BIOMECHANICAL ANALYSIS OF FAST BOWLING ACTION IN CRICKET

A SYNOPSIS OF THE THESIS SUBMITTED TO THE JADAVPUR UNIVERSITY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ARTS

By

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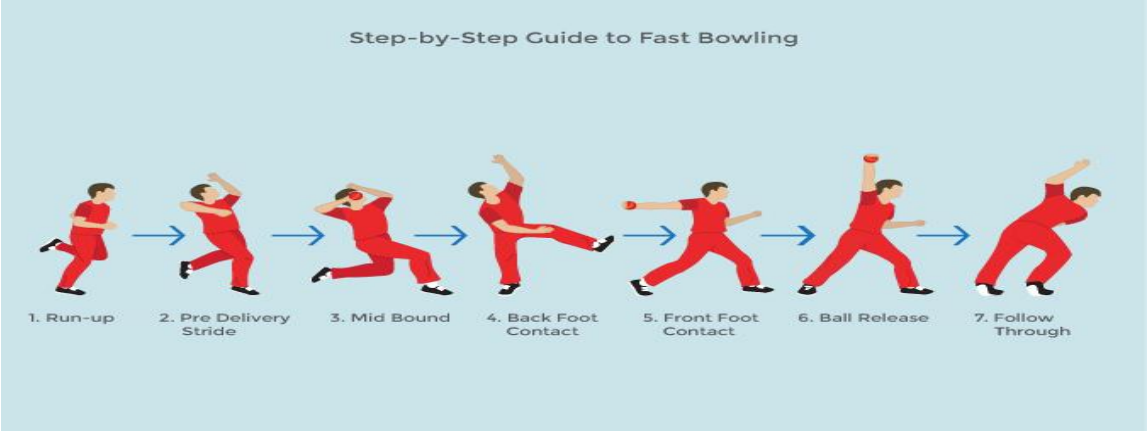
APRIL, 2021

INTRODUCTION

Cricket is a bat and ball game played between two teams of eleven players on a field at the centre of which is a 20 meter (22 yards) pitch with a wicket at each end, each comprising two bails balanced on three stumps. The batting side scores runs by striking the ball bowled at the wicket with the bat, while the bowling and fielding side tries to present this and dismiss each player (so they are "out"). A mean of dismissal include being bowled, when the ball hits the stumps and dislodges the bails, and by the fielding side catching the ball after it is hit by the bat, but before it hits the ground. When ten players have been dismissed, the innings ends and the teams swap roles. The game is adjudicated by two umpires, aided by a third umpire and match referee in international matches. They communicate with two off-field scores who record the match's statistical information. Cricket is the most popular games which are played across the world. Bowling, in cricket, is the action of propelling the ball toward the wicket defended by a batter. A player skilled at bowling is called a bowler; a bowler who is also a competent batter is known as an all-rounder. Due to its sophisticated way of execution, the fast bowling is one of the main important skills in the game of cricket. The skill of fast bowling requires several technical steps. The many important factors are responsible over a fast bowling. In bowling there are two types of bowling fast bowling and spin bowling. Fast bowling is one of the main approaches to bowling in the sport of cricket, the other being spin bowling. Practitioners of fast bowling are usually known as pace bowlers, quicks, or pacemen. They can also be referred to as a seam bowler, a swing bowler or a fast bowler who can swing it reflect the predominant characteristics of their deliveries. The aim of the fast bowling is to deliver the ball in such a fashion as to cause the batsman to make a mistake. The bowler achieves this by making the hard cricket ball deviate from a predictable, linear trajectory at a speed that limits the time the batsman has to compensate for it.



Phases of Bowling Action

(https://www.myactivesg.com)

Although we know from the previous investigation, how fast bowlers should have a bowling action. But all studies are a independent inquiries. Due to lack of previous study on women fast bowlers it's difficult to find out the review of literature. The current fast bowling coaching or teaching literature has been based on the studies of investigation optimal technique in the male fast bowlers.

At present Indian fast bowlers are taking important roll into the team. Bengal bowlers are also doing very well. The researcher thinks that if the technique of fast bowling action of the elite cricketers (men/women) of Bengal is presented to the new generation of upcoming players, they will benefit.

Being a cricketer of Bengal club cricket, university, district it is my curiosity to objectively know the biomechanical characteristics of fast bowling action. And know the differences in technique of male and female fast bowler's bowling action. And also to find out the relationship between fast bowling action and ball release speed. So the aim of the present study is to investigate biomechanical analysis of fast bowling action in cricket.

Statement of the Problem

The purpose of the study was to find out the **BIOMECHANICAL ANALYSIS OF FAST BOWLING ACTION IN CRICKET.**

Objectives of the Study

1. To describe the biomechanical characteristics of fast bowling actions for male and female players.
2. To compare the selected kinematic parameters for national level male and female fast bowlers.
3. To find out the relationship between approach parameters and ball release speed.

Delimitations

There were certain factors deliberately controlled for conducting the study. The present study was delimited to the following conditions:

1. The study was delimited to the male and female national level fast cricket bowlers of West Bengal.
2. Only the right handed bowlers were served as the subjects.
3. The subjects of the study were further delimited only12 male and 7 female cricket players were participated.
4. Data was collected during non-competition situation.
5. The data were recorded by the using video graphic technique.
6. Four video cameras were used for recording movement of the performance.

Limitation

1. Certain factors like diet, life style, habits, training protocols etc which might have had effect on the result of the study could not be controlled.
2. Non- availability of sophisticated instruments for measuring different parameters was considered as a limitation of the study.
3. No special motivational techniques were available during the data collection.

Hypothesis

The present study is based on following hypothesis:

H1- H_0 - There would be no significant differences in selected kinematic parameters for executing fast bowling action in case of male and female fast bowlers in cricket.

H2- H_0 -There would be no significant relationship between approach parameters and ball release speeds of male fast bowlers in cricket.

H3- H_0 – There would be no significant relationship between approach parameters and ball release speeds of female fast bowlers in cricket.

REVIEW OF RELATED LITERATURE

Biomechanics of the Bowling Delivery

A bowling delivery consists of 4 main phases: 1) run-up to back foot contact, 2) pre-delivery, 3) delivery stride and 4) follow through **(McGrath et al., 1996)**. In the first phase each bowler slowly starts walking or jogging, building up his speed to the point where he leaps into the air to start the pre-delivery stride over a specific measured run-up distance **(Bartlett et al., 1995)**. Each bowler chooses a self selected run-up length, which varies from 10-30 meters for a fast/medium bowler **(Davis, &Blanksby, 1976b).** The bowler starts the run-up with the purpose to reach as high as possible horizontal velocity 3-4 strides before the bowling crease **(Elliot et al., 1986)**. The approach velocity of the bowler influences the release velocity of the ball **(Stockhill, & Bartlett, 1993)**.The delivery stride can be divided into eight important subdivisions: 1) action classification, 2) back foot strike, 3) front foot strike, 4) stride length and alignment, 5) front knee angle, 6) shoulder and hip orientation, 7) non-bowling arm and trunk movements as well as 8) the ball release **(Bartlett et al., 1995)**. Bowlers can be classified into one of two types of bowling action, an open action or a side on action **(Elliot, & Foster, 1984)**. The two predictors used to classify bowlers between the two actions include 1) the angle at which the back foot makes contact with the ground at the end of the pre-delivery stride, and 2) the alignment of the shoulders at the beginning of the delivery stride **(Foster et al., 1989).**

Summary of Review of Related Literature

Cricket is the most popular games which are played across the world. Due to its sophisticated way of execution, the fast bowling is one of the main important skills in the game of cricket. The skill of fast bowling requires several technical steps. According to former Indian captain Kapil Dev said “fast bowling is an art”. The many important factors are responsible over a fast bowling. Hence, in this study the

researcher focused on the kinematic parameters contributing to efficient bowling action and to make it better. In this study the researcher has critically reviewed the biomechanical factors which contribute directly or indirectly to fast bowling. Here, it could be concluded that biomechanical factors like pre-delivery run-up speeds, knee angle at BR, long delivery stride length, higher ball release height, quicker vertical velocity of non-bowling arm and plant angle at FFC were very effective in achieving fastest ball release speed in case of male fast bowler. Biomechanical factors like pre-delivery run-up speeds, knee angle at BR, long delivery stride length, higher ball release height, quicker angular velocity of bowling arm and foot strike indicator were very effective in achieving fastest ball release speed in case of female fast bowler.

A study conducted by Felton "Comparison of biomechanical characteristics between male and female elite fast bowlers" this study investigated ball release speed and kinematic parameters between elite male and female cricket fast bowlers. The results indicated that the female bowlers generated less whole body linear momentum during the run-up than the males. The male bowlers also utilized a technique between BFC and FFC which more efficiently maintained linear momentum compared to the female.

The study conducted by Worthington "Relationships between fast bowling technique and ball release speed in cricket" here he analyzed the key aspects of technique that characterize the fastest bowlers. The results recommended that the fastest bowlers had a quicker run-up and maintain a straighter knee throughout the front foot contact phase. The fastest bowlers were also observed to exhibit larger amounts of upper trunk flexion up to ball release. The best individual predictor of ball release speed was the shoulder angle at ball release explaining 30% of the variation in ball release speed.

Hence in the most of related literature it was found that the kinematic parameters had an important role to play in enhancing the performance of fast bowlers, as after going through many of the related literature there were several questions and research gaps related to this aspect. To give the answer and to fulfill the research gap, the present researcher chooses to investigate on **"BIOMECHANICAL ANALYSIS OF FAST BOWLING ACTION IN CRICKET".**

METHODOLOGY

Subject: For this purpose, Nineteen (19) healthy national and club level fast bowlers (12 male &7 female) were chosen. Used outdoor standard cricket pitch with full length bowling run up (for male cricketer's Jadavpur University Cricket ground, Saltlake and for women Women's Cricket Academy, Vibekananda Park) and video cameras Nikon 3300D.

The Criterion Measures: The purpose of this study was to analyze some selected kinematic parameters of the movement during the execution of fast bowling technique for male and female cricketers.

Approach-Run-

- Stride Length (in centimeters)
- Approach Speed (meter per second "m/s")
- Body Lean (degree "0")

Pre-Delivery-

- Stride Length (centimeters)
- Run-up Speed at Pre- Delivery Stride (meter per second "m/s")

Bound-

- Bound Height (centimeters)
- Loss of horizontal velocity(∞ momentum) (meter per second "m/s")

Back Foot Contact-

- Knee angle at BFC (degree "0")

Front Foot Contact to Ball Release-

- Knee angle at FFC (degree "0")
- Knee Angle at BR (degree "0")
- Upper Trunk Flexion from FFC to BR (degree "0")
- Shoulder Angle at BR (degree "0")
- Delivery Stride Length (centimeters)
- % D.S.L. (% ofDelivery Standing Height)

- Ball Release Height (centimeters)
- % B.R.H. (% of Ball Release Height)
- Ball Release Speed (meterper second “m/s”)
- Angular Velocity of Bowling Arm (meter per second “m/s”)
- Vertical Velocity of Non-Bowling Arm (meter per second “m/s”)
- Plant Angle (degree “0”)
- Foot-Strike Indicator (degree “0”)

Follow Through-

- Body Lean (degree “0”)
- Loss of horizontal velocity(∞ momentum) (meter per second “m/s”)

Design of the Study: Research design is the blue print of the research procedure. Purposive Sampling Design was used for the collection of data.

Instruments and Tools: For collecting data the following instruments and tools were used:

1. Four Video Cameras- Nikon 3300D video cameras were using in a field setting operating at a nominal frame rate of 60 Hz and with a shutter speed of 1/2000 s and at 60fps.
2. Stadiometer/steel tape.
3. Weighing Machine.
4. Speed Gun (Bushnell)
5. Cricket balls and standard cricket bowling pitch.
6. Computer and motion analyzer software. (Kinovea 0.8.24).

Recording of Movements: In the beginning of recording of movement, the purpose of recording was briefly explained to the subjects for better understanding and to increase their motivation level. The height, body mass and anthropometric dimensions of the subjects was measured. Each subjects then performed a standardized warm-up for at 5 minute by stretching all major muscles groups for bowling. Then each subject was performed six (6) successful bowling into the valid area. The movement of the subjects for executing the fast bowling action (technique) was recorded by using fixed cameras. A successful bowling was defined as the ball in the legal delivery towards the stump (batsman side) on the pitch.

Procedure for Data Collection: The data was obtained during non-competition situation and used outdoor standard cricket pitch with full length bowling run up (for male cricketer's Jadavpur University Cricket ground, Saltlake and for women Women's Cricket Academy, Vibekananda Park). Nikon D3300 cameras were used to collect the action of fast bowling in cricket. The cameras were mounted on the firm tripod at the height of 1.3 meters from the ground and at a distance of 5 meters from the bowling area (marked) on sagittal right (3) & left (1) plane.

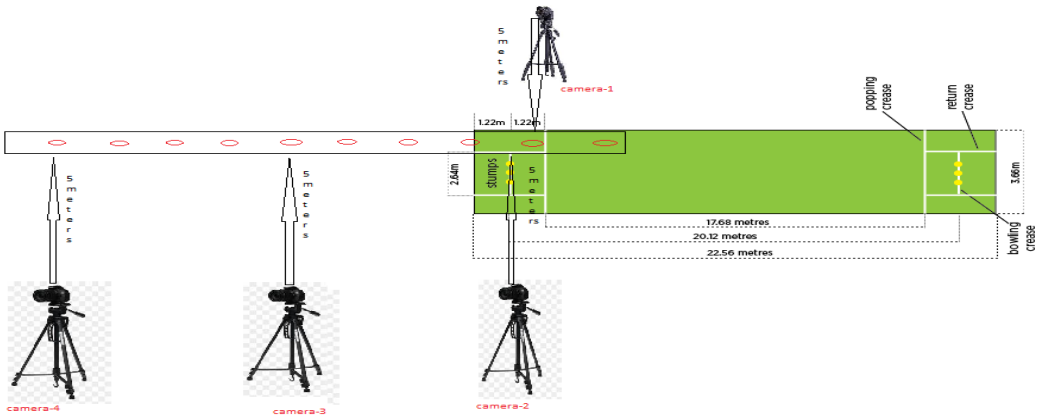


Figure -1: The Filming Environment for Data Collection

Method for Analysis of Recorded Film: To measure the selected kinematics parameters the film were analyzed. The capture movement was transferred from the camera to the computer and with the help of KINOVEA 0.8.24 software (motion analysis software) the motion of fast bowling action and delivery the ball for each subject were analyzed for collecting the required data.

A. Approach Body Lean: It was determined by measuring the angle of the leaning at hip joint during the initial approach of the subject.

Photograph -5: Approach Body Lean at Approach Run Phase

B. **Pre-Delivery Run-up Speed:** It was measured by the horizontal displacement of COM and time taken during the mid-point of the run-up.

Photograph -6: Pre-Delivery Run-up Speed at Pre-Delivery Phase

C. **Bound Height:** it was measured by vertical displacement of the COM at bound.

Photograph -7: Height Achieved at Bound Phase

D. **Ball Release Height:** it was measured by the vertical displacement from the ground to the release point of the ball.

Photograph -8: Ball Release Height at Front Foot Contact to Ball Release Phase

Statistical Analysis: Descriptive means, standard deviations, and ranges of all variables were calculated and evaluated. To compare the kinematic parameters of the

fast bowling action between the male and female fast bowlers the student t- test was used. The relationship of kinematics parameters and ball release speed were assessed using Pearson's correlation coefficients "r". All statistical procedures were conducted using the SPSS v.19 (SPSS Corporation, USA). The level of significance was judged at 0.05 level of significance.

RESULTS AND FINDINGS

The finding of the study concludes that the key technique for ball release speed in fast bowling in cricket for male and females. The results of this research found significant differences in kinematic parameters and ball release speeds which may indicate that the male fast bowlers use a different technique in fast bowling and to generate ball release speeds.

In kinematic parameters at Approach Run, stride length was found significant differences between male and female fast bowlers. But no significant different were found in approach speed and body lean.

At Pre-delivery phase, significant differences were found in pre-delivery stride length and run-up speeds of male and female fast bowlers in cricket. In this study found that on average the female fast bowlers had significantly shorter stride length and slower run-up speeds than their male counterparts.

At Bound phase, there were no significant differences found in bound height and loss of horizontal velocity(∞ momentum) of male and female fast bowling in cricket. High bound can lead to the knee on the back foot collapsing and so loss the horizontal velocity(∞ momentum).

At Back Foot Contact phase, the male fast bowlers were observed to have a higher back foot knee angle compared to the female bowlers during BFC. In this study the female fast bowlers may also lack of the muscular strength required to extend that trunk and keep balance with a higher knee angle at BFC.

At Front Foot Contact to Ball Release, the significant differences found between the male and female fast bowlers in cricket. In this research delivery stride length, % of standing height (DSL), ball release height, % of standing height (BRH), ball release speeds, angular velocity of bowling arm, vertical velocity of non-bowling arm and

plant angle at FFC significantly differences were found between male and female fast bowling in cricket. The male fast bowlers produced significantly slower ball release speeds compared to their male counterparts. The more angular velocity of the bowling arm and vertical velocity of non-bowling arm of the male fast bowlers were found. Knee angle at FFC, knee angle at BR, knee extension from FFC to BR, upper trunk flexion FFC to BR, shoulder angle at BR and foot strike indicator at FFC were found no significant differences of male and female fast bowling in cricket. The female fast bowlers had more knee extension angle from FFC to BR and shoulder angle at BR and foot strike indicator at FFC than male fast bowlers. Knee angle at FFC, knee angle at BR and upper trunk flexion FFC to BR had found more in male counterpart. The case of the differences in time between FFC to BR for males compared to females is still unknown and should be the focus of future research.

At Follow Through phase, we found that after ball release female fast bowlers take more body forward lean compared to their male fast bowlers and on average the female fast bowlers less loss of horizontal velocity($\propto$ momentum) than male fast bowlers to maintain their body balance. Very limited research are available as most analyses stop shortly after ball release so the findings still unknown and need further research on the follow through phase.

Relationship between selected anthropometric and kinematic parameters were investigated using Pearson's product-moment correlation coefficients of male and female fast bowling in cricket.

The results of the study have shown that some of the selected anthropometric parameters of the male fast bowlers i.e. height, weight, two hand span, leg length and arm length exhibited a significant relationships with the ball release speeds of male fast bowling in cricket. 56.2%, 34.1% and 51.2% of contribution in the ball release speeds of the male fast bowling was made by two hand span, leg length and arm length respectively. A very strong positive correlation found between two hand span and arm length with ball release speeds, and a strong positive correlation found between height and leg length with ball release speeds. This study suggests that tall bowlers with long arms and long legs are able to release the ball with higher speeds. In this study there were no significant relationships occur between standing arm rising height with ball release speeds but strong positive correlation found.

Also the results of the study have shown that some of the selected kinematical parameters i.e. pre-delivery run-up speeds, knee angle at BR, shoulder angle at BR, delivery stride length, ball release height, vertical velocity of non-bowling arm and plant angle at FFC found a significant relationship with ball release speeds of male fast bowling in cricket. 36.1%, 37.2%, 41.8% and 36.8% of contribution in the ball release speeds of the male fast bowling was made by pre-delivery run-up speeds, delivery stride length, ball release height and vertical velocity of non-bowling arm respectively. In this study there was a strong relationship found between knee angle at BR and ball release speeds.

The amount of shoulder angle at BR was significantly strong positive correlation found with ball release speeds in this current study. In this current investigation strong positive correlation were found between delivery stride length and ball release speeds. Ball release speeds were significantly correlated with ball release height in this study. The relationship between ball release height and faster ball release speeds contradicts the intuitive belief that a higher release position enables higher release speeds. The strong positive significant relationship observed between vertical velocity of non-bowling arm and plant angle at FFC with ball release speeds in this study. Plant angle at FFC were also observed to be positive correlation with ball release speeds.

In this study it was also found that stride length at approach run, approach speed, body lean at approach run, pre-delivery stride length, bound height, loss of horizontal velocity($\propto$ momentum) at bound, knee angle at BFC, knee angle at FFC, upper trunk flexion from FFC till BR, angular velocity of bowling arm, foot strike indicator at FFC, body lean at follow through and loss of horizontal velocity($\propto$ momentum) at follow through were not statistically significant but found positive correlation with ball release speeds of male fast bowling in cricket. The mechanism by which the fastest bowlers have increased amounts of upper trunk flexion between FFC and BR is unclear and warrants further investigation. The action of the angular velocity of bowling arm were shown to be the significant contribution with ball release speeds of male fast bowling in cricket.

The result of the study have shown that all the selected anthropometrical parameters of female fast bowling in cricket i.e. height, weight, two hand span, leg length, arm length and standing arm rising height exhibited not statistically significant with ball release speeds. But found positive relationship between anthropometric parameters

and ball release speeds of female fast bowling in cricket. In this study strong positive correlation was found between height and ball release speeds. A moderate correlation was found between standing arm raising height and ball release speeds and a weak correlation was reported between two hand span and arm length with ball release speeds of female fast bowling in cricket. The cause of the relationship between anthropometric parameters and ball release speeds is still unknown and no previous study found on the area of female fast bowling in cricket.

In this study the results have shown that all the selected kinematical parameters of female fast bowling in cricket i.e. stride length at approach run, approach speed, body lean at approach run, pre-delivery stride length, pre-delivery run-up speed, bound height, loss of horizontal velocity($\propto$ momentum) at bound, knee angle at BFC, knee angle at FFC, knee angle at BR, upper trunk flexion from FFC to BR, shoulder angle at BR, delivery stride length, ball release height, angular velocity of bowling arm, vertical velocity of non-bowling arm, plant angle at FFC, foot strike indicator at FFC, body lean at follow through and loss of horizontal velocity($\propto$ momentum) at follow through exhibited no statistically significant relationship with ball release speeds of female fast bowlers, but found positive correlation.

Approach run speeds and knee angle at FFC observed the very strong positive correlation with ball release speeds in this study.

In this study the results have shown that knee angle at BR, delivery stride length, ball release height, angular velocity of bowling arm and foot strike indicator at FFC reported strong positive correlation with ball release speeds and pre-delivery run-up speed and shoulder angle at BR observed relationship with ball release speeds moderate and weak positive correlation respectively. 49%, 32.3%, 38.9%, 36.7% and 45.9% of contribution in the ball release speeds of the female fast bowling was made by knee angle at FFC, knee angle at BR, delivery stride length, ball release height and foot-strike indicator at FFC respectively. In this study the researcher try to find out the relation between ball release speeds and follow through. So the results shown that body lean at follow through and loss of horizontal velocity($\propto$ momentum) positively correlated with ball release speeds of female fast bowling in cricket. But all the previous study based on male fast bowlers. So the cause of the relationship between selected anthropometric and kinematical parameters and ball release speeds of female fast bowling in cricket is still unknown and should be the focus of future research.

Discussion of Hypothesis

On the basis of reviews of literature and from expert's advice it was hypothesized that there would be no significant differences in selected kinematic parameters for executing fast bowling action in case of male and female fast bowling in cricket and also there would be no significant relationship between selected kinematic parameters with ball release speeds of male and female fast bowling in cricket. On the basis of the results of the present study the formulated hypothesis may be discussed as below:

1. According to first hypothesis it was assumed that there would be no difference in selected kinematic parameters in the execution of fast bowling action between male and female fast bowlers in cricket. But results at this study did not support this assumption. Results confirmed that male fast bowlers adopted a technique which is more efficient than female fast bowlers. So on the basis of the results the first hypothesis is rejected.
2. According to second hypothesis it was assumed that there would be no significant relationship between approach parameters and ball release speeds of male fast bowling in cricket. But the result supported this assumption for stride length at approach run, approach run speed, approach body lean, pre-delivery stride length, bound height, loss of horizontal velocity($\propto$ momentum) at bound phase, knee angle at BFC, knee angle at FFC, upper trunk flexion from FFC till BR, angular velocity of bowling arm, foot strike indicator at FFC, body lean at follow through and loss of horizontal velocity($\propto$ momentum) at follow through. In case of other selected kinematic parameters there were significant relationship observed like, pre-delivery run-up speeds, knee angle at BR, shoulder angle at BR, delivery stride length, ball release height, vertical velocity of non-bowling arm and plant angle at FFC found significant relationship with ball release speeds of male fast bowling in cricket. So on the basis of the result the second hypothesis was partially rejected.
3. According to third hypothesis it was assumed that there would be no significant relationship found between approach parameters and ball release speeds of female fast bowling in cricket. The results supported this assumption. So on the basis of this result the third hypothesis was accepted. But some selected approach parameters were observed positive relation with ball release speeds.

CONCLUSIONS

Based on the analysis and within the limitations of the study following conclusions were drawn:

1. The female fast bowlers have shorter and lighter than the male bowlers of fast bowling in cricket.
2. The male fast bowlers have long leg length, arm length, two hand span, and standing arm raising height as compared to female bowlers of fast bowling in cricket.
3. Male fast bowlers perform fast bowling in cricket with greater effect on kinematic parameters as to compare female fast bowlers in cricket.
4. At Approach run female fast bowlers have long stride length as compared to male fast bowlers.
5. At Pre-delivery the male fast bowlers have long stride length and subsequently quick run-up speeds as compared to female fast bowlers in cricket.
6. At Bound the female fast bowlers have higher bound height and less loss of horizontal velocity(∞ momentum) as compared to the male fast bowlers in cricket.
7. At BFC the male fast bowlers have greater knee angle as compared to female fast bowlers.
8. At FFC to BR the male fast bowlers have long delivery stride length, higher ball release height, faster ball release speeds, quick angular velocity on bowling arm quick vertical velocity of non-bowling arm and less plant angle as compared to female fast bowlers.
9. At Follow Through the female fast bowlers have more body lean and less loss of horizontal velocity(∞ momentum) as compared to male fast bowlers in cricket.
10. The kinematic differences between male and female fast bowlers indicate that in contrast to the male fast bowlers the amount of whole body angular momentum generated by the female fast bowlers is insufficient to solely generate ball release speeds.
11. Height, weight, arm length, leg length and two hand spans have very strong positive effect on ball release speeds of the male fast bowling in cricket.
12. Kinematic parameters i.e. pre-delivery run-up speeds, knee angle at BR, shoulder angle at BR, ball release height, vertical velocity of bowling arm and

plant angle at FFC have strong positive effect on ball release speeds of male fast bowling in cricket.

13. Male fast bowlers with long arm length, leg length, quicker pre-delivery run-up speeds, knee angle at BR, shoulder angle at BR, long delivery stride length, higher ball release height, quicker vertical velocity of non-bowling arm and plant angle at FFC are effective on achieving fastest ball release speeds in cricket.
14. Height, weight, arm length, leg length, two hand span and standing arm raising height have positive effect on ball release speeds of female fast bowling in cricket.
15. Kinematic parameters have a positive effect on ball release speeds of female fast bowling in cricket.
16. In particular the fastest bowlers have a fast pre-delivery run-up speeds, maintain a straighter knee, greater upper trunk flexion from FFC till BR, longer delivery stride length, higher ball release height, quicker angular velocity of bowling arm.

REFERENCES

Atwater, A.E. (1979).“Biomechanics of over arm throwing movements and of throwing injuries”. Exercise and Sport Sciences Reviews, 7.43-86.

Bartlett, R.M., Stockill, N.P., Elliott, B.C. & Burnett, A.F. (1996). “The biomechanics of fast bowling in men's cricket: A review.” Journal of Sports Sciences, 14, 403-424.

Burden, A.M., & Bartlett, R.M. (1990a). “A kinematic comparison between elite fast bowlers and college fast-medium bowlers”. Proceedings of the Sports Biomechanics Section of the British Association of Sports Sciences, 15, 41-46.

Davis, K. & Blanksby, B. (1976a). “The segmental components of fast bowling in cricket”. Australian Journal for Health, Physical Education and Recreation , 71 (suppl .) , 6-8.

Elliott, B.C.,Foster, D.,&Gray, S. (1986).“Biomechanics and physical factors affecting fast bowling”. Australian Journal of Science and Medicine in Sport, 18, 16-21.

Felton PJ, Lister SL,Worthington PJ, King MA. (2019).”Comparison of biomechanical characteristics between male and female elite fast bowlers”. J sports Sci. 2019; 37(6):665-670. doi:10.1080/02640414.2018.1522700

Ghosh, P., Mondal, P. (2017). “Anthropometric and biomechanical predictors of ball release speed in cricket fast bowling”. International Congress on Global Innovation and Research in Education, Sports Science and Yoga, ISBN- 978-93-87072-49-7. P-227-235.

Ghosh, P., Mondal, P. (2016). “Biomechanical factors contributing to effective bowling in cricket: A review study”. International Journal of Physical Education, Sports and Health 2016; 3(3): 61-65.

Sankar, C. K. (2011). “The relationship between anthropometric and kinematic variables and ball release speed in slow-medium bowling”. International Sports Biomechanics.

Stuelcken, M.C.& Sinclair, P.J.(2009) “A pilot study of the front foot ground reaction forces in elite female fast bowlers”. Journal of Science and Medicine in Sport, 12, 258-261.

Wormgoor S., Harden, L. & McKinon, W. (2010). Anthropometric, biomechanical and isokinetic strength predictors of ball release speed in high-performance cricket fast bowlers”. Journal of sports sciences; 28(9): 957-965.

Worthington, P.J. , King, M.A., & Ranson, C.A. (2013a). “Relationships between fast bowling technique and ball release speed in cricket”. Journal of Applied Biomechanics, 29, 78 - 84.

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