METHOD ARTICLE

Novel Twenty20 batting simulations: a strategy for research and improved practice [version 2; peer review: 1 approved, 3 approved with reservations]

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Abstract

Twenty20 cricket and batting in particular have remained vastly understudied to date. To elucidate the effects of batting on the batter, tools which replicate match play in controlled environments are essential. This study describes the development of two Twenty20 batting simulations, for a high and low strike rate innings, generated from retrospective analysis of international and domestic competition. Per delivery analysis of probabilities of run-type and on/off-strike denomination produce ball-by-ball simulations most congruent with retrospective competitive innings. Furthermore, both simulations are matched for duration and dictated through audio files. The 'high' strike rate innings requires a batter to score 88 runs from 51 deliveries, whereby 60 runs are from boundaries. Similarly, the 'low' strike rate innings requires a batter to score 61 runs from 51 deliveries, where 27 runs are scored from boundaries. Because batting simulations dictate run scoring outcomes, a method of quantifying a batter's performance from bat-ball contact scores is described. Ten elite batters achieved a mean performance score of 72 (SD = 26) and 88 (21) for the low and high strike rate simulations respectively. This study provides sport practitioners with a training technique to improve specific skill acquisition and enables research in understudied Twenty20 batting.

Keywords

Cricket, batting performance, simulation, innings

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1. Introduction

Bating in the sport of cricket is an interceptive task which creates a combination of physical (Johnstone & Ford, 2010; Pote & Christie, 2016) and cognitive stress (Goble & Christie, 2017). In a cricket match, runs are scored by sprinting between the wickets or by hitting the ball out of play (boundaries). During an innings, a batter and batting partner will attempt to accumulate runs, while trying to avoid being dismissed. Resultantly, a batter’s innings may be prolonged resulting in fatigue (Christie, Todd, & King, 2008; Johnstone & Ford, 2010) which may adversely affect batting performance. Traditional net-practice however, may not replicate the physical demands of an innings produced in competitive match-play (Goble & Christie, 2017; Vickery et al., 2018). Batters in practice, therefore, may not routinely experience batting under appropriate fatigue (Vickery & Nichol, 2020) despite evidence suggesting that “practice how you play” methodologies are beneficial to skill-acquisition. In cricket, the availability of competitive match data enables the development of detailed innings simulations that can be an effective addition to practice programmes. And a reliable method of recreating the physiological baseline of competitive batting for further scientific inquiry.

In previous studies, attempts to replicate a batting innings have taken various forms. Christie and colleagues (2008) replicated the physical demands of batting through shuttle running. Running multiple shuttles, the length of a cricket pitch (17.68m), physically mimics run scoring in cricket. However, shuttle running protocols neglect to account for the energetic cost of ball striking and boundaries where no shuttles are required. As a result, more sophisticated protocols which require batters to intercept deliveries were subsequently developed. The Battlezone protocol mimics a small-sided cricket match reduced to eight players and six repeated bouts, each consisting of eight overs (Vickery, Dascombe, Duffield, Kellett, & Portus, 2013). Batters are required to compete in a bout against two bowlers and four fielders in a 27m ring. However, the limited length (six overs per batting pair) and smaller field may limit the transferability of this protocol to elite sport and its validity for research. Finally, the BATEX (Houghton, Dawson, Rubenson, & Tobin, 2011) protocol simulates scoring a One Day International (ODI) century (100 runs) with ball-by-ball audio guidance. In this protocol batters are required to complete an innings of two hours and 20 minutes, the typical length of an ODI century (Houghton et al., 2011). Unlike the Battlezone protocol, which provides batters with freedom to score runs at any rate, BATEX instructs batters on the denomination of runs required – singles, doubles or boundaries - every over. Thus, BATEX mimics the amount of time spent at the crease and also allows the innings to follow a run scoring progression akin to centuries scored in ODI’s. Further, the BATEX protocol is divided into phases which allows researchers and sport practitioners to manipulate scoring zones and running intensities throughout the innings creating variability to the batters information sources and match realism (Pinder, Davids & Araujo, 2011; Woods et al., 2019). However, the BATEX protocol, being a simulation of the ODI format, may not be applicable to the increasingly popular, shorter Twenty20 format where an entire team innings is often completed within two hours.

To date no batting protocol has specifically aimed to address a Twenty20 innings. Batting may be performed at various run scoring intensities (strike rate) depending on the context of the innings and format of the game. Twenty20 cricket is the shortest format of the game (20 overs per side) resulting in higher run scoring intensities as batters attempt to score more runs from fewer available deliveries. Resultantly, a Twenty20 innings imposes unique movement demands compared to longer game formats (Petersen et al., 2010; Sholto-Douglas et al., 2020) and different approaches to batting technique (Noorbhai, 2020). Thus, centre-wicket batting simulations which are specific to Twenty20 cricket are required. Further, the BATEX protocol places minimal emphasis on the role of the batter’s partner. As batting is performed in pairs, consideration for how runs are scored while the batter in question is off-strike is necessary as this increases the workload placed on the batter.

This study aimed to develop two Twenty20 batting simulations which mimic the demands of competitive match play. To further highlight the impact of strike-rate, both simulations possess an equal number of deliveries, resulting in varying run scoring intensities throughout the innings.
2. Methods

Two Twenty20 simulations were developed to simulate match play for an individual achieving 1) ‘high’ and 2) ‘low’ strike rate innings. Both high and low strike rate simulations are equal in duration, achieved by standardizing the number of deliveries in both simulations. However, the strike rate and mode of run scoring in either innings varies in accordance with data obtained from selected innings. Relevant retrospective innings selection procedures and accessed databases are outlined in Figure 1.

2.1 Retrospective data acquisition - innings summaries

Match data from previous Twenty20 internationals (2006–2019) and the domestic Vivo Indian Premier League (IPL) competition (2008–2019) were exported from ESPNcricinfo (ESPN Sports Media Ltd, n.d.) using an Excel macro. ESPN’s statistical database ‘Statsguru’ provided match summaries and run tallies of individual innings produced in international competition. An advanced filter was applied to query an innings by innings list of top order batters (top seven) from all available seasons and competitions. To obtain innings summaries from the IPL, match scorecards were opened manually to import summaries produced by top seven batters from both teams. This process was repeated for every fixture within a season and from all available seasons at the time of analysis. Thus, a total sample of 12,990 individual innings were selected. These innings represented 5906 different batters, runs mean = 19.9 (SD = 21.2).

Figure 1. Schematic outline of data reduction procedures and relevant innings selection from online databases. Table 1 provides innings summaries of specialist batters within each ‘low’ and ‘high’ scoring subcategory. Table 2 provides refined innings summaries from each ‘low’ and ‘high’ subcategory with an equal number of on-strike deliveries. Table 3 and Table 4 represent the developed ball-by-ball simulations.
Two batting milestones, a half-century (50 runs) and century (100 runs), were selected to represent a ‘low’ and ‘high’ strike rate threshold. These milestones were selected as they represent meaningful team contributions and, secondly, are likely to be of a duration which warrants physiological study. From the 12,990 innings, 87 innings produced exactly 50 runs scored and only nine innings matched the 100 run criteria. Therefore, to increase the sample sizes around the chosen milestones, a range of \( \pm 1 \) SD of runs scored (SD = 21.2 runs) was applied. Thus, the half century (low strike rate) sample size increased to \( n = 3210 \) and included innings of 29–71 runs scored. Likewise, the century (high strike rate) sample size increased to include innings ranging from 79–121 runs scored, producing an \( n = 287 \). The innings summaries for these adjusted milestones are presented in Table 1.

The number of on-strike deliveries was selected as a robust measure of innings length. To standardize the duration of both batting simulations, frequency distributions of deliveries faced within each innings subset were drawn and the point of intersection with the largest sample size between the ‘high’ and ‘low’ strike rate innings was identified. The resultant overlap occurred at 51 deliveries faced, with a total of 27 half-centuries (‘low’), 18 centuries (‘high’). While these innings were of equal duration, it is important to note that fundamental differences in runs scored, strike rate, number of boundaries and ratio of boundaries to runs accumulated by running - define the intensity of each simulation. Therefore, to account for each of these factors and to develop accurate simulations, ball-by-ball match data was needed to provide records of how each individual innings (‘low’, \( n = 27 \) and ‘high’, \( n = 18 \)) progressed and how runs were accumulated throughout the innings.

2.2 Innings development - ball-by-ball match data

Ball-by-ball data was obtained from a second online database (Rushe, 2009). However, at the time of analysis, existing ball-by-ball match data from the online database reduced our sample to 22 ‘low’ and 17 ‘high’ strike rate innings - presented in Table 2.

**Table 1.** Average characteristics of individual innings milestones broadened by \( \pm 1 \) SD of runs scored.

|                     | ‘low’ strike rate (50 runs ± 1SD) | ‘high’ strike rate (100 runs ± 1SD) |
|---------------------|---------------------------------|-----------------------------------|
| Mean (SD) Median Range | Mean (SD) Median Range           |
| Runs scored 44.2 (11.5) 42 29–71 | 91.1 (10.3) 89 79–119            |
| On-strike deliveries 31.8 (9.9) 31 8–79 | 52.9 (8.6) 53 25–119             |
| Minutes at the crease 48 (17) 46 7–109 | 78 (14) 81 37–109               |
| Fours a 4.1 (2.1) 4 0–12 | 8.5 (2.8) 8 1–16                |
| Sixes b 1.7 (1.4) 1 0–9 | 4.7 (2.5) 5 0–13                |
| Strike rate c 147 (39) 139 67–422 | 177 (30) 171 123–194            |

Data represent competitive individual innings produced in Twenty20 internationals and the Vivo Indian Premier League between 2006–2019. Innings milestones are broadened to categorize a range of \( \pm 1 \) SD (21 runs) around the given milestone, increasing the number of innings within each category. ‘low’ strike rate \( n = 3210 \) individual innings, ‘high’ strike rate \( n = 287 \).

a Intercepted delivery which leaves the field of play with a minimum of one bounce, batter credited four runs.

b Intercepted delivery which leaves the field of play without a bounce, batter credited 6 runs.

c Run scoring intensity - fraction of runs scored and on-strike deliveries.

**Table 2.** Average characteristics of broadened innings milestones at the point of greatest overlap in number of on-strike deliveries.

|                     | ‘low’ strike rate (n = 22) | ‘high’ strike rate (n = 17) |
|---------------------|----------------------------|----------------------------|
| Mean (SD) Median Range | Mean (SD) Median Range |
| Runs scored 61.3 (8.9) 65 39–71 | 90.4 (11.1) 89 79–117 |
| Minutes at the crease 61 (14) 60 51–101 | 76 (14) 81 55–112 |
| Fours a 5.4 (2.4) 6 1–10 | 8.5 (2.9) 9 4–15 |
| Sixes b 1.8 (1.5) 1 0–5 | 4.4 (2.9) 4 1–13 |
| Strike rate c 120 (18) 128 76–139 | 177 (22) 175 154–229 |

Data represent competitive individual innings produced in Twenty20 internationals and the Vivo Indian Premier League between 2006–2019 with a standardized workload of 51 on-strike deliveries.

a Intercepted delivery which leaves the field of play with a minimum of one bounce, batter credited four runs.

b Intercepted delivery which leaves the field of play without a bounce, batter credited 6 runs.

c Run scoring intensity - fraction of runs scored and on-strike deliveries.
Match data was downloaded as comma separated variables (CSV’s) and reduced to isolate the relevant innings within the match (Lopes, 2021). These CSV’s were imported into an R script for analysis. The purpose of analysing ball-by-ball innings data was to determine; i) the deliveries with the highest frequency of dot balls, singles, twos, threes, fours and sixes, ii) how runs were accumulated, and iii) the scoring rates of each individual innings. Furthermore, because batting is performed in pairs, each innings was analysed for its respective partnership data to determine; i) the average partnership deliveries faced and hence the overall duration of the simulation, ii) the number of deliveries which the batter is most likely on/off-strike, and iii) the proportion of runs scored by the batter’s partner. By analysing ball-by-ball data, the average number of dot balls, singles, twos, threes, fours and sixes were calculated for both the ‘low’ and ‘high’ strike rate innings.

For each individual innings, the role of the batter’s partner was determined using a second R script. Ball-by-ball partnership data was extracted from the match data for every delivery faced by the batter’s partner/s (Lopes, 2021). This provided the number of deliveries faced during the innings as well as the sequence of runs scored by the batter’s partner/s. Like the development of the high and low scoring innings, the length of the overall partnership (deliveries faced by both batter and partner/s) was determined by the point of greatest overlap in overall partnership length from the representative high and low scoring innings. However, three overlaps were identified each with a sample size of one. As a result, the overlap which was nearest to the median of deliveries faced for the overall partnership was chosen as the best representative of the partner’s role in both high and low strike rate simulations. This overlap was identified as 43 deliveries resulting in a total simulation length of 94 deliveries. To determine which of the total 94 deliveries the batter is on strike for, a strike score was calculated for every delivery by assigning a ‘1’ if the batter was on-strike and ‘0’ if the batter was off-strike for every innings. Thereafter, each delivery was scored using Equation 1.

\[
\text{Strike Score} = \left( \frac{\text{Ball No.}}{P.\text{Length}} \right) \times \text{Strike Score}
\]  

Whereby, ‘Ball No.’ is the sequenced number of the delivery in question (e.g. one, two, … 94), ‘P. Length’ denotes the partnership length or number of deliveries within the given partnership and ‘Strike Score’ denotes the assigned binary score given to the delivery whether the batter was on-strike (1) or off-strike (0). The median was calculated for each delivery and rounded up to identify each ball number (of all 94 deliveries) the batter will be on strike for. This procedure was completed for both simulations.

Once on/off-strike deliveries were determined, assigning runs to deliveries completed the development of the simulations. For on-strike deliveries, the number of dot balls, singles, twos, threes, fours and sixes were tallied for every delivery (independently for high scoring and low scoring simulations) to determine which deliveries produce the highest frequency/probability of each possible score. From these probabilities run types (dot ball, one, two… etc.) were assigned in descending order of probability. In the case where deliveries produced identical probabilities for two or more run types, priority was given to the run type with the least overall frequency in the innings (for example, sixes were prioritized over dot balls). Lastly, because dictating the exact outcome of each delivery is not representative of match play, every six deliveries (one over) required run types were grouped, giving batters freedom to decide which on-strike delivery, within an over, will produce a given run type according to the stroke played. As studying effects of batting partner/s is not a primary outcome of the batting simulations, required runs from off-strike deliveries were made identical for both high and low scoring simulations. Using the same method described for on-strike deliveries, run type was assigned to each off-strike delivery.

2.3 Simulated innings task design

Time motion analysis of Vivo IPL Twenty20 matches was performed and determined the average interval between deliveries to be 35 seconds and 80 seconds between overs, consistent with findings of Houghton and colleagues (2011). An audio recording was created using a written script and computer text-speech function (Supplementary Material A, B) to govern intervals between overs/deliveries. Further, the audio recording describes; i) when the batter is on/off-strike ii), the run requirements for each over and their denomination (singles, doubles, boundaries etc.), and iii) an indication of the start and end of each over.

During each on-strike delivery, the batter is free to select which on-strike deliveries to score from and what run type is achieved from a given delivery. The only constraints placed are that the batter must match the run type with the achieved stroke and that all required shuttles for an over must be achieved. To match run type with achieved stroke for a given delivery, batters are required to penetrate a scoring zone to be awarded ‘four’ and bat-ball contact must be achieved for all other run types. However, if the number of on-strike deliveries remaining in an over are near-depleted, shuttles may be enforced regardless of achieved contact or scoring zone penetration. For a ‘1’ batters should complete a single shuttle (17.68m) likewise, for ‘2’s batters should complete a double shuttle, and three shuttles for a ‘3’. For all shuttles, batters are required to complete a 180° turn at the end of the crease when completing the final shuttle for a given delivery. Boundaries
will require one and a half shuttles for a ‘four’ and no shuttles for a ‘six’. When the batter is off-strike, instruction from the audio tape will dictate the required shuttles necessary for each off-strike delivery and the batter will complete these shuttles beginning on the audio cue. After necessary shuttles have been completed the batter will walk back to the striking crease. Shuttles must be run at maximum intensity akin to match play where batters attempt to maximize the number of runs scored from every delivery.

Figure 2. Procedural outline and arena schematic (drawn to scale) depicting regulation size action/indoor cricket arena and regulation length pitch (17.68m).
To improve the ecological validity and dynamics of the simulations, three phases were introduced to represent how an innings would develop under match conditions. These consisted of a ‘PowerPlay’ phase of six overs and two phases of five overs each, the ‘Middle’ and ‘Close Innings’ phases. During these phases, fielding positions or scoring zones can be altered to present varying scoring zones to encourage the batter to manipulate the ball into different areas of the field/arena. In cricket, the Powerplay consists of six overs whereby a maximum of two fielders are placed outside the inner ring while the remaining overs allow a maximum of five fielders outside the inner ring (ICC, n.d.). No more than five fielders may be placed on the ‘leg-side’ throughout the innings (ICC, n.d.). Therefore, we suggest a reduction in the number of available scoring zones following the ‘PowerPlay’ phase and discretion in the remaining number and placement of zones depending on the desired objectives of the simulation and skill of the batter.

To incentivise the batter and provide a form of match pressure, an overall batting performance score can be obtained according to the method of Muller and Abernethy (2008). Briefly, the method entails tallying bat-ball contacts according to three criteria. Good ball contact requires contact on the face of the bat and the ball deflecting in the intended direction (2 points). Bad ball contact entails contact with the bat and the ball deflects into an unintended direction (1 point). One point is deducted for an unsuccessful attempt at contact (-1 point) and a ‘leave’ entails an intentional lack of contact with the ball (1 point). The achieved score for a given delivery is doubled if the stroke penetrates a scoring zone. If a batter is dismissed, the final achieved batting score is halved, with further deduction factors applied for multiple dismissals (i.e. two dismissals; performance score divided by three). Batters are instructed to bat for a maximized performance score by ensuring optimal bat-ball contacts, manipulating deliveries into pre-assigned scoring zones as often as possible and avoiding a loss of wicket. Attempting to achieve a maximal performance score in the simulation places a form of pressure on the batter improving match realism. According to the batting performance score criteria, a maximum score of 4 points may be achieved per on-strike delivery resulting in a maximum simulation score of 204 points from 51 on-strike deliveries.

The method was piloted in a controlled study and recruited 10 experienced (competitive playing experience >6 years) batters who bat in the top seven of their respective teams. Participants were required to be currently competing in amateur cricket leagues and free from injury (age: 22.3 (SD = 3.4) years, stature: 178 (8) centimetres, mass: 80.9 (9.0) kilograms). Procedures were reviewed by the Human Research Ethics Committee (clearance no: M180872) and participants signed informed consent. An arena schematic and procedural outlines are provided in Figure 2. Participants completed both batting simulations, in a randomised order, separated by a minimum of 48 hours. A regulation size indoor/action cricket arena with artificial playing surface was used and deliveries projected from an electric bowling machine Figure 2. For the purpose of this study, deliveries were aimed at ‘off-stump’, projected at a velocity of 110 km h⁻¹, with lateral movement away from the batter and off-stump. Deliveries were not permutated to provide consistency between assessments. In the PowerPlay phase, four scoring zones (2.5 meters wide) were placed in positions to mimic fielding gaps at third-man, extra cover, mid-wicket and long-on. Scoring zones were demarcated with coloured cones placed on the ground visible to batters, who were also verbally informed to their placement and changes throughout the simulation. Once the PowerPlay phase was concluded, one scoring zone (third-man) was removed to increase the difficulty of achieving boundaries in the ‘Middle’ and ‘Close Innings’ phase.

3. Results
The developed simulations are 1 hr 2 min in duration and provided in audio format for ease of accessibility (Lopes, 2021). Ball-by-ball run requirements and on-strike delivery numbers, within an over, are presented in Table 3 (‘low’ strike rate innings) and Table 4 (‘high’ strike rate innings). The low strike rate simulation requires a batter to score 61 runs at a strike

### Table 3. Ball-by-ball simulation of a Twenty20 ‘low’ strike rate innings (50 runs ± 15SD).

| Phase     | Over No. | On-strike delivery No. | Run Requirements |
|-----------|----------|------------------------|------------------|
|           |          |                        | On-strike | Off-strike |
| PowerPlay | 1        | 1, 4, 6                | 0, 0, 0   | 0, 1, 0   |
|           | 2        | 1, 3, 5, 6             | 4, 0, 0, 0 | 0, 3      |
|           | 3        | 2, 3, 4, 5             | 0, 0, 4, 0 | 0, 1      |
|           | 4        | 1, 4, 6                | 0, 0, 1    | 4, 0, 0   |
|           | 5        | 2, 4, 6                | 0, 0, 2    | 0, 0, 0   |
|           | 6        | 1, 3, 6                | 1, 0, 0    | 1, 4, 1   |
rate of 120, whereby 27 runs are scored through boundaries. The ‘high’ strike rate simulation requires a batter to score 88 runs at a strike rate of 173, whereby 60 runs are scored through boundaries.

In the half-century innings, batters achieved a batting performance score mean (SD): 72 (26) points, while the century produced a mean (SD): 88 (21). Table 5 presents by-phase summaries of both simulations and achieved performance scores adjusted to percent scores with associated point multipliers (scoring zone placement) and deductions (play-and-miss).

Table 3. Continued

| Phase       | Over No. | On-strike delivery No. | Run Requirements |
|-------------|----------|------------------------|------------------|
|             |          |                        | On-strike | Off-strike |
| Middle      |          |                        |           |           |
|             | 7        | 1, 2, 3, 4             | 1, 1, 0, 0 | 4, 0      |
|             | 8        | 1, 2, 4                | 1, 1, 1    | 4, 1, 1   |
|             | 9        | 1, 2, 4, 6             | 1, 0, 2, 4 | 0, 1      |
|             | 10       | 2, 4, 6                | 1, 1, 4    | 4, 1, 0   |
|             | 11       | 1, 3, 4, 6             | 2, 6, 1, 2 | 1, 0      |
| Close Innings|        |                        |           |           |
|             | 12       | 2, 3, 6                | 0, 1, 1    | 0, 0, 0   |
|             | 13       | 2, 4, 6                | 2, 1, 1    | 1, 0, 0   |
|             | 14       | 1, 5, 6                | 1, 1, 1    | 1, 4, 0   |
|             | 15       | 3, 4, 6                | 1, 4, 6    | 1, 2, 0   |
|             | 16       | 2                      | 0          | 1, 2, 1   |

Ball-by-ball audio dictation provided in supplementary material A.

Table 4. Ball-by-ball simulation of a Twenty20 ‘high’ strike rate innings (100 runs ± 1SD).

| Phase       | Over No. | On-strike delivery No. | Run Requirements |
|-------------|----------|------------------------|------------------|
|             |          |                        | On-strike | Off-strike |
| PowerPlay   | 1        | 1, 3, 5                | 0, 0, 4 | 0, 1, 0 |
|             | 2        | 1, 3, 4                | 1, 4, 0 | 0, 3, 0 |
|             | 3        | 2, 3, 4, 6             | 0, 0, 1, 1 | 1, 4, |
|             | 4        | 1, 2, 3, 5             | 0, 4, 1, 4 | 0, 0 |
|             | 5        | 1, 2, 5                | 1, 0, 0 | 0, 0, 0 |
|             | 6        | 1, 4, 6                | 1, 0, 0 | 1, 4, 1 |
| Middle      | 7        | 1, 5, 6, 6             | 6, 1, 0 | 4, 0, 4 |
|             | 8        | 1, 3, 4                | 1, 1, 4 | 1, 1, 1 |
|             | 9        | 1, 2                    | 1, 1 | 1, 4, 1, 0 |
|             | 10       | 1, 2, 3, 5, 6          | 1, 2, 1, 0, 1 | 1 |
|             | 11       | 2, 3, 5                | 2, 1, 1 | 0, 0, 0 |
| Close Innings|        |                        |           |           |
|             | 12       | 2, 3, 4, 6             | 2, 6, 4, 6 | 0, 1     |
|             | 13       | 2, 4, 6                | 1, 6, 1    | 0, 0, 1 |
|             | 14       | 2, 3, 5                | 1, 0, 1 | 4, 0, 1 |
|             | 15       | 1, 3, 6                | 4, 2, 4 | 2, 0, 1 |
|             | 16       | 1, 2                    | 4, 0 | 2, 1 |

Ball-by-ball audio dictation provided in supplementary material B.
4. Discussion

This study has developed two comprehensive batting simulations which are unique to Twenty20 cricket. Descriptions of high and low strike rate individual innings which vary in strike rate and requirement of boundaries are detailed ball-by-ball. Additionally, we suggest a method of improving the ecological dynamics and validity of batting simulations. These considerations improve match realism allowing researchers to produce match representative data and are a tool for sport practitioners to bolster training programmes.

Previous studies have investigated the physiological costs of scoring an ODI century (Goble & Christie, 2017; Houghton et al., 2011; Pote & Christie) or the effect of shuttle running volume (Christie et al., 2008) on a batter’s physiology. However, the simulations developed in this study provide researchers with the necessary tools to investigate Twenty20 batting in a more comprehensive manner. Namely, the simulations developed in this study may highlight the impact of run scoring intensity (strike rate) on the batters’ physiology which previously was not possible. Additionally, compared to shuttle running protocols and net practice, batting simulations as described in this study provide a more accurate representation of the stressors imposed on a batter during match play (Goble & Christie, 2017; Vickery et al., 2018).

Several theories of skill acquisition attest to the benefit of utilizing realistic game scenarios in training. The idea can be traced to Thorndike (1913) who developed identical elements theory. In essence, it is proposed that motor learning is enhanced when characteristics of practice and competition are most interchangeable. Beyond learning, another view termed the Specific Adaptation to Imposed Demands (SAID) principle proposes that physiological adaptations are sensitive to stressors (Reilly et al., 2009). Taken together, practice design in sport should consider its transferability into competition, which can be achieved by intentionally mimicking aspects of competition. Araújo & Davids (2016) further advise on avenues which could be explored such as, psychological (coping with internal representations of match pressure, performance anxiety etc.), motor – the physical and muscular stress associated with an innings. Finally, perceptual and cognitive, which would relate to the batters ability to understand the implications of a bowling/fielding change or identifying the kinematic identities of an off-spinners stock and variation deliveries (Araújo & Davids, 2016; Müller et al., 2019). Importantly though, when designing representative training tasks according to this framework, careful consideration should be taken in understanding the constraints present in competition as these constraints govern performance in the competitive environment. Training should provide opportunities for athletes to learn actions/responses which combat constraints as they present in competition. For example, centre-wicket simulations, like BATEX and those described in our study, recreate psychological constraints of coping with fatigue, coupled with a limited number of deliveries to achieve a targeted tally of runs and a further constraint on where runs are available with the use of scoring zones. The constraints present dynamically, akin to competitive innings’, and practitioners can respond to an athletes performance in a given simulation by restricting the number or placement of scoring zones, encouraging new responses and ultimately facilitating learning (Pinder, Davids & Araujo, 2011; Araújo & Davids, 2016).

In contrast, the simulations in this study critically lack a component of representative design due to the use of a projectile bowling machine. The temporal constraints of intercepting a high-velocity delivery exemplifies another scenario where batting skill is specific to perceptive variables of the competitive environment. Put simply, skilled batters alleviate temporal constraints by anticipating characteristics of upcoming ball-motion before the ball is released (Abernethy & Russel 1984; Müller Abernethy & Farrow, 2006; Müller, Brenton & Mansingh, 2021). To achieve this, batters perceive kinematic variables in the bowler’s action and generate responses according to these availing kinematic cues. Therefore, a batters responding stroke is coupled with his/her perception of the bowlers action, particularly the bowling arm and

### Table 5. Innings simulation summary and mean batting performance parameters from 10 experienced, top order batters.

| Innings | 'low' strike rate (50 runs ± 1SD) | 'high' strike rate (100 runs ± 1SD) |
|---------|----------------------------------|------------------------------------|
| Phase   | PowerPlay | Middle | Close Inn. | PowerPlay | Middle | Close Inn. |
| On-strike deliveries | 20 | 18 | 13 | 20 | 16 | 15 |
| Required strike rate | 60 | 161 | 154 | 110 | 150 | 280 |
| Scoring zone placements* | 3.5 | 3.1 | 1.2 | 3.3 | 2.5 | 2.9 |
| Point deductions† | 2.3 | 1.6 | 0.9 | 2.5 | 1.4 | 0.8 |
| Performance score§ (%) | 44.4 | 47.6 | 44.6 | 43.5 | 46.7 | 48.8 |

*Intercepted deliveries which penetrate demarcated scoring zones - bat-ball contact score multiplied by two.
†1 point deducted for every failed attempt at ball contact.
§Bat-ball contact scores tallied and adjusted for maximum available points (4 points per on-strike delivery).
shoulder (Müller et al., 2006). When deliveries are projected from a bowling machine, these perceptive variables are eliminated from the batting task, altering how batters infer future events from present cues (ecological validity) is reduced (Araujo, Davids & Passos, 2007; Woods et al., 2019) Pinder and colleagues (2009) demonstrated that batters do in fact alter their behaviour when intercepting deliveries projected from a bowling machine compared to live bowlers. Practice centred around bowling machines is therefore sub-optimal for learning and skill transfer to the competitive environment for the same reason traditional net practice, even with live bowlers, fails to replicate the numerous constraints present in competition. Although we have shown projectile bowling machines provide a convenient workaround for practitioners to implement training tasks which highlight often neglected constraints, the use and misuse of such equipment should be noted. A further enhanced representative learning design could see live bowlers competing against a single batter performing either the low or high strike rate simulation.

Batting simulations dictate run requirements thus, losing the metric of runs scored as a valuable measure of performance and incentive. To account for this, we implemented a method which objectively quantifies the batter’s performance from bat-ball contacts, stroke placement and dismissals. Batters achieved similar scores in both simulations (Table 5) which may indicate a ceiling of skill set for our sample at the time of investigating or a lack of sensitivity in our scoring method. Future research should identify additional variables which may contribute to batting performance scores that are representative of skill. Further developing a dependable method of scoring batting performance will benefit both researchers and coaches. Sport practitioners can also adjust details of the Twenty20 simulations such as, the number and placement of scoring zones or setting batting performance score targets to create varying demands of difficulty for different athletes. However, innings simulations are naturally limited in flexibility because run scoring outcomes and on/off-strike denomination are dictated. As a result, effectiveness for skill acquisition and the batter’s interest may reduce with repetition. To alleviate this, additional simulations which highlight unique game dynamics namely, recovering from a sudden loss of multiple wickets or catering to specific batting order positions could be developed.

5. Conclusion
Batting research in cricket requires intricate methods of replicating the stressors and demands of an individual innings. By doing so, the physiological effects of batting on the batter may be investigated while also providing a tool for specific skill acquisition. The simulations developed in this study replicate an hour-long partnership consisting of 51 on-strike deliveries and played at either a high or low strike rate. Batters produced similar scores in both the high and low strike rate innings when quantifying their performance based on bat-ball contacts and stroke placement. Utilizing these simulations should provide an enhanced training stimulus to traditional net-based practice while future research investigates other factors that contribute to a batters performance.

Data availability
Zenodo: Cricket-Research: Developing Twenty20 batting simulations. http://doi.org/10.5281/zenodo.4740316 (Lopes, 2021)

This project contains the following underlying data:

- Supp.Material.A.m4a (audio description used to implement the low strike rate innings)
- Supp.Material.B.m4a (audio description used to implement the high strike rate innings)
- T20Simulation.R (Code to reduce ball-by-ball match data for development of additional batting simulations)
- T20TOP7.csv (Innings summaries produced by specialist batters in the Indian Premier League and international competition between 2006-2018)

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).
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Open Peer Review

Will Vickery
Coaching and Officiating, Sport and Community Capability, Australian Sports Commission, Melbourne, Victoria, Australia

General Comments:

The authors have provided a novel training methodology that many practitioners may find useful in their journey to develop and improve their T20 batters. With research existing in this area, it was good to see an evolution of this and how it has been able to help develop the protocols used in the current study. Below are some points for consideration, first general comments followed by more specific ones. The key points that need to be considered include:
- The representativeness of the batting simulations within batting context of T20 cricket (i.e. various batting positions and their role).
- Greater detail regarding the creation of and running of the batting simulations.
- Greater discussion of the findings from this study based on the aim.

Specific Comments

Introduction Page 3: Consider rewording these sentences as the beginning of the second is an extension of the first but it begins with And, therefore not following grammatical standards. “In cricket, the availability of competitive match data enables the development of detailed innings simulations that can be an effective addition to practice programmes. And a reliable method of recreating the physiological baseline of competitive batting for further scientific inquiry.”

Introduction Page 3: Please include the original occurrence of The Battlezone in the literature here “The Battlezone protocol mimics a small-sided cricket match reduced to eight players and six repeated bouts, each consisting of eight overs.” Renshaw, I., Chappell, G., Fitzgerald, D., Davison, J., & McFadyen, B. (2010, June). The battle zone: constraint-led coaching in action. In 1 of 1-Conference of Science, Medicine & Coaching in Cricket 2010 (p. 181).[Ref 2].

Please also note that this is only one way in which The Battlezone was used, there were changes in
the number of overs per batting group within other publications, along with changes to the field dimensions, field settings and rules. It should be noted in the current study that this is only an example of one Battlezone protocol.

Introduction Page 3: It is unclear why the authors have decided to create two batting simulations based on the information presented within the Introduction. Some justification for why is required before stating that this is the aim.

Methods Retrospective data acquisition - innings summaries Page 4: The authors chose to include international matches and the IPL. Although a high standard of cricket, justification is required as to why a domestic franchised tournament (IPL) was chosen alongside international standard matches which would arguably be considered the highest level of T20 cricket. Further, even with the high standard of the IPL potentially matching the international matches, justification for why it was chosen and not included other domestic franchise tournaments is needed.

Methods Retrospective data acquisition - innings summaries Page 4: Please provide reasoning as to why “top order” was considered as someone within the first 7 batters when typically, those below batting position 3 are considered middle order. This is important since the length of a batting innings is likely to be considerably impacted based on batting position in a T20 innings where those at the top are more likely to have greater opportunity to bat for extended periods of time compared to those lower down the order. This potentially influences the runs scored and the strike rates of these batters.

Methods Retrospective data acquisition - innings summaries Page 4: The authors state “To obtain innings summaries from the IPL, match scorecards were opened manually to import summaries produced by top seven batters from both teams.”, was this this also the case for the international matches or was another method used?

Methods Retrospective data acquisition - innings summaries Page 4: It would be of interest to know the batting position that this number of deliveries most occurred “The resultant overlap occurred at 51 deliveries faced, with a total of 27 half-centuries (‘low’) and 18 centuries (‘high’).” Since this may provide greater context as to how the simulation is representative of the match situation where this is occurring which may have application for coaches wanting to implement this into their training.

Methods Simulated innings task design Page 6: Were the international matches included in this part of the data collection process “Time motion analysis of Vivo IPL Twenty20 matches...”?

Methods Simulated innings task design Page 6: Please include who this audio recording was intended for “An audio recording was created using a written script and computer text-speech function (Supplementary Material A, B) to govern intervals between overs/deliveries.”

Methods Simulated innings task design Page 6: Were the batters required to keep track of the on-strike deliveries and run type themselves or were they assisted to make sure that all types and shuttles were completed? Please include more detail of how the batters ensured they “scored” the required amount of runs and completed the shuttle runs.

Methods Simulated innings task design Page 6: When describing the batting protocol, what
happens if no bat-ball contact is made with regards to the shuttle running?

Methods Simulated innings task design Page 6: Greater detail of what the scoring zone is and how it was used and modified throughout the situations is required. There is currently limited information about what it is and how it was used before this is mentioned here.

Methods Simulated innings task design Page 6/7: Please provide reasoning for why “Boundaries will require one and a half shuttles for a ‘four’”. Is this common within the current T20 context?

Methods Simulated innings task design Page 7: Was the running intensity monitored to ensure that batters did run at maximum intensity during each shuttle? Further, how was it determined what maximum intensity was prior to the batting simulation?

Methods Simulated innings task design Page 7: The use of phases to represent the batting innings may not be representative of all batting innings that align with the strike rate/scoring that was used. Those batting in the lower batting position (e.g. 6, 7) are unlikely to bat during the initial power play overs (for example). Therefore, would this phase be relevant for those from these batting positions? This may need to be addressed when explaining a T20 batting innings within the introduction.

Methods Simulated innings task design Page 8: With the simulation based on data from professional level cricket players, please justify why amateur players were used for this study. It is possible that the simulations do not match the playing conditions and scenarios experienced by the players in the current study.

Discussion Page 10: Rather than “ecological dynamics” the term “representative” would be more suitable for describing a method of improving the batting simulations.

Discussion Page 10: Consider including some of the findings from Ref [1]. Journal of Sports Sciences, 40(5), 498-508 and Lascu, A., Spratford, W., Pyne, D. B., & Etxebarria, N. (2021). Evaluating task design for skill development in an amateur female cricket team. Physical Education and Sport Pedagogy, 26(4), 330-344 to assist in explain how the representative of a task can be improved specifically in a cricket context.

Discussion Page 10: Please change to wording of how BATEX is described as it was performed in a netted area rather than on a centre wicket “centre-wicket simulations, like BATEX..”.

Discussion Page 10: When addressing “the simulations in this study critically lack a component of representative design due to the use of a projectile bowling machine.”, please include how the environment could be more representative of match context (i.e. the current study used an indoor, artificial surface with limited information gained from what would be happening in the field).

Discussion Page 10-11: Much of the discussion focuses on how the study could be improved and become more representative of a match context. This is well developed and provides insight into what future research could include, however, there is limited discussion of the findings of the study when referring back to the aim. Consider including more about what aspects of the simulations did “mimic the demands of competitive match play”.
References
1. Lascu A, Spratford W, Pyne D, Etxebarria N: Evaluating task design for skill development in an amateur female cricket team. Physical Education and Sport Pedagogy. 2021; 26 (4): 330-344 Publisher Full Text
2. Renshaw, Ian, Chappell, Greg, Fitzgerald, David, Davison, John, & McFadyen, Brian: The battle zone: Constraint-led coaching in action. In Portus, M (Ed.) Proceedings of the 2010 Conference of Science, Medicine and Coaching in Cricket. Cricket Australia. 2010.

Is the rationale for developing the new method (or application) clearly explained?
Partly

Is the description of the method technically sound?
Partly

Are sufficient details provided to allow replication of the method development and its use by others?
Partly

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Sport coaching, cricket, practice design

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
Dhaka Division, Bangladesh

I would like to express my gratitude for the opportunity to review the interesting study titled "Novel Twenty20 batting simulations: a strategy for research and improved practice." It was a privilege to evaluate such a well-conducted study that addresses the need for realistic practice scenarios in cricket training. The study presents a thorough investigation into the development of batting simulations, providing valuable insights into the methods used and the potential applications of the simulations in cricket research and practice. The rigorous methodology and comprehensive description of the simulations contribute to the quality and relevance of the study. I commend the authors for their meticulous approach and attention to detail throughout the manuscript. The study's findings have the potential to significantly impact the field of cricket training and performance assessment.

**Strengths:**
- **Rigorous Methodology:** The authors have employed a systematic approach to develop the batting simulations, utilizing a combination of match data analysis, literature review, and pilot testing. The incorporation of both retrospective data acquisition and real-world testing enhances the validity and reliability of the simulations.
- **Comprehensive Description:** The manuscript provides a comprehensive overview of the batting simulations, including detailed descriptions of the scoring mechanisms, task design, and performance evaluation. This level of detail allows readers to understand the nuances of the simulations and their potential applications in cricket training and research.
- **Ecological Validity:** The simulations aim to replicate the physiological and cognitive demands of Twenty20 cricket, addressing the limitations of traditional net-based practice. By incorporating factors such as run scoring intensity, partnership dynamics, and match pressure, the simulations provide a more realistic training environment for batters.

**Suggestions for improvement:**
- **Clarity in the Data Acquisition Section:** While the manuscript outlines the process of data acquisition, there is a lack of clarity regarding the selection criteria for the innings used in the study. Providing more explicit details on how specific innings were chosen from the ESPN Cricinfo database and the criteria used to narrow down the sample would enhance the transparency and reproducibility of the study.
- **Discussion of Variability in Pilot Testing Results:** Although the results section mentions the performance scores achieved by participants in pilot testing, there is limited discussion on the variability observed among participants. Including a discussion on the range of performance scores, potential factors contributing to variability (e.g., individual differences in skill level, familiarity with the task), and implications for interpreting the results would provide valuable insights.
- **Ecological Validity Considerations:** While the manuscript addresses the need for ecological validity in batting simulations, there is limited discussion on the extent to which the developed simulations capture the complexity of real match situations. Consideration of additional contextual factors that may influence batting performance in Twenty20 cricket (e.g., match conditions, opposition tactics) and their integration into the simulations would strengthen the ecological validity and practical relevance of the study.
- **Generalization of Findings:** The study primarily focuses on the development and initial testing of the batting simulations with a specific group of participants. However, there is limited discussion on the generalizability of the findings to broader populations of cricket players, including those at different skill levels or age groups. Discussing the potential limitations and applicability of the
simulations across diverse cricket contexts would enhance the relevance and utility of the study for a wider audience.

**Future Research Directions:** While the manuscript briefly mentions potential future research directions, such as exploring additional factors influencing batting performance, there is limited elaboration on specific avenues for further investigation. Providing more detailed suggestions for future research, including potential hypotheses to test and methodological considerations, would guide the development of follow-up studies and advance the field.

**Is the rationale for developing the new method (or application) clearly explained?**
Yes

**Is the description of the method technically sound?**
Yes

**Are sufficient details provided to allow replication of the method development and its use by others?**
Yes

**If any results are presented, are all the source data underlying the results available to ensure full reproducibility?**
No source data required

**Are the conclusions about the method and its performance adequately supported by the findings presented in the article?**
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Sports ScienceExercise ScienceSports InjuriesExercise PerformanceSport BiomechanicsExercise Physiology

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Reviewer Report 12 April 2024

https://doi.org/10.5256/f1000research.121763.r250661

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Sean Muller
Centre for Smart Analytics, Federation University Australia, Ballarat, Victoria, Australia
Thank you for your revisions and stating limitations of the project.

Is the rationale for developing the new method (or application) clearly explained?
Yes

Is the description of the method technically sound?
Yes

Are sufficient details provided to allow replication of the method development and its use by others?
Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Expertise and motor skill learning.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.
1. It is not clear why a bowling machine was utilised? Bowling / real-life kinematics are key, especially for high strike rate scoring. This needs to be listed as a limitation.

2. Were the deliveries bowled permutated?

3. The discussion requires a well-rounded discussion including aspects of task and temporal constrains of batting, motor control, performance analysis and batting kinetics/kinematics (even though this study is based on simulation and research strategy).

You may also want to consider other T20 studies your paper:
1. Davis, J., Perera, H. and Swartz, T.B., 2015. A simulator for Twenty20 cricket

2. Sholto-Douglas, R., Cook, R., Wilkie, M. and Christie, C.J.A., 2020. Movement demands of an elite cricket team during the big bash league in Australia

3. Noorbhai, H. (2020). The backlift techniques of cricketers in the Indian Premier League: batting implications for the shorter format. International Sports Studies

4. Irvine, S. and Kennedy, R., 2017. Analysis of performance indicators that most significantly affect International Twenty20 cricket

References
1. Davis J, Perera H, Swartz T: A Simulator for Twenty20 Cricket. Australian & New Zealand Journal of Statistics. 2015; 57 (1): 55-71 Publisher Full Text
2. Sholto-Douglas R, Cook R, Wilkie M, Christie Cj: Movement Demands of an Elite Cricket Team During the Big Bash League in Australia. J Sports Sci Med. 19 (1): 59-64 PubMed Abstract
3. Noorbhai H: The backlift techniques of cricketers in the Indian Premier League: batting implications for the shorter format. International Sports Studies. 2020; 42 (1): 47-54 Publisher Full Text
4. Irvine S, Kennedy R: Analysis of performance indicators that most significantly affect International Twenty20 cricket. International Journal of Performance Analysis in Sport. 2017; 17 (3): 350-359 Publisher Full Text

Is the rationale for developing the new method (or application) clearly explained?
Yes

Is the description of the method technically sound?
Yes

Are sufficient details provided to allow replication of the method development and its use by others?
Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?
No source data required
Are the conclusions about the method and its performance adequately supported by the findings presented in the article?
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Cricket Sciences and Sports Biomechanics.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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**Author Response 22 Feb 2024**

**Tiago Lopes**

Thank you providing input to improve the quality of this work. Following your comments, the manuscript has been adjusted to discuss the limitations of using a bowling machine in research and batting simulations. A clarification on the set-up of the bowling machine and permutation of deliveries is provided. Reviewed literature has also been updated from your input. For brevity, some information has remained omitted including the T20 simulator by Davis, Perera & Swartz which addresses a different objective to that presented in this study.

**Competing Interests:** No competing interests were disclosed.

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**Reviewer Report 09 June 2021**

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**Sean Muller**

Centre for Smart Analytics, Federation University Australia, Ballarat, Victoria, Australia

Thanks for the opportunity to review an interesting study. Well done to the authors for going to great effort to design and test the simulated batting task. I only have a few points to make, which the authors should consider and revise the manuscript. First, I understand the reasoning for using a bowling machine, but it does not present important bowler kinematic cues. Contextual (field-placing) information is also important particularly for T20 cricket. Was the complete field placing presented to batsmen throughout phases of the test? These cues are important to load the cognition of batters like occurs in competition (noting the authors have mentioned “...to closely replicate match-play,...”). Presenting these sources of information is important for future design of simulators. Please discuss this as a limitation and how it might be improved upon in future research. Second, the correct terminology is representative task design, not ecological validity (see
Araújo & Davids, 2015). Third, introduction and discussion sections; ecological-dynamics theory is not the only framework that guides “....constructing highly-specific game scenarios....". The specificity of practice hypothesis (see Magill & Anderson, 2017; Thorndike, 1906) provides the same guidance. Please revise this in the manuscript to provide a more balanced discussion of the literature.

References
1. Araújo D, Davids K: Towards a theoretically-driven model of correspondence between behaviours in one context to another: Implications for studying sport performance. *International Journal of Sport Psychology*. 2015; 46: 745-757
2. Magill R. A, Anderson D: Motor learning and control: Concepts and applications (11th ed.). *McGraw Hill*. 2017.
3. Thorndike E. L: Principles of Teaching. *Seiler*. 1906.

Is the rationale for developing the new method (or application) clearly explained?
Partly

Is the description of the method technically sound?
Yes

Are sufficient details provided to allow replication of the method development and its use by others?
Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?
No source data required

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?
Yes

*Competing Interests*: No competing interests were disclosed.

*Reviewer Expertise*: Expertise and motor skill learning.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 22 Feb 2024

Tiago Lopes

Thank you for your valuable input and fair critique to this version of the manuscript. Following your comments the manuscript has been revised to include; a more balanced discussion of representative task design with updated references, critique around the use of
bowling machines in future studies and simulators which will disregard kinematic cues of the bowling action, clarification on the presentation and instruction provided to batters for fielding positions.

**Competing Interests:** No competing interests were disclosed.