# The reliability and sensitivity of performance measures in a novel pace bowling test

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## TITLE PAGE

**Title:**

# The reliability and sensitivity of performance measures in a novel pace bowling test

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## Abstract

***Objectives:*** Evaluate the reliability and sensitivity of performance measures in a novel pace bowling test. ***Methods:*** Thirteen male amateur club fast bowlers completed a novel pace bowling test on two separate occasions, 4-7 days apart. Participants delivered 48 balls (8 overs), at five targets on a suspended sheet, situated behind a ‘live’ batter who stood in a right-handed and left-handed stance for an equal amount of deliveries. Delivery instruction was frequently changed, with all deliveries executed in a pre-planned sequence. Ball release speed data was captured by radar gun. A high-speed camera captured the moment of ball impact to the target sheet, for assessment of radial error and bivariate variable error. Delivery rating of perceived exertion (% from 0–100) was collected as a measure of intensity. ***Results:*** Intraclass correlation coefficient and coefficient of variation data revealed excellent reliability for peak and mean ball release speed, acceptable reliability for delivery rating of perceived exertion, and poor reliability for mean radial error, bivariate variable error, and variability of ball release speed. The smallest worthwhile change data indicated high sensitivity with peak and mean ball release speed, and lower sensitivity with mean radial error and bivariate variable error. ***Conclusions:*** The novel pace bowling test comprises improvements in ecological validity compared to its predecessors, and can be used to provide a more comprehensive evaluation of pace bowling performance. The smallest worthwhile change data can improve interpretation of pace bowling research findings and may therefore influence recommendations for applied practice.

**Keywords:** Cricket, Performance, Bowling speed, Bowling accuracy, Smallest worthwhile change

# Introduction

Pace bowling forms an integral and exciting component to the international game of cricket. Pace bowlers form the majority of the 'bowling attack' against opposition batters. The International Cricket Council (ICC) ranks and scores bowlers in each match format (i.e., Twenty20, One-Day International, Test) based on the number of dismissals taken (i.e., wickets), the performance score of the dismissed batters, and the amount of runs conceded; while other factors such as total runs scored in the match, bowling workload, and the match result also have an influence.[1] This scoring and ranking system has two notable limitations; 1) only international-standard bowlers are evaluated, meaning a majority of bowlers who participate in cricket worldwide are not scored, and 2) the performance score is influenced by factors outside the bowlers' control (e.g., fielding errors, environmental conditions) and therefore does not truly reflect the bowlers' standard of performance.

Speed, accuracy, and consistency (of speed and accuracy) are performance variables that are within the control of a pace bowler, and are arguably important to match performance. Bowling fast reduces the batters' reaction time and movement time,[2] which may lead to the batter not striking the ball, or mistiming the ball strike. Consistently fast delivery speeds prolong this advantage over the batter. An accurate delivery refers to a ball that has followed the pace bowlers' intended trajectory (line and length). An accurate delivery can result in a dismissal or reduce the amount of runs scored by the batter. Consistently accurate bowling means the 'grouping' of deliveries of an intended trajectory are closer together (i.e., less variability in trajectory). Bowling with less variability in accuracy can arguably make it difficult for batters to score throughout a bowling spell, as the bowler or captain can position fielders in areas where the batter is most likely to hit the ball. This can subsequently lead to an increase in scoring pressure, and poorer decision making and stroke play from the batter.

Some of these performance variables have been assessed in a variety of pace bowling tests.[3-5] However, several inconsistencies appear between tests, ranging from: the test environment, pitch and cricket ball characteristics, implemented warm-ups, test familiarisation procedures, permitted run-up lengths, bowling spell lengths, delivery sequence, test instructions, and how bowling speed and accuracy data were collected and reported. To date, no pace bowling test has included a 'live' batsman in attempt to provide bowlers with specific cues for accuracy purposes. One test involved bowlers delivering to a superimposed image of a right-handed batsman on a vertical target sheet,[3] with no bowling to a left-handed batsman. Furthermore, a slower-ball delivery has not been included in a pace bowling performance test. This type of delivery is often used to bring about a mistimed stroke from the batter. Of further concern is the lack of established reliability and sensitivity in measurements of consistency (speed and accuracy). Knowledge of the reliability and sensitivity data in all pace bowling performance measures would allow researchers to more accurately quantify pace bowling performance following short- and long-term interventions. A standardised test would be beneficial for ensuring consistency in testing and data collection procedures in future pace bowling research.

The limitations and methodological differences between tests highlight the need for the development of a standardised and more ecologically valid pace bowling test, with established reliability and sensitivity data. Therefore, the aim of this investigation was to evaluate the reliability and sensitivity of performance measures in a novel and more ecologically valid pace bowling test. For the purposes of this investigation, reliability referred to how reproducible (or similar) a measure was between tests,[6] while sensitivity indicated the ability of a measure to detect small but important changes in performance.[7]

## Methods

### Subjects

Thirteen male amateur community-standard pace bowlers (mean ± SD 22.8 ± 5.6 years, 80.2 ± 11.9 kg, 1.82 ± 0.07 m) from the Ballarat Cricket Association (A and B grade standard) participated in this investigation. Eleven of the participants were right-handed bowlers, and two were left-handed bowlers. All procedures were approved by Federation University Human Research Ethics Committee (project number: A12-086) and written informed consent was obtained for each participant or parent/guardian prior to the commencement of the study. Participants were included if they were injury free at least six months prior to the time of testing.

### Design

The study involved a repeated measures design. Participants completed a pace bowling test on the same time of day on two separate occasions 4-7 days apart. This followed six familiarisation sessions dispersed over three weeks to learn the pace bowling test, and to provide ample bowling workload for participants in the off-season. The familiarisation period permitted pace bowlers to become accustomed to the swing characteristics of the cricket balls and the ball bounce characteristics of the synthetic grass cricket pitch used in the test. Participants were instructed to refrain from alcohol and caffeine consumption 24 hours prior to testing, and avoid any form of resistance training for 48 hours.

## Methodology

A standardised general and specific warm-up preceded the test, and involved 20 m shuttle runs of progressive intensity, side to side shuffles, 15 m sub-maximal sprints, and dynamic stretches. Participants delivered 10 warm-up balls of progressive intensity (60-95% perceived exertion) to a variety of targets. A new 156 g two-piece red cricket ball (Tuf Pitch, Kookaburra, Melbourne, Australia) was used for the warm-up and subsequent test. A one-minute recovery followed the warm-up, and participants were instructed prior to test:

> “Bowl as fast, accurate and consistently as possible as you would in a match. We are measuring all of these elements. At different times throughout the test, you will be instructed to bowl some deliveries at maximal speed and some deliveries with your preferred slower ball. Your speed and accuracy with these balls is also measured.”

The test was conducted indoors on a synthetic grass pitch, with an extended but enclosed portion of the run-up situated outside. Ambient temperature was controlled indoors and ranged from 19-21° C throughout testing sessions. Participants were tested in pairs per session. As one would bowl an over, the other performed fielding activities, to better replicate cricket match play.[8] These fielding activities included a 5 m walk in with the bowler each delivery. On the second and fourth deliveries of the over, a wicket-keeper rolled out a cricket ball along the ground, and the bowler performed an additional 10 m sprint to field the ball, followed by an underarm throw to a set of cricket stumps. Participants swapped after the over was completed.

The test was eight overs long (48 legal deliveries) per participant. The popping crease at the bowler’s end of the wicket was monitored each delivery for any front-foot no-balls. If the bowler over-stepped the line, or bowled the ball off the wicket, the delivery had to be immediately bowled again. A delivery instruction comprising the target to aim at (after bounce) and intensity (match-intensity, maximal-effort, slower ball) was provided at the start of the run-up. A suspended white vinyl sheet hung from a horizontal pole at the batting crease, and drawn on it were five black circular cross-hair targets and cricket stumps (Figure 1). Pilot testing determined the appropriate location of the yorker (full-pitched delivery directed at the batters’ feet) target to be 30 cm above the base of the middle stump with respect to the stance of a ‘live’ batter and the bounce of the new ball. The batter ‘took guard’ on the line of middle stump and stood with feet parallel and either side to the popping crease. A 'live' batter was included for two primary reasons, 1) to provide specific cues for the bouncer (short pitched delivery targeting the batters' head) and yorker deliveries, and 2) to enhance the ecological validity of the test. Prior to delivery the batter was instructed on stance (right or left handed) and delivery target. The batter attempted to evade each delivery with a pre-planned movement, but only initiated movement after the ball was released. The timing of this movement was confirmed though analysis of collected high-speed camera footage in specialised software (Redlake MASD MotionScope, Redlake Imaging Corporation, CA, USA). The high-speed camera (PCI 2000 S, Redlake Imaging Corporation, CA, USA) operated at 250 frames per second and a shutter speed of 0.004 s. Given the standard of the pace bowlers in this investigation, the batter usually had no difficulty in taking evasive action, however, on a few occasions the batsman was struck. In this event, the delivery had to be performed again so the bowling accuracy data could be analysed. Deliveries were sequenced in a semi-randomised order (Table 1), because in cricket match play, not every delivery is intended for the same trajectory or speed. The ratio of deliveries at each target and intensity also varied, to better replicate real-world bowling. Deliveries were bowled every 40 s. Delivery rating of perceived exertion (percentage from 0–100) of each ball was collected from the bowler when walking back to the start of their run-up. Participants were asked "how hard was that delivery out of 100%?" This rating system was adopted instead of the traditional rating of perceived exertion scale (0-10),[9] because in pilot testing, participants understood and related better with the percentage method when bowling.

Insert Figure 1 about here
Insert Table 1 about here

Ball release speed of each delivery was measured by a radar gun (Stalker Pro, Applied Concepts, Texas, USA). The radar gun was mounted on a tripod and positioned 1.37 m behind the popping crease, with a 0.3 m lateral shift from the line of middle stump, to avoid contact with the bowler in the run-up. The radar gun was fixed at a height of 1.95 m, and an angle of 25° to capture point of release. Cosine effect error in ball release speed was corrected for in a purpose-made spreadsheet by dividing measured speed by 0.906 (i.e., cosine of 25°). From this data, three values were calculated: 1) peak ball release speed; the mean of all four maximal-effort deliveries, 2) mean ball release speed; comprising 40 match-intensity deliveries only, and 3) variability of ball release speed, the standard deviation of 40 match-intensity deliveries only. Maximal-effort and slower-ball deliveries were omitted from mean ball release speed and variability of ball release speed calculations.

Bowling accuracy data was captured by the high-speed camera. The high-speed camera was mounted on a tripod and positioned 0.36 m from the popping crease, with a 0.3 m lateral shift from the line of middle stump, to avoid contact with the bowler in the run-up. The high-speed camera was fixed at a height of 1.47 m, and an angle of 10° to capture the entire target sheet. Recorded video footage was imported into Dartfish Connect (Version 7.0, Dartfish, Melbourne, Australia) for analysis. The measurement function was calibrated in Dartfish Connect by drawing a vertical line from the centre of the bouncer target to the top of middle stump target, which was exactly 1.0 m apart. The radial error, along with $x$ and $y$ coordinates were calculated for each delivery.[3] From this data, two values were calculated: 1) mean radial error; from 40 match-intensity deliveries only (representing bowling accuracy), and 2) bivariate variable error;[3] from 32 match-intensity deliveries pooled from both off-stump targets (representing the consistency of bowling accuracy). Maximal-effort and slower-ball deliveries were excluded from the mean radial error calculation. Preliminary within-participant correlational analysis revealed a significant relationship between ball release speed and radial error in five participants. Such within-participant variability would likely increase the standard error of measurement for both accuracy variables. The yorker and bouncer deliveries were further omitted from the bivariate variable error calculation due to the low sample of balls at each target. A low sample of deliveries can cause a large fluctuation in the bivariate variable error, subsequently increasing the standard error of measurement.

## Statistical Analysis

The normality of each variable was assessed using a Shapiro-Wilk test in IBM SPSS Statistics (Version 24.0, IMB Corp., Armonk, NY). All variables met the normal distribution. Each variable was entered into a purpose-made Microsoft Excel spreadsheet,[10] where the standard error of measurement, exponentially-transformed coefficient of variation (CV) with 90% confidence intervals, and intraclass correlation coefficient (ICC, Model 2,k)[11] were calculated as measures of reliability. An ICC greater than 0.8, and a CV less than 10% were considered to exhibit ‘acceptable’ reliability in this study.[12,13] The smallest worthwhile change represented the sensitivity of each measure, and was calculated by multiplying the standard error of measurement by 1.5.[6] A paired samples $t$-Test (2-tailed) was conducted to detect systematic bias for each variable.[14] The relationship between ball release speed and radial error for each participant was calculated with a Pearson’s correlation coefficient (2-tailed), with all deliveries pooled from both bowling tests. The strength of each correlation was classified using modified thresholds / descriptors as follows: trivial (r < 0.10), small (r = 0.10–0.29), moderate (r = 0.30–0.49), large (r = 0.50–0.69), very large (r = 0.70–0.90), and nearly perfect (r > 0.90).[15] Significance was set at $p < 0.05$ for all analyses.

## Results

There were no statistically significant differences in performance variables between tests ($p > 0.05$, Table 2). The ICCs of peak, mean, and variability of ball release speed were high (0.981, 0.988, and 0.851, respectively, Table 2). All other performance measures presented with ICCs below 0.8 (Table 2). The CV of peak ball release speed, mean ball release speed, and mean delivery rating of perceived exertion were low (1.0%, 1.0%, and 3.9%, respectively), while the variability of ball release speed, mean radial error, and bivariate variable error exhibited a high CV (12.1%, 12.5%, and 15.3%, respectively, Table 2). Peak and mean ball release speed exhibited high sensitivity with a smallest worthwhile change of 0.5 m·s$^{-1}$ (1.8 km·h$^{-1}$) each. Low sensitivity in mean radial error and bivariate variable error was observed with a smallest worthwhile change of 6.9 cm and 8.4 cm respectively (Table 2).

The pace bowlers in this investigation released the ball at peak speeds of 33.0 ± 2.2 m·s$^{-1}$ (118.9 ± 7.8 km·h$^{-1}$) and 33.1 ± 2.3 m·s$^{-1}$ (119.3 ± 8.3 km·h$^{-1}$) in both trials (Table 2). The variability of ball release speed was 0.8 ± 0.2–0.3 m·s$^{-1}$ (2.9 ± 0.7–1.1 km·h$^{-1}$, Table 2). There was a 2 cm (4.6%) difference in mean radial error between trials ($p = 0.303$, Table 2). A 4 cm (10.0%) change in bivariate variable error was evident between tests ($p = 0.100$, Table 2). Five participants exhibited a significant relationship between ball release speed and radial error ($p < 0.05$, Table 3).

Insert Table 2 about here
Insert Table 3 about here

## Discussion

This study evaluated the reliability and sensitivity of performance measures in a novel pace bowling test. Importantly, no learning or fatigue effects were evident between-tests for any variable ($p > 0.05$). Peak bowling speed and mean bowling speed were the most reliable measures in this study, with ICCs above 0.9 and a CV at 1.0%. Both variables demonstrated high sensitivity with a smallest worthwhile change of 0.5 m·s$^{-1}$ (Table 2), similar to a recent study of 0.6 m·s$^{-1}$.[16] Petersen et al[5] arbitrarily set the smallest worthwhile change for mean ball release speed to be either 1.4 $m{\cdot}s^{-1}$ or 0.7 $m{\cdot}s^{-1}$ for their training intervention. For a smallest worthwhile change of 0.7 $m{\cdot}s^{-1}$, the odds that the change in mean ball release speed from their training intervention was beneficial, trivial, or harmful to performance was 59/41/<0.1%.[5] If the smallest worthwhile change of 0.5 $m{\cdot}s^{-1}$ was selected, then the change in mean ball release speed would have been more beneficial and less trivial. This example highlights that the experimentally-determined smallest worthwhile change value can improve interpretation of pace bowling research findings and therefore influence recommendations for applied practice.

The rather large CV in mean radial error, bivariate variable error, and variability of ball release speed may be explained by dynamic systems theory.[17] According to dynamics systems theory, the optimal pattern of coordination and control is governed by organismic, task, and environmental constraints.[17] In this investigation, three to four changes in task instruction were given within each over; either the effort of delivery, target location, and batter orientation. This may have altered the optimal pattern of coordination and control and resulted in participants bowling at more variable speeds and trajectories throughout the test. Participants may have found it difficult to adapt to frequent changes in delivery instruction, an ability that national-standard counterparts appear to be faster at.[3] Notably, five participants exhibited a significant relationship between ball release speed and radial error (Table 3). For this reason the maximal-effort and slower-ball deliveries were excluded from reliability and sensitivity assessment, as the greater within-participant variation would have increased the radial error CV and smallest worthwhile change respectively.

Nevertheless, the smallest worthwhile change of mean radial error and bivariate variable error were 6.9 cm and 8.4 cm respectively; similar to the diameter of a cricket ball (7.11–7.26 cm), and comparable to the smallest worthwhile change of the ‘performance execution’ measure.[16] However, the 12.5% CV in mean radial error is lower than the 20-89% CV reported in the performance execution variable.[16] The measurement of performance execution involved bowlers nominating their delivery length and line, with the delivery scored either a 2, 1, or 0, based on how well the delivery was executed according to the nomination. This variable is less reliable than the radial error measurement used in this investigation and others.[3] In terms of sensitivity, although the smallest worthwhile change data were similar between studies, McNamara et al[16] calculated the smallest worthwhile change differently by multiplying the between-bowlers SD by 0.2. If this calculation was used in the present investigation, the smallest worthwhile change for mean radial error and bivariate variable error would have been 1.6 cm and 1.5 cm respectively, averaged across both trials. These figures represent a relatively large shift in sensitivity to what this study reported. Nevertheless, the mean radial error measurement is encouraged to be used in future investigations, however, the sensitivity of this measure is to be considered when evaluating the effectiveness of short- and long-term interventions. For example, the odds that a 15.0 cm improvement in mean radial error following an intervention would be beneficial/trivial/harmful is 88/12/0%, based on the established smallest worthwhile change data of 6.9 cm.

Mean delivery rating of perceived exertion exhibited a poor ICC (0.650) but an acceptable CV (3.9%). The poor ICC observed with mean delivery rating of perceived exertion could be attributed to the small inter-participant variability in this measure.[18] The ICC is a relative measure of reliability, and examines how well the rank order for a variable is maintained between tests.[6] The CV however, portrays information regarding the magnitude of the measurement error, and can be compared to other variables within and between investigations, and thus is preferred to the standard error of measurement alone.[6] Therefore, while the ICC was poor, the reliability could be deemed acceptable due to the low CV. The delivery rating of perceived exertion could be used as an internal measure for future workload monitoring in pace bowling, with the benefit of a ball by ball rating, not a sessional rating.[19]

This study is not without its limitations. The 'live' batter may have added to the ecological validity of the test, but a few deliveries struck the batter resulting in pain and bruising. Consequently, this test is probably more appropriate for use in applied research. The high-speed camera was positioned on a 10° angle to capture the entire target sheet, and so this may have led to measurement error. The target sheet sometimes crinkled and/or moved during the test due to repetitive ball strike and air flow indoors. While every effort was made to realign the target sheet to floor markers prior to delivery, participants may have been distracted with any sudden changes in target location.

It is recommended that future research evaluate the construct validity of pace bowling performance measures by comparing pace bowlers of various performance standards (e.g., club, state, national). Validation of delivery rating of perceived exertion is also warranted, as this measure can potentially be used for future workload monitoring in pace bowling.

## Practical Applications

The novel pace bowling test developed in this investigation can be used by researchers and coaches to evaluate performance more accurately using the experimentally-determined smallest worthwhile change data of each variable. This test can be used to assess the effects of short- and long-term interventions (e.g., biomechanical, physiological, physical) on pace bowling performance, and act to advance research and applied practice in cricket.

## Conclusions

The novel pace bowling test includes a number of improvements from its predecessors; the inclusion of a 'live' batter, equal ratio of deliveries to a right- and left-handed batter, a slower-ball delivery, the additional measure of variability of ball release speed, and the inclusion of delivery rating of perceived exertion. Peak and mean ball release speed exhibit excellent reliability and high sensitivity. Delivery rating of perceived effort was deemed to have acceptable reliability, while mean radial error, bivariate variable error, and variability of ball release speed possessed poor reliability and low sensitivity.

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**Figure 1** **Target Sheet Design**

*Note:* Not drawn perfect to scale.

**Table 1 Delivery Sequence in the Pace Bowling Test**

| | **Over 1 & 5** | **Over 2 & 6** | **Over 3 & 7** | **Over 4 & 8** |
|---|---|---|---|---|
| Ball 1 | OFF, RH, MI | OFF, LH, MI | OFF, LH, MI | OFF, RH, MI |
| Ball 2 | OFF, RH, MI | OFF, LH, MI | OFF, LH, MI | OFF, RH, MI |
| Ball 3 | OFF, RH, MI | OFF, RH, MI | OFF, LH, MI | OFF, LH, MI |
| Ball 4 | OFF, RH, MI | OFF, RH, MI | OFF, LH. MI | OFF, LH, MI |
| Ball 5 | OFF, RH, ME | BOU, RH, MI | OFF, LH, ME | BOU, LH, MI |
| Ball 6 | MID, RH, SB | YOR, RH, MI | MID, LH, SB | YOR, LH, MI |

*Abbreviations:* RH, right-handed batter; LH, left-handed batter; OFF, outside off stump target; MID, top of middle stump target; BOU, target near batter’s head; YOR, target near base of middle stump; MI, match-intensity delivery; ME, maximal-effort delivery; SB, slower-ball delivery.

**Table 2** **Reliability and Sensitivity of Pace Bowling Performance Measures**

| | **T1 Mean ± *SD*** | **T2 Mean ± *SD*** | ***Change (%)*** | ***p*** | **ICC** | **SEM** | **CV (%)** | **SWC** |
|---|---|---|---|---|---|---|---|---|
| Peak ball release speed (m·s$^{-1}$) | 33.0 ± 2.2 | 33.1 ± 2.3 | 0.4 | 0.391 | 0.981 | 0.3 | 1.0 (0.8–1.6) | 0.5 |
| Mean ball release speed (m·s$^{-1}$) | 31.3 ± 2.4 | 31.3 ± 2.4 | 0.0 | 0.937 | 0.988 | 0.3 | 1.0 (0.8–1.6) | 0.5 |
| Variability of ball release speed (m·s$^{-1}$) | 0.8 ± 0.2 | 0.8 ± 0.3 | 0.0 | 0.397 | 0.851 | 0.1 | 12.1 (9.0–19.0) | 0.2 |
| Mean radial error (cm) | 43.3 ± 7.5 | 41.3 ± 8.1 | -4.6 | 0.303 | 0.685 | 4.6 | 12.5 (9.3–19.6) | 6.9 |
| Bivariate variable error (cm) | 40.0 ± 7.3 | 36.0 ± 7.3 | -10.0 | 0.100 | 0.434 | 5.6 | 15.3 (11.3–24.0) | 8.4 |
| Mean delivery rating of perceived exertion (% of 100) | 86.1 ± 5.2 | 86.7 ± 5.2 | 0.7 | 0.629 | 0.650 | 3.2 | 3.9 (2.9–6.0) | 4.8 |

*Abbreviations:* T1, test one; T2, test two; ICC, intraclass correlation coefficient; SEM, standard error of measurement; CV, coefficient of variation; SWC, smallest worthwhile change.

*Note:* Upper and lower confidence intervals were set at 90%, expressed in parentheses.

**Table 3** **Within-Participant Analysis of Speed-Radial Error Relationship**

| Participant | Correlation | *p* | Correlation Descriptor |
|---|---|---|---|
| 1 | 0.184 | 0.074 | Small |
| 2 | -0.096 | 0.358 | Trivial |
| 3 | -0.145 | 0.164 | Small |
| 4 | 0.210 | 0.042 | Small |
| 5 | -0.142 | 0.169 | Small |
| 6 | 0.047 | 0.650 | Trivial |
| 7 | 0.223 | 0.033 | Small |
| 8 | -0.257 | 0.013 | Small |
| 9 | 0.116 | 0.266 | Small |
| 10 | 0.077 | 0.461 | Trivial |
| 11 | -0.302 | 0.003 | Moderate |
| 12 | -0.115 | 0.263 | Small |
| 13 | -0.396 | < 0.001 | Moderate |