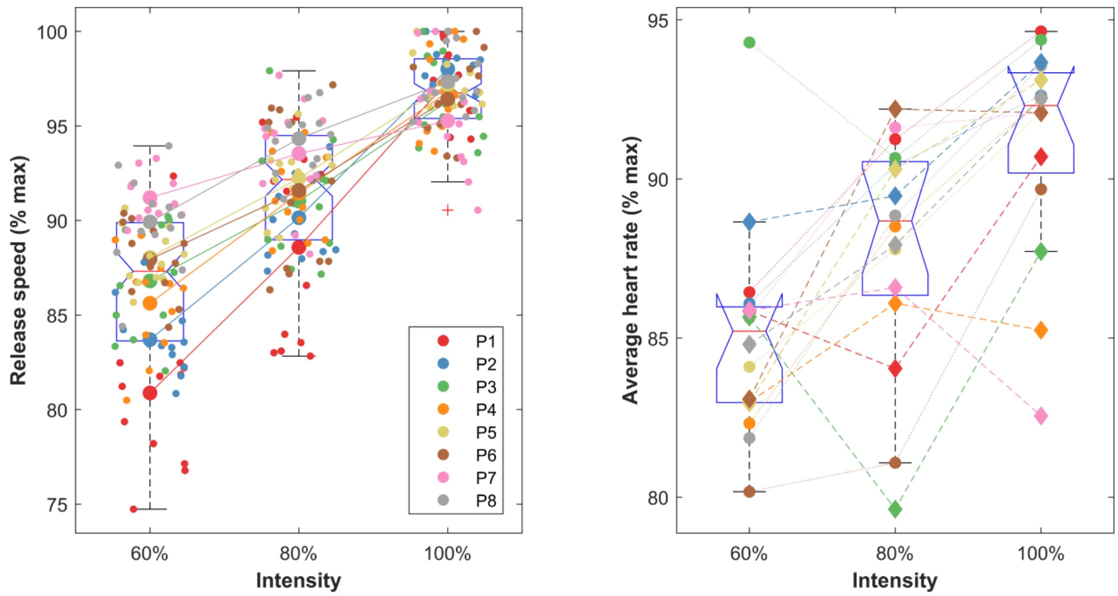

Figure 1: Boxplots showing the release speeds (left panel) and average heart rates (right panel) of all participants positively scale with prescribed intensity. For the release speed plot, large dots represent the average for each participant across both sessions; small dots represent each delivery. For the average heart rate plot, circles/dashed lines represent session one and diamonds/solid lines represent session two.

4. Discussion

Fast bowlers in this study successfully scaled their effort with the prescribed intensities, regardless of the variable used to measure 'effort'. No single effort variable provided a better measure/ estimate of release speed than another. For example, RPE values were the most similar to release speed but the linear regression model had the worst fit at all intensities. Between session differences were minimal; there was an average release speed difference of 0.75 kmh^{-1} (1.67 %) which may have resulted from the randomised order of intensities in both sessions. The relative motivation of participants may also have influenced the inter-session differences. Moreover, differing fitness levels, bowling styles, run-up lengths and physical characteristics may all have influenced the lack of strong correlations in the raw group data. The correlations between release speed and other potential intensity measures (heart rate, RPE) are stronger when examined relative to participant maximums, indicating that the normalisation of certain variables is an important consideration for model fitting.

The correlations between potential intensity variables provide some context on how the measurement of workload in fast bowlers could be improved. As mentioned by McNamara et al. (2018), release speed can be used to indicate intensity, but is not without its practical limitations that reduce its effectiveness as an intensity measure in a group training session. For example, considerable resources are required to collect release speed data from multiple bowlers working at any one time across various training nets. The moderate-strong correlation ($r = 0.55$) between release speed and RPE means that, in general, participants were able to provide an appropriate estimate of the intensity at which they were working; however, there was no equivalence with release speed in either the 60% or 80% overs. It is also not known whether the correlation between release speed and RPE would persist if specific intensities are not prescribed. There is also the consideration of when to collect the ratings – providing a rating after every ball (Feros et al., 2017) has the potential to be tedious for bowlers and practically infeasible over any period of regular training time. However, this is the only method that will exclude rest, which can affect RPE measures (Minganti et al., 2011). Conversely, session RPEs (Hulin et al., 2013; Vickery et al., 2017) assume that work rate is fairly constant, i.e. there are no spikes in effort/intensity within the session. No matter the method used, the effectiveness of RPE as a workload tool would likely improve as familiarity with the scale increases.

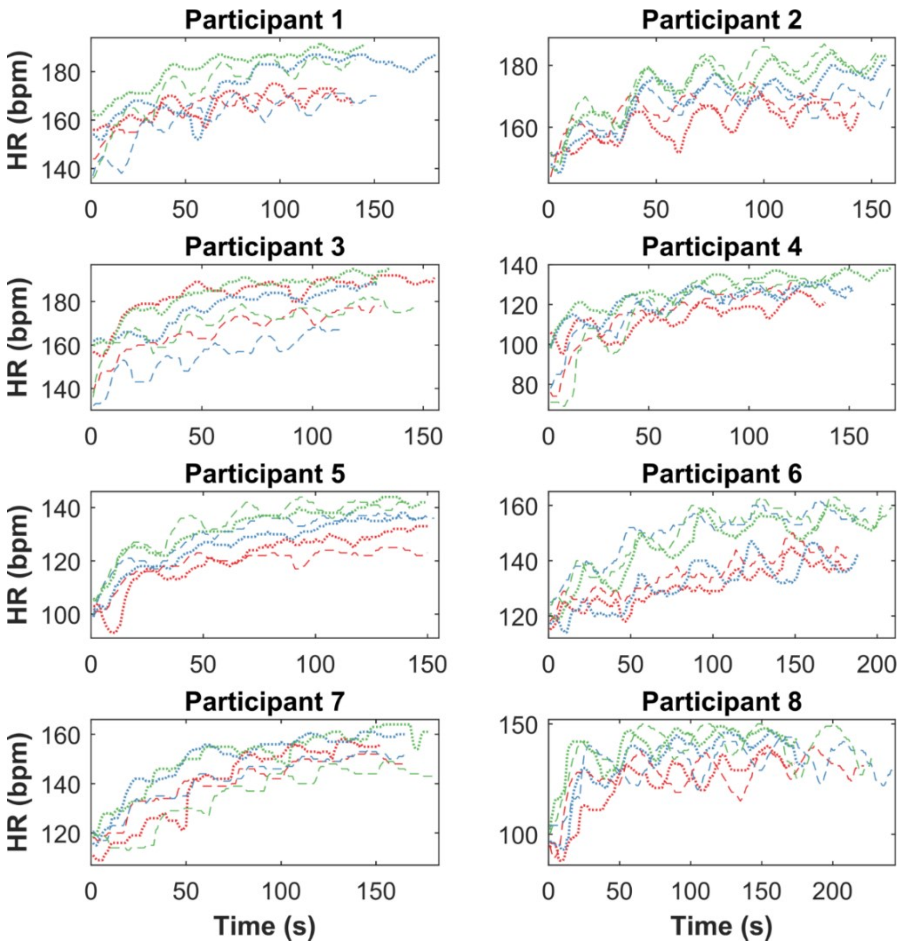

Figure 2: Heart rate responses of participants over the two sessions at each of the three intensities: 60% (red), 80% (blue) and 100% (green) in session one (dotted lines) and session two (dashed lines).

Moderate-strong correlations between release speed and both peak (*r* = 0.80) and average (*r* = 0.68) heart rate indicate that, generally, a greater amount of physiological energy/work is needed in order for bowlers to bowl faster, e.g. by increasing run-up speed (Worthington, King, & Ranson, 2013). Our results indicate that either heart rate variable may be a reasonable estimate of internal workload (as would RPE); however, further investigation regarding the specific measure used may be required before the measure could be accepted as valid and reliable. For instance, it is not clear how to deal with the heart rate responses in training, which likely include multiple bowlers, and more than one over bowled at a time, compared to a match, in which one bowler bowls one over of six consecutive deliveries at a time. Furthermore, a method to account for the inherent variability of heart rate over the course of a season (due to changing fitness levels, fatigue (Halson, 2014), temperature etc.) would need to be developed.

The relationship between prescribed and measured intensity was also of interest in this study. Although this is yet to be reported in fast bowlers, it has been reported that perceived effort (prescribed intensity) did not exactly match measured effort (throwing velocity) in baseball pitchers, with a 0.44% decrease in velocity for every 1% decrease in prescribed intensity (Melugin et al., 2019). However, this relationship assumes two things: Firstly, that that prescribed intensity will always equal the perceived effort; for athletes unfamiliar with working at submaximal intensities, this is unlikely to be the case. The second assumption is that intensity or effort can always be measured using throwing velocity/release speed. This is complicated in fast bowling given that numerous combinations of run-up length, run-up speed, effort at the crease, etc. could be combined to produce the same release speed. Additionally, the bowlers' ability to scale their bowling intensity with the prescribed intensity is complicated by the interpretation of the slope of the prescribed intensity scale: what do lower prescribed intensities such as 40%, or even 0%, correspond to? What does an RPE of 6 correspond to? Although 100% intensity can be easily determined/estimated based on release speed; comprehending submaximal intensities is more difficult and may be done inconsistently between bowlers. Regardless of these assumptions, in this study there was a 0.29%

drop in absolute release speed for every 1% decrease in prescribed intensity, similar to the relationship in baseball pitchers (Melugin et al., 2019).

Equivalence testing on fast bowling data was introduced in this study, with two potential uses analysed – comparing between two sessions (e.g. are the release speeds in session one and session two equivalent) and comparing potential intensity measures (e.g. heart rate and RPE) to more accepted measures (e.g. release speed). Although equivalence testing is relatively new to the field of biomechanics and sports science, the authors believe that it provides an improved description of the relationships between variables by testing for equivalence and rejecting the presence of the smallest effect size of interest (Lakens et al., 2018). In comparison, t-tests and ANOVA are designed to detect differences, meaning equivalence testing is more appropriate when comparing between sessions as you would expect similar results. Alternatively, using equivalence testing to compare potential measures of intensity (e.g. RPE, heart rate) to 'known' measures (Dixon et al., 2018) (e.g. release speed) provides an alternate description of the relationship between variables and provides valuable context in this study. Release speed had similar strength correlations with RPE (r = 0.77) and average heart rate (r = 0.68), but when equivalence is examined, it can be seen that average heart rate is more equivalent at submaximal intensities, whereas RPE is more equivalent at a maximal intensity. While this does not necessarily mean that heart rate is a better estimate of effort at submaximal intensities, nor likewise for RPE at a maximal intensity, it does highlight the risks of examining only a correlation coefficient. Even though RPE was more highly correlated, the RPE ratings were not equivalent to release speeds at either 60% or 80% intensity and the residuals from the RPE linear regression model were also relatively large. Describing relationships by evaluating the strength of their linearity (e.g., correlation or regression analysis), as well as by examining how similar the measures are to one another would provide more context than either one on its own, so should be given consideration in future, relevant studies.

This study was powered at 12 participants, which equates to 67% power with the sample size achieved due to the COVID-19 outbreak shortening the data collection. It is recognised that a lower statistical power is not ideal, particularly when performing correlational analyses and equivalence testing; however, the amount of release speed data collected (288 balls) was the same as two previous studies on fast bowlers (McNamara et al., 2018, 2015) Repeating the experiment with two overs at each intensity in each session and recording the heart rate for ~10 seconds longer at the end of each over would likely improve the quality of heart rate data. The same could be said for the RPE data if participants were familiarised with RPE prior to the first testing session.

5. Conclusion

The significant correlations between release speed, heart rate and RPE across submaximal intensities mean that both heart rate (peak and average) and RPE could be used to estimate internal workload in fast bowlers. Although the measures require some consideration prior to their use to maximise effectiveness, any measure that is implemented consistently will add more context to workloads than simply counting the number of balls bowled and should be encouraged. This is important for practitioners aiming to track the workload of fast bowlers in the field.

Conflict of Interest

The authors declare no conflict of interests

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