FACTORS DETERMINING BALL RELEASE VELOCITY OF WOMEN PACE BOWLERS IN CRICKET

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

BY
NEPTUNE GHOSH
Reg. No. AOPED0100117

DEPARTMENT OF PHYSICAL EDUCATION
(FACULTY OF ARTS)
JADAVPUR UNIVERSITY
KOLKATA-700032
WEST BENGAL
INDIA

MAY, 2025

Dedicated to

My parents,

Mr. Rajkumar Ghosh,

Mrs. Purnima Ghosh,

My better half,

Mrs. Moupali Mishra

And

My beloved daughter

Aryahi Ghosh

CERTIFICATE

Certified that the thesis entitled **"Factors Determining Ball Release Velocity of Women Pace Bowlers in Cricket"** submitted by me for the award of the Degree of Doctor of Philosophy in Arts at Jadavpur University is based upon my work carried out under the supervision of **Dr. Papan Mondal, Associate Professor, Department of Physical Education, Jadavpur University, Kolkata** and that neither this thesis nor any part of it has been submitted before for any degree or diploma anywhere / elsewhere.

Countersigned by the Supervisor | Candidate

Date: | Date:

ACKNOWLEDGEMENTS

I acknowledge my sincere gratitude to my teacher and guide ***Dr. Papan Mondal,*** *Associate Professor of Department of Physical Education, Jadavpur University for his valuable Biomechanical assistance and overall guidance and recommendation.*

I also acknowledge my sincere gratitude to ***Prof. Asish Paul (internal expert of RAC),*** *Professor, Department of Physical Education, Jadavpur University, Kolkata, for his valuable suggestion and technical guidance throughout the whole work.*

I express my sincere gratitude to ***Dr. Abhijit Thander (external expert of RAC),*** *Assistant Professor, Dept. of Physical Education and Sports Science, Visva Bharati University for his timely support specially for biggest support in subject arrangement.*

I also express my sincere gratitude to ***Dr. Sridip Chatterjee****, Associate Professor & HOD, Department of Physical Education, Jadavpur University, Kolkata, for giving the direction to my research work towards the completion.*

I am very much thankful to my esteemed teachers ***Prof. Sudip Sundar Das*** *and* ***Prof. Ashoke Kumar Biswas,*** *Professors, Department of Physical Education, Jadavpur University, Kolkata, along with all other teaching and non-teaching faculties of the department for their valuable advices, encouragement and co-operation for the successful completion of this research work.*

I would like to acknowledge ***Prof. Samarjit Das,*** *Professor, Indian Statistical Institute, Kolkata, for his priceless assistance in the statistical procedure of this work.*

I would like to thank to my ideal person, ***Mr. Abhishek Tripathi,*** *Principal, PM SHRI Kendriya Vidyalaya No.2 AFS, Kalaikunda, who always showed a positive attitude towards my work, encouraged me a lot and always co-operated by sanctioning the leave whenever I needed for this work.*

Special thanks to my fellow friend, ***Mr. Kallol Ghosh*** *for arrangement of subjects and all-round assistance. Also, thanks to my senior,* ***Dr. Pallab Ghosh****,* ***other Ph.D. scholars and B.P.Ed & M.P.Ed. students*** *for rendering assistance in data collection.*

My thankful gratitude to my father, mother and specially my better half for having patience and sacrificing their deserving time with smiley face for my research.

(Neptune Ghosh)

PREFACE

This research work is the outcome of the present researcher’s sustained academic interest in examining the scientific foundations of performance in women's cricket, with a particular emphasis on pace bowling. In light of the growing participation of women in the sport and the lack of sufficient research focused on female athletes, this study was undertaken to investigate the relationship between selected anthropometric, kinematic, and physical fitness parameters and ball release velocity in female pace bowlers.

The study was conducted on a purposive sample of twelve state-level female pace bowlers. Their high level of skill and commitment to the game enabled the present researcher to carry out detailed assessments using advanced motion analysis systems and standardized physical performance tests. This approach ensured a focused analysis of variables relevant to the performance of female athletes, rather than relying on inferences drawn from male-dominated research findings.

During the investigation, the present researcher maintained a strong focus on generating data-driven insights to support evidence-based coaching strategies and training interventions specifically designed for female pace bowlers. The findings are intended to contribute to the development of performance models that are both practical and scientifically grounded.

The present study will be successful if this research work can contribute some light to the field of women's cricket performance and inspire further research in the domain of female athlete development within sports science.

TABLE OF CONTENTS

		Page No.
	LIST OF TABLES	viii
	LIST OF FIGURES	ix
CHAPTER- 1:	**INTRODUCTION**	**1-20**
	1.1 General introduction	1
	1.2 Statement of the Problem	16
	1.3 Objectives of the Problem	16
	1.4 Delimitations	17
	1.5 Limitations	17
	1.6 Hypothesis	18
	1.7 Definition and Explanation of the Technical Terms	19
	1.8 Significance of the Problem	20
CHAPTER- 2:	**REVIEW OF RELATED LITERATURE**	**21-58**
CHAPTER- 3:	**METHODOLOGY**	**59-98**
	3.1 Selection of the Subjects	59
	3.2 Selection of the Variables	59
	3.3 Instruments and Tools	61
	3.4 Procedure for the Administering the Test	62
	3.5 Design of the study	96
	3.6 Statistical Procedure	98
	3.7 Level of significance	98
CHAPTER- 4:	**ANALYSIS OF THE DATA AND RESULT OF THE STUDY**	**99-147**
	4.1 Findings	99
	4.2 Discussion of findings	133
	4.3 Testing of Hypothesis	146

CHAPTER- 5:	**SUMMARY, CONCLUSION AND RECOMMENDATION**	**148-157**
	5.1 Summary	148
	5.2 Conclusion	154
	5.3 Recommendation	156
BIBLIOGRAPHY		**158-172**
APPENDICES		**173-189**
Appendix-1	Anti-Plagiarism Certificate	173
Appendix-2	Ground Permission for Data Collection	174
Appendix-3	Sample Score Sheet for Data Collection of Demographic Details	175
Appendix-4	Sample Score Sheet for Data Collection of Anthropometric Parameters	176
Appendix-5	Sample Score Sheet for Data Collection of Physical Fitness Parameters	177
Appendix-6	Player’s Bio Data Format for Data Collection	178
Appendix-7	Consent/ Self-declaration Format for Data Collection	179
Appendix-8	First Page of Publication 1	180
Appendix-9	First Page of Publication 2	181
Appendix-10	Certificate of Seminar Presentation	182
Appendix-11	Marksheet of Course Work	183
Appendix-12	Certificate of UGC-NET	184
Appendix-13	Certificate of WBSET	185
Appendix-14	Permission Letter of 1st Extension of Ph.D. Registration	186
Appendix-15	Permission Letter of 2nd Extension of Ph.D. Registration	187
Appendix-16	Photographs of Data Collection	188
Appendix-17	Group Photo of Experts and Team Involved in Data Collection	189

LIST OF TABLES

Table		Page
Table 1	Descriptive Statistics of Personal Data	99
Table 2	Descriptive Statistics of Anthropometric Variables.	100
Table 3	Correlation between Ball Release Velocity and Anthropometric Variables	102
Table 4	Descriptive Statistics of Kinematic Variables Measured on Best Ball Deliveries (n = 12)	104
Table 5	Correlation between Ball Release Velocity and Kinematic Variables Measured on Best Ball Deliveries (n = 12)	106
Table 6	Descriptive Statistics of Kinematic Variables Measured on All Ball Deliveries (n = 72)	111
Table 7	Correlation between Ball Release Velocity and Kinematic Variables Measured on All Ball Deliveries (n = 72)	113
Table 8	Model Summery of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)	121
Table 9	Coefficient of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)	123
Table 10	Compiled Table of Correlation and Regression Analysis of Kinematic Variables with Ball Release Velocity Measured on Best Deliveries (n = 12) and All Ball Deliveries (n = 72)	126
Table 11	Descriptive Statistics of Physical Fitness Variables	127
Table 12	Correlation between Ball Release Velocity and Physical Fitness Variables	129

LIST OF FIGURES

Figure	Name of Figure	Page
Figure 1	Measurement of Height	63
Figure 2	Measurement of Weight	63
Figure 3	Measurement of Upper Arm Length	64
Figure 4	Measurement of Forearm Length	65
Figure 5	Measurement of Hand Length	65
Figure 6	Measurement of Arm Span	66
Figure 7	Measurement of Upper Leg Length	66
Figure 8	Measurement of Lower Leg Length	67
Figure 9	Measurement of Foot Length	67
Figure 10	Measurement of Standing Reach Height	68
Figure 11	Illustration of Filming Environment	69
Figure 12	Photograph of Real Filming Environment	69
Figure 13	Warm Up Session of the Players	70
Figure 14	Reference Scale	71
Figure 15	Measurement of Run-Up Length	72
Figure 16	Measurement of Final Run-Up Velocity	73
Figure 17	Measurement of Bound Height	74
Figure 18	Measurement of Final Stride Length	75
Figure 19	Measurement of Ball Release Height	76
Figure 20	Measurement of Ball Release Angle	77
Figure 21	Measurement of Ball Release Velocity	78
Figure 22	Measurement of Ankle Joint Angle at FFC	79
Figure 23	Measurement of Knee Joint Angle at FFC	80
Figure 24	Measurement of Hip Joint Angle at FFC	81
Figure 25	Measurement of Shoulder Joint Angle at FFC	82
Figure 26	Measurement of Ankle Joint Angle at BR	83
Figure 27	Measurement of Knee Joint Angle at BR	84
Figure 28	Measurement of Hip Joint Angle at BR	85
Figure 29	Measurement of Shoulder Joint Angle at BR	86
Figure 30	Measurement of Arm Strength	88

Figure	Name of Figure	Page
Figure 31	Measurement of Back Strength	89
Figure 32	Measurement of Leg Strength	90
Figure 33	Overhead Medicine Ball Throw Test	91
Figure 34	Vertical Jump Test	92
Figure 35	Prone Hold Test	93
Figure 36	20m Speed Test	94
Figure 37	Flexometer for Sit and Reach Test	95
Figure 38	Illustration of Design of the Study	97
Figure 39	Graphical Representation of Correlation between Ball Release Velocity and Anthropometric Variables	102
Figure 40	Graphical Representation of Correlation between Ball Release Velocity and Kinematic Variables Measured on Best Ball Deliveries (n = 12)	108
Figure 41	Graphical Representation of Correlation between Bound Height and Ball Release Velocity measured on Best Ball Deliveries (n = 12)	108
Figure 42	Graphical Representation of Correlation between Ankle Joint Angle at BR and Ball Release Velocity measured on Best Ball Deliveries (n = 12)	109
Figure 43	Graphical Representation of Correlation between Knee Joint Angle at BR and Ball Release Velocity measured on Best Ball Deliveries (n = 12)	109
Figure 44	Graphical Representation of Correlation between Ankle Planter Flexion from FFC to BR and Ball Release Velocity measured on Best Ball Deliveries (n = 12)	110
Figure 45	Graphical Representation of Correlation between Ball Release Velocity and Kinematic Variables Measured on All Ball Deliveries (n = 72)	115
Figure 46	Graphical Representation of Correlation between Ball Release Velocity and Final Run-up Velocity Measured on All Ball Deliveries (n = 72)	116

Figure	Name of Figure	Page
Figure 47	Graphical Representation of Correlation between Ball Release Velocity and Bound Height Measured on All Ball Deliveries (n = 72)	116
Figure 48	Graphical Representation of Correlation between Ball Release Velocity and Ball Release Height Measured on All Ball Deliveries (n = 72)	117
Figure 49	Graphical Representation of Correlation between Ball Release Velocity and Ball Release Angle Measured on All Ball Deliveries (n = 72)	117
Figure 50	Graphical Representation of Correlation between Ball Release Velocity and Knee Angle at FFC Measured on All Ball Deliveries (n = 72)	118
Figure 51	Graphical Representation of Correlation between Ball Release Velocity and Ankle Joint Angle at BR Measured on All Ball Deliveries (n = 72)	118
Figure 52	Graphical Representation of Correlation between Ball Release Velocity and Knee Joint Angle at BR Measured on All Ball Deliveries (n = 72)	119
Figure 53	Graphical Representation of Correlation between Ball Release Velocity and Hip Joint Angle at BR Measured on All Ball Deliveries (n = 72)	119
Figure 54	Graphical Representation of Correlation between Ball Release Velocity and Shoulder Joint Angle at BR Measured on All Ball Deliveries (n = 72)	120
Figure 55	Graphical Representation of Correlation between Ball Release Velocity and Ankle Planter Flexion from FFC to BR Measured on All Ball Deliveries (n = 72)	120
Figure 56	Graphical Representation of Correlation between Ball Release Velocity and Knee Flexion from FFC to BR Measured on All Ball Deliveries (n = 72)	121
Figure 57	Graphical Representation of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)	124

Figure	Name of Figure	Page
Figure 58	Graphical Representation of Correlation between Ball Release Velocity and Physical Fitness Variables	130
Figure 59	Graphical Representation of Correlation between Ball Release Velocity and Arm Strength of the Subjects	131
Figure 60	Graphical Representation of Correlation between Ball Release Velocity and Leg Strength of the Subjects	131
Figure 61	Graphical Representation of Correlation between Ball Release Velocity and Core Stability of the Subjects	132
Figure 62	Graphical Representation of Correlation between Ball Release Velocity and Speed of the Subjects	132
Figure 63	Graphical Representation of Correlation between Ball Release Velocity and Flexibility of the Subjects	133

CHAPTER - I

1. INTRODUCTION:

1.1. General Introduction:

The Game of Cricket

Cricket is a popular bat and ball sport that originated in England and has become a global game, particularly prominent in countries such as India, South Africa, Australia, West Indies, Pakistan etc. The game is contested by two teams, each comprising eleven players, on a circular or oval-shaped field, with the primary objective being to achieve a greater number of runs than the opponent. The game centers around two key components: batting and bowling, with fielding being a complementary element. (Longmore et al., 2024)

Basic Structure of the game is Innings and Over. An innings consists of a set number of overs (6 legal deliveries per over). In limited formats (like ODIs and T20s), there is a fixed number of overs. In Test matches, there is no limit, and the batting side remains at the crease until all ten wickets fall or a declaration is made. (Marylebone Cricket Club, 2017a)

One team takes batting while the other bowls and fields. Batsmen struggle for scoring maximum runs by striking the ball into the field and running between the wickets by hitting boundaries (4 runs if the ball touches the boundary line after contacting the inside ground, 6 runs if it crosses without touching). The bowling team aims to dismiss the batsmen by getting them out in various ways, such as: Bowled: The ball hits the stumps, Caught: Any fielder caught the ball before it touches the ground, LBW (Leg Before Wicket): The batsman is out if a ball that would have hit the stumps strikes their leg instead. (Marylebone Cricket Club, 2017b)

There are three formats of cricket which are used worldwide to organize any cricket tournament. They are Test Cricket, One Day Internationals (ODIs) and Twenty20 (T20). In case of Test Cricket, the game is played for consecutive five days, in which each team has two innings. In One Day Internationals (ODIs), each team faces a fixed number of 50 overs. And in case of Twenty20 (T20), each team plays 20 overs, making it a shorter and faster-paced format. (International Cricket Council, 2023)

History of Cricket

Cricket is celebrated for its strategy, skill, and sportsmanship, with a rich history and a passionate global following. Cricket is believed to have originated in England during the 16th century, with early forms of the game played by children in the southeastern counties. The first recorded match took place in 1697 in Sussex, marking the transition from informal play to organized competition. (Longmore et al., 2024)

The Marylebone Cricket Club (MCC) is a cornerstone of cricket history, established in 1787 as a club for members who played at Lord's Cricket Ground in London. Initially created to promote and organize cricket, the MCC quickly became central to the sport's development in England. One of its primary contributions was the formulation of the first formal Laws of Cricket in 1788, which outlined rules governing play, including details on batting, bowling, and pitch dimensions. Over time, the MCC has adapted these laws to keep pace with changes in the game, ensuring they remain relevant. (Raikar, 2024)

International Matches

International cricket matches have a rich and storied history, evolving from local contests to a global phenomenon. The first recognized international match was played between the United States and Canada in 1844, but it wasn't until the birth of Test cricket in 1877 that international competition gained prestige. The inaugural Test match, held at the Melbourne Cricket Ground between England and Australia, set the standard for the format, emphasizing skill and endurance. The legendary Ashes rivalry began in 1882 after Australia defeated England at The Oval, leading to the term "The Ashes" and establishing one of cricket's most celebrated contests. (Longmore et al., 2024)

As more countries began to play Test matches—South Africa in 1889, India in 1932, and the West Indies in 1928—the landscape of international cricket expanded. When the International Cricket Council (ICC) was formed in 1909, it helped oversee the growing sport globally. The introduction of One Day Internationals (ODIs) in the 1970s revolutionized cricket, with the first ODI played during the inaugural Cricket World Cup in 1975. This format provided a shorter, more spectator-friendly version of the game, significantly increasing its popularity, particularly after India's 1983 World Cup victory. (Longmore et al., 2024)

The rise of Twenty20 (T20) cricket in the early 2000s brought another significant shift, with the first T20 International played in 2006 and the inaugural T20 World Cup following in 2007. T20 cricket's explosive nature attracted new audiences and led to the establishment of domestic leagues like the Indian Premier League (IPL) (Cricinfo, 2016). In recent years, technological advancements have also transformed international matches, with the Decision Review System (DRS) enhancing accuracy in officiating by allowing teams to challenge umpire decisions using ball-tracking and ultra-edge technology. Today, international cricket includes a vibrant mix of Test series, ODIs, and T20 matches, overseen by the ICC through various prestigious tournaments, drawing millions of fans worldwide and reflecting the dynamic nature of the sport. (Longmore et al., 2024)

Women Cricket

Women's cricket has its roots in the late 18th century, with the earliest documented match occurring in 1745 in England. The establishment of the British Ladies' Cricket Association in 1926 marked a significant step toward organizing the women's game, leading to increased competition and the creation of structured matches (Threlfall-Sykes, 2015).

The first instance of international women's cricket occurred in 1934 when England and Australia faced off in the inaugural women's Test match, which took place at the North Sydney Oval. The Women's Cricket World Cup, first held in 1973, was the first-ever global cricket tournament, predating the men's equivalent by two years. (Duncan, 2013)

The launch of One Day Internationals (ODIs) in the 1970s, followed by the creation of the Women’s T20 World Cup in 2009, has significantly advanced the sport, by drawing larger audiences and motivating a new generation of female cricketers. The rise of domestic leagues, such as the Women's Premier League in India, has also been instrumental in raising the profile of women's cricket, providing platforms for players to showcase their skills and gain financial support. (Duncan, 2013)

In recent years, efforts to promote gender equality in sports have led to increased investment in women's cricket, both from governing bodies and sponsors. Major cricket boards now support women's teams with greater resources, focusing on training, development, and competitive opportunities. The visibility of women's cricket has also improved significantly, with more matches being broadcasted and covered by media outlets, helping to build a larger fan base. (Fletcher et al., 2024)

However, the commitment to promoting women's cricket continues to grow, with increased participation at grassroots levels and a focus on nurturing talent. The women's cricket appears to set a bright future, as it strives for greater recognition and equality within the broader sporting landscape. (Butts at al., 2023)

Women Cricket in India

The origins of women's cricket in India date back to the 1930s, when matches were arranged by several regional clubs. However, it was in 1976 that the Indian women's cricket team was officially formed, representing a crucial milestone in the development of Indian sports. (Duncan, 2013)

The Indian women's team played its first Test match against England in 1976, a landmark event that introduced the team to international competition. The match took place at the P. Sarada Rao Stadium in Bangalore, laying the foundation for India's participation in global cricket. The Women's Cricket World Cup, first organized in 1973, saw India competing for the first time in 1978, which helped raise awareness and interest in women's cricket throughout the country. (Kulkarni, 2000)

In the decades that followed, the Indian women's team achieved notable successes, including reaching the finals of Women's World Cup in both 2005 and 2017. The 2017 final, held at Lord's, was particularly significant, as it garnered widespread media attention and a substantial increase in viewership, showcasing the potential of women's cricket in India. This match inspired many young girls to take up the sport, leading to a surge in participation at grassroots levels. (Duncan, 2013)

When the Women’s T20 format was introduced, it accelerated the growth and popularity of women's cricket in India. The inaugural T20 World Cup for Women in 2009 featured India as a competitive side, and the format's fast-paced nature has attracted a broader audience. Additionally, the introduction of the Women’s Premier League (WPL) in 2023 marked a significant milestone, providing a scope for female cricketers to show their skills and gain financial independence, much like their male counterparts in IPL. (Bhattacharjee, 2024)

In recent times, the Board of Control for Cricket in India (BCCI) and sponsors have significantly boosted their investment and support for women's cricket. This includes improved training facilities, professional contracts for players, and increased visibility through media coverage. The commitment to gender equality in sports has also contributed to the growing popularity of women's cricket, with more matches being broadcast and marketed effectively. (Bhattacharjee, 2024)

Bowling in Women Cricket

Bowling in cricket is a fundamental aspect of the game, where the bowler aims to either dismiss the batter or limit the scoring of runs. This is achieved by delivering the ball in various ways, such as fast bowling, spin, or swing, to outmaneuver the batter. Each set of six deliveries constitutes an "over," after which another bowler takes over from the opposite end. (Boyat et al., 2021)

Bowling in women's cricket follows the same fundamental principles as in men's cricket, with bowlers aiming to dismiss batters or restrict run scoring. Over the years, women's cricket has seen the rise of highly skilled bowlers in both fast bowling and spin bowling departments. Players like Jhulan Goswami, one of the fastest bowlers in women's cricket history, and Anisa Mohammed, a prolific spinner, have made significant contributions to the game. Women's cricket has increasingly showcased diverse bowling styles, from pace and swing to off-spin and leg-spin, making the game more competitive and exciting. (Bandarupalli, 2022)

The shorter formats, such as T20 cricket, have brought a new dynamic to women's bowling, where bowlers have had to adapt by developing variations like slower balls, yorkers, and cutters to outwit batters. As women's cricket grows in popularity and receives more support, the standard of bowling continues to rise, with a focus on improving speed, accuracy, and tactical approaches. (Manawadu et al., 2022)

Historically, women's bowling often mirrored the styles of their male counterparts, but female bowlers have increasingly developed their unique identities. Fast bowling, medium pace, and spin bowling are the primary styles, each demanding distinct skills and training.

Notable fast bowlers, such as Jhulan Goswami from India, have made a considerable impact on the sport. With her remarkable speed and accuracy, Goswami has become one of the leading wicket-takers in women's One Day Internationals (ODIs), highlighting the effectiveness of fast bowlers in the women's game. Meanwhile, spinners like Sophie Ecclestone of England have garnered attention for their ability to deceive batswomen with variations in spin and flight, demonstrating the strategic depth that spin bowling adds to the game. (Bandarupalli, 2022)

Training and conditioning for female bowlers have also improved, focusing on strength, flexibility, and injury prevention. Increased access to specialized coaching and modern training facilities has enabled bowlers to refine their techniques, although disparities in resources compared to men's cricket persist. The rise of competitive leagues and international tournaments have provided female bowlers with platforms to showcase their talents on a global stage, garnering more attention and inspiring young athletes. (Felton & King, 2017)

Women's bowling has gained more recognition in recent years, especially with the rise of competitive leagues and international tournaments. These platforms allow bowlers to showcase their talents on a global stage, attracting more fans and inspiring young girls to take up the sport. Despite the progress, there is still a need for continued investment in women's cricket to ensure that bowlers receive the support necessary for their development. Overall, bowling in women's cricket is marked by diverse styles and significant achievements. (Butts at al., 2023)

Despite the progress, challenges remain, particularly regarding equal access to training resources and funding. Continued investment in women's cricket is crucial to ensuring that bowlers receive the necessary support for their development. As the sport continues to grow, the contributions of female bowlers will play a pivotal role in brightening the future of women's cricket. (Butts at al., 2023)

Anthropometry

Anthropometry in cricket refers to the study of human body measurements and proportions, which can significantly influence performance, particularly in bowling and batting. Understanding anthropometric factors helps coaches and players optimize physical attributes to enhance athletic performance. (Norton & Olds, 1996)

Here’s an overview of the key aspects of anthropometry in cricket:

1. **Height**: Taller bowlers often have advantages in terms of ball release velocity and bounce, allowing them to deliver the ball at a steeper angle. (Lyons et al., 2023)

2. **Arm Length**: Longer arms can facilitate a greater bowling arc, potentially increasing the velocity and trajectory of the ball. This is particularly important for fast bowlers, as a longer lever can lead to higher release speeds. (Glazier et al., 2000; Lyons et al., 2023)

3. **Leg Length**: The ratio of leg length to height can affect a bowler's run-up and stride length. Optimal leg length can enhance acceleration and stability during the delivery stride, impacting overall bowling performance. (Sankar, 2011)

4. **Body Composition**: The ratio of lean muscle mass to body fat influences a player's strength, speed, and endurance. Bowlers with a higher proportion of lean muscle may generate more power and speed in their deliveries. (November & Leach, 2016)

Application of Anthropometry in Cricket

1. **Player Selection**: Coaches often use anthropometric measurements to identify players with physical attributes that align with specific roles, such as fast bowlers or spinners. (Stuelcken et al., 2007)

2. **Training Programs**: Customized training regimens can be developed based on a player’s anthropometric profile. For instance, taller bowlers may focus more on developing core stability and leg strength, while shorter bowlers may emphasize speed and agility. (Weldon et al., 2021)

3. **Injury Prevention**: Recognizing the relationship between body dimensions and movement patterns can help in designing injury prevention programs. Tailoring exercises to improve strength and flexibility based on anthropometric measurements can reduce the risk of injuries. (Sharma & Kailashiya, 2017)

4. **Performance Analysis**: By analysing the anthropometric data of successful players, coaches can establish benchmarks for aspiring athletes. This data can guide young players in developing their physical attributes to match those of top performers in the sport. (Cullen et al., 2022)

Kinematics

Kinematics in cricket, particularly in the area of cricket bowling, involves the study of motion without considering the forces that cause it. It focuses on understanding how bowlers move their bodies and the ball during delivery, analysing factors such as displacement, velocity, and acceleration. (Hamill & Knutzen, 2015)

Here's an overview of the key aspects of kinematics as they relate to cricket bowling:

1. **Displacement**: This refers to the change in position of the bowler from their starting point (the run-up) to the point of release. A bowler's run-up length and angle can influence their overall displacement and contribute to their bowling effectiveness. (Bartlett et al., 1996)

2. **Velocity**: In bowling, velocity can be divided into two types: linear velocity and angular velocity. Linear velocity refers to the speed at which the bowler moves towards the crease, while angular velocity pertains to the speed of the arm's rotation during the delivery. High release velocities can enhance the

difficulty for batsmen, making it crucial for fast bowlers to optimize both types of velocity. (Middleton et al., 2015)

3. **Acceleration**: This is the rate of change of velocity and is significant during a bowler's delivery stride. A bowler accelerates as they approach the crease, achieving maximum velocity at the point of release. Proper acceleration techniques can lead to more effective deliveries. (Bailey et al., 2023)

4. **Projectile Motion**: Once the ball is released, it follows a projectile motion path, influenced by gravity and air resistance. Understanding the principles of projectile motion helps bowlers to strategize their deliveries, as factors like angle of release and initial velocity determine how the ball behaves in the air and upon landing. (Coutis, 1998)

5. **Segmental Joint Angles:** Segmental joint angles refer to the specific angles formed at the joints connecting individual body segments—such as the knee, hip, ankle, shoulder, and elbow—during movement. In cricket pace bowling, these joint angles are critical in determining how efficiently the bowler generates, controls, and transfers force throughout the delivery stride. (Cochrane et al., 2013; Ghosh & Mondal, 2024; Felton et al., 2023)

6. **Flexion and Extension:** Flexion refers to the bending movement that decreases the angle between two body parts—like bending the knee or elbow—while extension refers to the straightening movement that increases that angle. During the bowling action, coordinated flexion and extension of joints help generate and transfer force effectively. (Jessop & Pain, 2016)

Application of Kinematics in Bowling

- **Technique Analysis**: Coaches often analyse a bowler's technique using kinematic principles to identify areas for improvement. Video analysis can capture a bowler's motion, allowing for detailed assessments of their run-up, delivery stride, and follow-through. (Paswan, 2020)

- **Performance Optimization**: By understanding the kinematics involved in bowling, athletes can refine their techniques to achieve higher release velocities and better accuracy. This includes adjusting their run-up length, arm angle, and body positioning during the delivery. (Paswan, 2020)

- **Injury Prevention**: Kinematic analysis can also play a crucial role in injury prevention. By ensuring that bowlers maintain proper mechanics throughout their delivery, coaches can help minimize the risk of injuries related to overuse or improper form. (Arumugam et al., 2023)

Physical Fitness

Physical fitness is crucial for cricket players, influencing their performance, endurance, and overall ability to compete effectively. In cricket, the demands on players vary by role, such as batting, bowling, or fielding, but certain aspects of fitness are universally important. (Caspersen et al., 1985)

Here's an overview of the key components of physical fitness in cricket:

1. **Endurance**: Cricket matches can last several hours, requiring players to maintain a high level of physical exertion over extended periods. Aerobic endurance helps players sustain their energy levels, especially in longer

formats like Test matches. Conditioning drills, long-distance running, and interval training can enhance this aspect. (Logeswaran et al., 2022)

2. **Strength**: Both upper and lower body strength are vital for cricketers. Bowlers require strong legs and core muscles to generate power during their delivery, while batsmen benefit from upper body strength to hit the ball effectively. Weight training, resistance exercises, and plyometric workouts are commonly used to build strength. (Sarmah et al., 2025)

3. **Speed and Agility**: Quick reflexes and the ability to change direction rapidly are essential, particularly for fielders and batsmen. Speed training, agility drills, and sprint intervals help improve these attributes, allowing players to respond effectively in dynamic situations. (Dhapola, 2017; Ashraf et al., 2019; Rehman & Sivakumar, 2021)

4. **Flexibility**: Flexibility aids in injury prevention and enhances overall performance. It allows players to execute a full range of motion, which is particularly important for bowlers to achieve optimal bowling techniques and for batsmen to play shots effectively. Stretching routines and yoga can be beneficial in improving flexibility. (Sisodia & Bagchi, 2017).

5. **Coordination and Balance**: Effective coordination and balance are critical for all cricket players. Batsmen need good hand-eye coordination for accurate shot-making, while bowlers must maintain balance during their delivery stride. Drills that focus on balance, such as stability exercises and coordination routines, can enhance these skills. (Mayengbam & Rajashekaran, 2024; Daniel & Senthil, 2024)

6. **Core Stability**: A strong core is essential for generating power and maintaining stability during bowling and batting. Core exercises, such as planks, medicine ball workouts, and rotational movements, help strengthen the muscles that support the spine and pelvis, which is crucial for injury prevention. (Anand et al., 2017).

Application of Physical Fitness in Cricket

1. **Training Regimens**: Customized fitness programs are often developed based on individual player needs, considering their roles and physical attributes. Coaches may use fitness assessments to tailor training routines that improve specific fitness components. (Wagh et al., 2022)

2. **Injury Prevention**: Maintaining physical fitness can help reduce the risk of injuries common in cricket, such as strains and sprains. A balanced fitness program that incorporates strength, flexibility, and conditioning is vital for keeping players healthy throughout the season. (Pote & Christie, 2018)

3. **Performance Analysis**: Monitoring physical fitness can provide valuable insights into a player's performance. Fitness metrics can be tracked to identify areas for improvement, enabling coaches to make informed decisions regarding training and player selection. (Herridge et al., 2020; Petersen, 2010; Wagh et al., 2022)

Cricket is the very passionate game in the present time and women are in the developing stage in this game. Felton, P. J. & King M. A. (2017) suggested the coaches to be aware during coaching, as the gender difference exists in kinematic variables among the pace bowlers. The training method of women should not be same as men because there are anatomical and physiological differences between them.

Everything a coach do with a male cricketer for improving his performance, may not be applicable for a female cricketer or may need to do something else which is not required for a male cricketer. Here is the scope of research and research findings only can help here scientifically.

A large number of research has been executed on men cricket. But women cricket is lacking it till the time. As ball release speed is a crucial component of pace bowling, it was the center point of research by the few researchers. Lyons, C. et al. (2023) concluded that increased height and larger bowling shoulder angles at ball release helps to increase ball release speed. In another study, Bailey, D., et al., (2023) suggested that maximum run-up velocity during delivery stride, is a key factor associated with ball velocity in elite female pace bowlers. Till, these findings are not sufficient for such a royal game. More researches on women cricket bowling under different type of parameters are needed to draw a concrete conclusion about women cricket bowling. That is why the present researcher felt the necessity of working of women cricket. As ball release velocity is a critical aspect of bowling in cricket, significantly impacting a bowler's effectiveness and the overall dynamics of the game, the present researcher wanted to investigate the factors affecting ball release velocity in the bowling of women cricket.

1.2. Statement of the Problem:

In the present study, the researcher's intention was to find out the factors determining the ball release velocity in women cricket bowling, which includes anthropometric factors, kinematic factors and physical fitness factors. Thus, considering the above concept of thought, the present researcher has entitled his Ph.D. thesis as "FACTORS DETERMINING BALL RELEASE VELOCITY OF WOMEN PACE BOWLERS IN CRICKET".

1.3. Objectives of the Problem:

i. To examine the relationship of selected anthropometric variables namely, upper arm length (acromiale-radiale), forearm length (radiale-stylion radiale), hand length (midstylion-dactylion), arm span, upper leg length (trochanterion-tibiale laterale), lower leg length (tibiale laterale), foot length and standing reach height with ball release velocity of women pace bowlers in cricket.

ii. To explore the relationships of selected kinematic parameters i.e. Run up length, final run-up velocity, bound height, final stride length, ball release height, ball release angle, angle of segmental joints at front foot contact (ankle, knee, hip, shoulder), angle of segmental joints at ball release (ankle, knee, hip, shoulder), flexion of segmental joints from front foot contact to ball release (ankle, knee, hip, shoulder) with ball release velocity of women pace bowlers in cricket.

iii. To analyse the relationships of selected physical fitness parameters like arm strength, back strength, leg strength, upper body power, lower body power, core stability, speed, flexibility with ball release velocity of women pace bowlers in cricket.

1.4.Delimitation:

i. The subjects for this research work were delimited to twelve right-handed women pace bowlers only.
ii. The age range of the subjects was delimited from 18 to 28 years.
iii. The standard of the subjects for this research work was delimited to state level only.
iv. The parameters of this research work were delimited to the selected anthropometric, kinematic and physical fitness parameters only.
v. The data was not collected during competition situations.

1.5.Limitation:

i. Non-availability of sufficient subject from the same level and age group was the main limitation of the study. Only twelve players were found.
ii. The video cameras, used for motion analysis were limited frame quality of 60 fps. Better camera quality with more frame rate capability could result more accurate analysis.
iii. Non-availability of advanced video analysis software was also the limitation of the study. Kinovea 0.9.5 video analysis software was used for analysing the video.
iv. Weather and non-availability of sophisticated instrument were the limitation of the study.
v. Motivation, arousal and other psychological parameters were not same for all subjects during test.

1.6. Hypothesis:

Based on a thorough review of relevant literature, previous research findings, expert opinions from the Research Advisory Committee (RAC), and the present researcher's own understanding of the problem, the following null hypotheses were formulated:

$H_0$1: There will be no significant influence of selected anthropometric parameters namely, upper arm length (acromiale-radiale), forearm length (radiale-stylion radiale), hand length (midstylion-dactylion), arm span, upper leg length (trochanterion-tibiale laterale), lower leg length (tibiale laterale), foot length and standing reach height on ball release velocity in women cricket bowling.

$H_0$2: There would be no significant influence of selected kinematic parameters i.e. Run up length, final run-up velocity, bound height, final stride length, ball release height, ball release angle, angle of segmental joints at front foot contact (ankle, knee, hip, shoulder), angle of segmental joints at ball release (ankle, knee, hip, shoulder), flexion of segmental joints from front foot contact to ball release (ankle, knee, hip, shoulder) on ball release velocity in women cricket bowling.

$H_0$3: There would be no significant influence of selected physical fitness parameters like arm strength, back strength, leg strength, upper body power, lower body power, core stability, speed, flexibility on ball release velocity in women cricket bowling.

1.7.Definition and Explanation of the Technical Terms:

i. Ball Release Velocity:

The speed of the ball at the moment it leaves the bowler's hand (Hanley, 2005).

ii. Final Run-Up Velocity:

The speed at which the bowler is moving horizontally during Pre-delivery stride (Glazier et al., 2000).

iii. Bound Height:

The vertical displacement of the bowler during the pre-delivery stride or bound phase. (Bull et al., 2024).

iv. Final Stride Length:

The distance between the back foot landing and front foot landing during delivery stride (Kiely et al., 2021).

v. Ball Release Height:

The vertical height of the ball from the ground at the time of release (Kiely et al., 2021).

vi. Ball Release Angle:

The downward angle at which the ball is released concerning the horizontal plane. (Manawadu et al., 2022).

vii. Front Foot Contact (FFC):

The moment when the bowler's front foot lands on the pitch at the delivery stride (Kiely et al., 2021).

viii. Ball Release (BR):

The instant when the ball leaves the bowler's hand at the time of the delivery (Kiely et al., 2021).

1.8. Significance of the Study:

The results of the study would help the field of physical education and sports in many ways. Some of the major influences would be as follows:

i. The result of the study will be helpful to thoroughly understand the biomechanical factors behind the selected technique in Women Cricket.
ii. The result of the study will provide the suggestions which could be helpful for rectifying the errors committed by the players during pace bowling in Women Cricket.
iii. The result of the study will be helpful to categorize women cricketers from very beginning stage.
iv. The result of the study will help to make prognosis of the beginners about their cricketing future.
v. The result of the study will be helpful to predict and to improve the higher performance for the basic level players.
vi. The result of the study will be helpful for modifying the training method for women pace bowlers.
vii. The result may be helpful for the prevention of injury of the pace bowlers.
viii. The result of the study will help to conduct more advanced research on the same field by taking better equipment and subject.

CHAPTER - II

2. REVIEW OF RELATED LITERATURE:

The researcher has gone through the related literatures available in the library, Department of Physical Education, Jadavpur University and various websites. The relevant studies found in the various sources, which the researcher has come across, have been cited below.

Bull, H. G., Alway, P., & King, M. A. (2024) have made research into the biomechanics of fast bowlers during the pre-delivery stride suggests that different kinematic factors significantly correlate with bowling performance. Authors of the study investigated the associations between the pre-delivery stride technique and ball release velocity. It was found that more vertical take-off angles during the pre-delivery stride were linked with slower run-up velocities. This is consistent with the biomechanical principle that faster run-up velocities are typically associated with more horizontal take-off angles, which in turn can contribute to higher ball speeds at release. The findings suggest that modifying take-off angles could be a strategy to optimize run-up velocity and, consequently, ball release speed. Moreover, a significant relationship between the downward landing velocity and thoracolumbar flexion was also identified in this study. The research revealed that faster landing velocities corresponded with reduced thoracolumbar flexion during the bowling action. This is particularly relevant since thoracolumbar flexion has been associated with spinal injuries and long-term wear and tear in fast bowlers. Interestingly, the study also observed an association between higher run-up velocities and greater front knee flexion at front foot contact. This finding implies that while a faster run-up may increase speed, it must be approached cautiously due to the mechanical strain it places on the bowler's body. This review of the literature thus suggests that optimizing the pre-delivery stride is a nuanced process, where variables such as take-off angles, landing velocities, and knee flexion must be carefully considered. Additionally, individual physical capacity and technique adjustments must be tailored to the specific needs of each bowler to ensure that biomechanical changes are beneficial without leading to unintended consequences.

Feros, S. A., Gerhardy, M. H., Fyfe, J. J., & Dwyer, D. B. (2024) had made research to examine the relationship between ball release speed and specific bowling kinematics in nineteen female pace bowlers. Each participant bowled eighteen ball in the match-intensity. From these, six deliveries that met the selection criteria were analyzed for peak ball release speed and all other kinematic data. The study found a linear relationship ($r^2 = 0.34$, $p = 0.048$) between the release speed of ball and orientation of pelvis at BFC and a non-linear relationship between ball release speed and thoraco-pelvic lateral flexion at front foot flat ($r^2 = 0.69$, $p < 0.001$). Faster bowlers tended to have a more side-on pelvis orientation at back foot contact and a more upright trunk posture at front foot flat when compared to their slower counterparts. The side-on direction of pelvis at back foot landing allows for greater angular momentum in the transverse plane for whole-body, which can contribute to faster ball release. Additionally, a more upright trunk at front foot flat suggests a delayed onset of trunk flexion, supporting better segmental sequencing for maximized ball release speed.

Bailey, D., Saw, A. E., Crowther, R. H., & Sims, K. (2023) have analysed in-match data from global positioning system (GPS) units and ball velocity measurements in elite female pace bowlers to determine whether run-up and delivery stride characteristics affect ball velocity. A total of 28 elite female pace bowlers were selected who participated in a T20 competition and 1,050 deliveries were analysed. GPS data, including gyroscope and accelerometer readings, were used alongside ball velocity data. Linear regressions were applied as statistical procedure. The results of the study highlight that ball release velocity in female pace bowlers is significantly influenced by various aspects of their run-up and delivery mechanics. Specifically, absolute ball velocity was found to be strongly linked with run-up distance, average and maximum run-up velocity, maximum velocity during the delivery stride, peak resultant acceleration, and peak roll—indicating the importance of both linear and rotational movements. Relative ball velocity showed a closer association with maximum run-up and delivery stride velocities, suggesting that speed relative to an individual's capacity is also crucial. Multivariate analysis further confirmed that the most reliable predictors of ball speed were maximum delivery stride velocity, peak acceleration, run-up distance, and peak roll. These findings suggest that female fast bowlers aiming to increase their bowling speed should prioritize developing greater velocity during the delivery stride phase. However, the study also emphasizes the importance of considering individual biomechanical and strength differences, to ensure that any technical adjustments or training interventions do not negatively impact the bowler's overall technique or increase injury risk.

Lyons, C., Felton, P., & McCabe, C. (2023) have explored the association between kinematic and anthropometric factors derived from male pace bowlers and ball release speed (BRS) in female pace bowlers. In this study involving eleven female pace bowlers, researchers examined how anthropometric and kinematic variables relate to Ball Release Speed (BRS). Using stepwise linear regression and Pearson correlation, they found that the bowling shoulder angle at ball release was the strongest predictor of BRS, explaining 89% of the variance. Among anthropometric factors, height emerged as the most significant, accounting for 53% of the variance. Additionally, run-up speed and arm length showed significant positive correlations with BRS. When height was controlled for, a straighter front knee angle at front foot contact was also linked to higher BRS. Interestingly, no significant relationship was found between trunk flexion and BRS, suggesting that female bowlers may use a combination of trunk flexion and rotation to generate speed. Overall, female bowlers with higher BRS tended to have faster run-ups, straighter front knees, and delayed arm movements—mechanics often observed in male pace bowlers.

Manawadu, K., Felton, P., Hiley, M., & King, M. (2022) had conducted a study which aimed to examine the differences in ball release parameters across various pitch-length deliveries in cricket fast bowling. Data was collected from 21 male fast bowlers, who collectively performed 707 fast bowling trials, including bouncers, yorkers, and stock deliveries. Analysis revealed that the ball release angle varied significantly ($p < 0.05$) among all three types of deliveries (bouncer, yorker and stock). Additionally, bouncer deliveries had significantly distinct release speeds and heights ($p < 0.05$) relative to yorkers and stock balls. The findings also indicated that bowlers faced greater challenges in consistently executing yorker deliveries than bouncers and stock balls. These results offer valuable insights for coaching strategies and further research, particularly in exploring the biomechanical factors influencing the fast bowling of different lengths.

Sarkar, D. (2022) has made a comparison between rural and university-level male cricketers (medium fast bowlers) in context of anthropometric and physical fitness variables. Twenty participants (aged 15–25 years) were selected from Bongaon block and Guru Ghasidas Vishwavidyalaya using purposive sampling. Four anthropometric measurements (standing height, arm length, leg length, body weight) and five physical fitness tests (handgrip strength, leg strength, back strength, flexibility) were evaluated. The data was analyzed using SPSS (v-26.0), with an independent t-test for group comparison and Pearson correlation for relationships among variables. The results showed that rural bowlers had significantly greater flexibility and leg strength compared to university bowlers. Additionally, significant positive correlations were found between height and leg length, dominant handgrip strength with leg strength, and back strength, in relation to several anthropometric variables.

Epifano, D. J., Ryan, S., Clarke, A. C., & Middleton, K. J. (2021) have explored the fast-bowling delivery intensity in different conditions. In this study, a group of fifteen competitive male fast bowlers below elite level delivered balls at three intensities: warm-up phase, match-intensity phase, and maximal-effort phase. A principal component analysis identified perceived exertion and seven variables related to bowling exertion for further analysis. These variables were derived from inertial measurement units mounted on the trunk and tibia. Repeated measures ANOVAs revealed significant effects of intensity on all outcome variables, with large effect sizes. Both maximal and match intensity measures were significantly higher than those recorded during the warm-up, but no significant differences were found between maximal and match intensities. This suggests that inertial measurement units effectively distinguish between warm-up and higher intensity efforts, providing a unique and efficient method to quantify fast bowling exertion in cricket.

Joshi, G., Singh, A., & Sathe, A. (2021). worked on a research paper which aimed at understanding how different bowling surfaces, specifically natural turf and concrete, affect the bowling speed of forty-one asymptomatic cricket pace bowlers with no reported injuries in the three months leading up to the study. Utilizing a cross-sectional design, the study included evaluations of the physical profiles of participants and assessments of bowling velocity measured using an SRA 3000 Tracer Precision Radar gun. Statistical analysis of the data, including mean values, standard deviations, and t-values, revealed that the speed of the ball decreases less after pitching on a concrete surface compared to natural turf. The findings indicate that Post-pitch velocity exhibits a slight elevation on concrete, and the velocity differential between the release and bounce points is minimized. The study concludes with potential applications of these findings, such as enhancing bat swing judgment based on ball speed, the possibility of substituting a tennis cricket ball for practice time to replicate speed conditions, and emphasizing the importance of protective gear in training.

Kiely, N., Pickering Rodriguez, L., Watsford, M., Reddin, T., Hardy, S., & Duffield, R. (2021) conducted a research work to explored the relationships among ball speed, bowling technique and physical capacity of the cricket fast bowlers. Several technical factors were significantly correlated with ball speed, including shorter bowling action duration, faster run-up velocity, and reduced back foot contact (BFC) time. Additionally, shorter durations from front foot contact (FFC) to ball release (BR), increased acceleration during the delivery stride phase, and shorter delivery stride duration were linked with higher ball speeds. Time to peak horizontal braking force, peak pelvis center of mass (COM) velocity from BFC to BR, and peak vertical ground reaction force (GRF) time were also associated with ball speed. Physical capacities such as 10-30 m split time, 30 m sprint, and isometric mid-thigh pull (IMTP) strength showed significant correlations with ball speed as well. A stepwise regression analysis revealed that bowling action 10-30 m split time and duration together explained 54% of the variation in ball speed. The results suggest that faster run-ups, reduced BFC times, and more rapid GRF application during FFC are critical for increasing ball speed. Additionally, authors suggested that sprint speed and lower-body strength are important modifiable factors that coaches should focus on for improving fast-bowling performance.

Manna, C., & Thander, A. (2021) have prepared a study to compare the immediate effects of Suryanamaskar and dynamic stretching on the motor performance of club-level cricket players. This study involved thirty club-level cricket players, who underwent training interventions consisting of 10 minutes of Suryanamaskar and a dynamic stretching routine. The dynamic protocol included a sequence of progressive exercises performed over a 20-meter distance with jog recovery, as recommended by Young (2007). Baseline data were collected without any warm-up, followed by immediate testing after the completion of each warm-up protocol. The motor performance parameters assessed included speed, upper-body and shoulder muscular endurance, core stability, balance, static strength, agility, and explosive leg power. A paired t-test was used for statistical analysis, with the significance level set at $p < 0.05$. The findings revealed that both Suryanamaskar and dynamic stretching significantly enhanced motor performance when compared to the no warm-up condition. Notable improvements were observed in sprint speed, agility, upper-body and shoulder strength endurance, core stability, balance, and vertical jump height. These were evidenced by faster sprint and agility test times, higher push-up counts within a minute, longer prone hold durations, and greater vertical jump distances. However, no statistically significant differences were found between the two warm-up protocols. The study concluded that both Suryanamaskar and dynamic stretching are equally effective warm-up strategies and have a positive impact on motor performance and bowling accuracy in club-level cricketers.

Biswas, A. and Ghosh, A. K. (2020) conducted a study aiming to explore the anthropometric characteristics and somatotype profiles of cricketers based on their roles, such as bowlers, batsmen, and all-rounders. The study evaluated 60 male district-level cricketers from West Bengal (average age 17.58 ± 2.09 years), focusing on 13 anthropometric parameters, including somatotype profiling. The results highlighted that, bowlers had greater height and arm span, physical traits that provide a biomechanical advantage in bowling performance. Somatotype analysis classified batsmen, bowlers, and all-rounders with close values: batsmen (2.8-3.9-3.3), bowlers (2.8-3.8-3.4), and all-rounders (2.9-3.8-3.5), all falling under the meso-ectomorphic category, with a mean somatotype of 2.8-3.8-3.4. This indicates a physique that emphasizes muscularity (mesomorphy) followed by linearity (ectomorphy) across all player types. The study concludes that district-level cricketers in West Bengal commonly exhibit a meso-ectomorphic build, which may contribute positively to their performance across different cricketing roles.

Paswan, C. K. (2020) had made a biomechanical analysis of selected kinematic variables in release phase of medium pace cricket bowler. This study aimed to analyze the biomechanical aspects of the release phase in medium pace bowling, focusing on factors affecting accuracy. Thirty medium pace bowlers from cricket academies in Gwalior, Madhya Pradesh, were selected using purposive sampling. The Richard Aldworth Stretch Pace Bowling Test was employed to evaluate the bowlers' accuracy, and videography was used to record the process. The data was analyzed using Structural Equation Modeling with SPSS AMOS 23 software. The findings indicated that the angles of the right shoulder (0.048), right hip (0.001), and left wrist (0.007) accounted for 49% of the variance in predicting the center of gravity during the release phase. Additionally, the angles of the right ankle (0.023), right elbow (0.010), and left ankle (0.036) explained about 42% of the variance in bowling accuracy. These results highlight the significant impact of these biomechanical variables on pace bowling accuracy in cricket.

Callaghan, S. J., Lockie, R. G., Andrews, W. A., Yu, W., Chipchase, R. F., & Nimphius, S. (2019) have gone through the research to examine the impact of an eight-over spell on pace bowling. This study aimed to evaluate the impact of an extended eight-over spell on the biomechanics and performance of pace bowling at different delivery lengths. The research involved nine male fast bowlers (mean age 18.8 ± 1.7 years) who bowled continuously while targeting short, good, and full lengths ranging from 0–10 meters from the batter's stumps. Researchers assessed several biomechanical and performance factors, including trunk, knee, and shoulder kinematics, ground reaction forces at front foot contact (FFC), run-up velocity, and ball release speed (BRS). Advanced statistical tools such as paired t-tests, Hedges' g effect sizes, and statistical parametric mapping were employed to compare performance in the first and final three overs of the spell. The findings revealed no statistically significant changes ($p = 0.05–0.98$) in any measured variable across the spell, and effect sizes ranged from trivial to moderate ($g = 0.00–0.73$). This suggests that fast bowlers are capable of sustaining both their ball speed and biomechanical technique despite the accumulated physical demand of an extended spell. The study concludes that current load monitoring and management strategies in pace bowling are effective, allowing bowlers to maintain performance consistency and reduce the risk of biomechanical breakdown across longer spells.

Desai, P., Yeole, U., Waghmare, A., & Andhare, N. (2019) worked for study which focused on the high risk of shoulder injuries among fast cricket bowlers, attributed to factors such as shoulder distraction forces, abnormal postural adaptivity, improper techniques, and unbalanced physical demands during the bowling action. The aim was to assess shoulder functional disability, shoulder girdle muscle strength, and arm rotation speed using the Shoulder Pain and Disability Index (SPADI), a sphygmomanometer, and a tachometer, respectively. A total of 70 fast bowlers participated in the study. The SPADI score (69.72 ± 12.869) indicated high levels of pain and disability. The muscle strength evaluation showed mean values of 103.85 ± 8.052 for internal rotators, 104 ± 11.869 for external rotators, and 88 ± 8.823 for scapular retractors. Arm rotation speed was recorded at 199.4 ± 13.608. The results suggested that reduced shoulder girdle muscle strength negatively impacts the performance of fast bowlers, potentially contributing to a higher risk of injury.

Feros, S. A., Young, W. B., & O'Brien, B. J. (2019) have prepared a research paper which aimed to explore these interconnections between pace bowling kinematics, pace bowling skill and physical capacities. The study investigated the relationship between physical capacities, bowling kinematics, and performance in 31 male club-level pace bowlers over three test sessions held 4–7 days apart. The first session featured an 8-over pace bowling assessment measuring ball release speed, accuracy, and kinematic variables, while the second and third sessions focused on physical performance tests. The analysis revealed that both peak and mean ball release (BR) speeds were positively associated with upper-body strength, particularly 1-repetition maximum pull-up strength ($r = 0.56$, $p = 0.005$), and negatively correlated with 20-meter sprint times—indicating that faster sprinters tended to bowl faster. In terms of accuracy, mean radial error (a measure of precision) was linked with sprint speed, height, and power output from countermovement jumps (CMJs). Specifically, bowlers who were faster and more explosive (higher peak power from CMJs) demonstrated better accuracy. Additionally, bivariate variable error (a consistency measure) was associated with the front-leg extension angle at ball release and approach speed, suggesting that technique during delivery plays a crucial role in consistency. Overall, the findings emphasize that upper-body strength, sprint speed, explosive lower-body power, and front-leg mechanics all significantly contribute to bowling speed and accuracy. These insights can assist strength and conditioning coaches in designing targeted training programs to optimize performance in pace bowlers.

Thander, A., & Prasad, S. S. (2019) have written a research paper aiming to explore whether there is a significant relationship between ball release velocity and various kinematic factors in U-19 pace bowlers delivering their fastest balls. This study focused on analyzing the kinematic factors influencing ball release velocity in ten junior male pace bowlers (mean age: 18.1 ± 0.94 years) from Ghazipur, Uttar Pradesh. All participants were injury-free and were recorded bowling on a standard outdoor turf pitch (20.12 meters) with adequate run-up space. The researchers used four high-definition video cameras (recording at 50 Hz and 60 fps) placed strategically in both sagittal and frontal planes to capture the bowlers' actions. Motion data were processed using Kinovea 8.24, and statistical correlations were calculated using Pearson's Product Moment method in IBM-SPSS 20. The results showed that ball release velocity (BRV) had a significant positive correlation with shoulder angle at ball release (r = 0.638), meaning that a more optimal shoulder position contributed to higher bowling speeds. In contrast, run-up velocity (r = -0.747) and trunk lateral flexion (r = -0.666) had significant negative correlations with BRV. These findings suggest that excessive speed during the run-up and excessive lateral bending of the trunk might reduce effective energy transfer, negatively impacting the speed of delivery. In conclusion, the study emphasizes that technical adjustments in shoulder positioning, controlled run-up velocity, and minimizing trunk lateral flexion can enhance ball speed in junior pace bowlers, offering valuable insight for coaches working with developing athletes.

Govindasamy, K., Thangamuthu, P., Anitha, J., Lakshmanan, C., & Marithangam, M. (2018) have analyzed the anthropometric characteristics of fast and spin bowlers in cricket academies affiliated with the Tamil Nadu Cricket Association. A total of 30 players from the YMCA Cricket Academy in Chennai, aged 16 to 23 years, participated. The subjects were randomly divided into two groups: Spin Bowler Group (15 players) and Fast Bowler Group (15 players). Anthropometric measurements taken included height, weight, arm girth (relaxed and flexed), waist girth, and calf girth. The data was analyzed using an independent t-test via SPSS software, with a significance level set at 0.05. The findings revealed that there were no significant differences between the two groups in arm girth (both relaxed and flexed) and calf girth. However, significant differences were observed in height, weight, and waist girth between the spin bowlers and fast bowlers. This suggests that while arm and calf size may not distinguish between these types of bowlers, overall body size (height, weight) and waist girth are more influential factors in differentiating fast bowlers from spin bowlers.

Anand, P. C., Khanna, G. L., Chorsiya, V., & Geomon, T. (2017) have worked together to investigate the relationship between core stability and bowling speed in medium and medium-fast cricket bowlers. This study explored the relationship between core stability and bowling speed in 82 asymptomatic fast bowlers, aiming to determine whether a stronger core correlates with improved performance. Core stability was evaluated using the plank test, a reliable measure of muscular endurance and control in the trunk region. Bowling speed was measured using a radar speed gun. The participants had a mean age of 19.9±1.86 years, average height of 172.47±6.2 cm, weight of 65.83±8.75 kg, and BMI of 22.16±2.44 kg/m². On average, participants held the plank for 256.27±82.00 seconds, while their mean bowling speed was 109.43±7.04 km/h. Statistical analysis revealed a strong positive correlation between plank time and bowling speed ($r = 0.736$, $p < 0.0001$). This suggests that bowlers with greater core stability were able to generate and sustain higher ball velocities. The findings highlight the importance of the core in maintaining trunk control over the pelvis and legs—critical for the efficient transfer and control of force throughout the bowling action. The study concludes that core strength and stability are key components in enhancing bowling performance, and players with well-developed core muscles demonstrated significantly higher bowling speeds than those with lower core stability.

Anand, P. C., Khanna, G. L., Chorsiya, V., & Rana, A. (2017) have worked in another study to investigate the relationship of the shoulder strength with the speed of the ball in Cricket bowling. This study investigated the relationship between shoulder strength and bowling speed among 82 male cricket bowlers from various academies. Participants had an average age of 19.9 years, a mean BMI of 22.15 kg/m², and an average bowling speed of 109.42 km/h. Shoulder strength was assessed across multiple movements, including internal and external rotation, abduction, adduction, flexion, and extension. The results revealed strong positive correlations between bowling speed and internal rotation strength ($r = 0.59$), external rotation strength ($r = 0.59$), adduction ($r = 0.60$), and abduction ($r = 0.56$). Moderate correlations were also observed with flexion (r = 0.48) and extension strength (r = 0.46). These findings suggest that bowlers with stronger shoulder muscles—particularly those involved in rotational movements—tend to bowl at higher speeds. Therefore, developing shoulder strength through targeted training can be a crucial component in enhancing bowling performance in cricket.

Felton, P. J. & King M. A. (2017) have presented their research findings in 26th Congress of the International Society of Biomechanics at Brisbane, Australia. This study analyzed gender-based differences in the kinematic characteristics of fast bowling by examining twenty elite fast bowlers, consisting of both female and male athletes. The female bowlers had an average age of 19.8 years, average body mass of 64.48 kg, and height of 1.67 m, while the male bowlers averaged 20.1 years in age, 81.5 kg in mass, and 1.88 m in height. Data were collected at the ECB National Cricket Performance Centre using a high-precision Vicon MX motion analysis system with 18 cameras operating at 300 Hz. Bowlers delivered six stock balls on a standard artificial wicket indoors, using their regular run-up. A total of 47 reflective markers were used to track body motion, along with an additional marker on the ball to assess ball speed. Data processing included filtering marker trajectories with a fourth-order Butterworth filter. The three best deliveries for each bowler were averaged, and 14 key kinematic parameters linked to ball release speed were extracted. Statistical analysis using Independent Samples t-tests revealed that some of these parameters showed significant gender differences, indicating that men and women may exhibit distinct biomechanical patterns in fast bowling. These insights may help in tailoring coaching strategies and performance optimization based on sex-specific biomechanics.

Sisodia, A. & Bagchi, (2017) have conducted a research work to examine the relationship between flexibility and ball velocity in cricket fast bowling. Sixty male cricket players aged 17 to 25 from universities in Goa, Maharashtra, and Karnataka participated in the study, with five not completing all test items. The ball's velocity was the dependent variable, while the flexibility of various body parts served as independent variables. Flexibility was measured using a yardstick and rural guide for ankle and shoulder flexibility, a modified sit-and-reach test for hip flexibility, a bridge-up test for spine flexibility, and a goniometer for wrist flexibility. Ball velocity was calculated by dividing the distance (17 meters) by the time taken for the ball to cover that distance. A correlational design was used, and Pearson's Product Moment Correlation was employed to determine the relationship between flexibility and ball velocity. Results showed significant positive correlations between spine flexibility ($r = 0.726$) and wrist flexibility ($r = 0.726$) with ball velocity, indicating that increased flexibility in these areas is associated with higher bowling speeds. However, there was no significant correlation between ball velocity and flexibility in the shoulder ($r = 0.236$), hip ($r = 0.015$), or ankle ($r = 0.099$). The study concludes that enhancing spine and wrist flexibility can positively influence fast bowling speed, while shoulder, hip, and ankle flexibility have less impact.

Thandar, A. and Khan, M. (2017) have investigated to examine the impact of front foot placement on the bowling action during the delivery stride in cricket. In this study, four inter-university level pace bowlers (age: 22.25 ± 0.47 years) were analyzed to examine how front foot placement affects bowling action. Using a two-dimensional motion analysis system, each bowler was fitted with 14 reflective markers and asked to deliver six balls aimed at a good length. A high-speed camera captured their movements, and shoulder alignment was used to categorize their bowling techniques. The angle and position of the front foot were measured during three critical phases: back foot contact, delivery stride, and ball release. The data, assessed through descriptive statistics and graphical representation, revealed that at the moment of back foot contact, the bowlers' front foot tended to land slightly towards the on-side. However, as the delivery stride progressed, there was a noticeable shift—on average, about 11.54 cm—towards the off-side. This change in foot placement increased the bowlers' front-on alignment, which led to greater shoulder-hip counter-rotation. As a result, the bowlers adopted a "mixed" action, a hybrid technique that can increase the risk of injury due to the added strain on the spine and shoulders. These findings highlight the biomechanical influence of foot positioning on bowling technique and potential implications for injury prevention and coaching.

Felton, P. J., & King, M. A. (2016) have published a research paper where they examined the influence of elbow hyperextension on ball speed in fast bowling, using a two-segment planar simulation model tailored to an elite fast bowler. The simulations successfully mirrored three actual performances, with a further performance used to validate the model. The findings indicated that elbow hyperextension led to a 4% increase in ball speed compared to a straight-arm model. The study concluded that maximizing ball speed is dependent on two key factors: the degree of peak elbow hyperextension and the extent to which the elbow recoils toward a straight position after reaching maximum hyperextension.

Goswami, S., Srivastava, V. K., & Rajpoot, Y. S. (2016) have tried to explore the relationship between ball velocity and hand grip strength in male off-spin cricket bowlers. The study involved 30 off-spin bowlers with an average age of 19.80 years and an average of 3.66 years of cricket-playing experience. The primary objective was to explore the relationship between hand grip strength and ball velocity. Ball velocity was calculated based on the time taken by the ball to travel a distance of 18.90 meters, while the maximum grip strength of the dominant hand was measured using a hand dynamometer. Anthropometric data such as body height, body mass, arm length, and palm length were also recorded for each participant. The findings showed a statistically significant correlation ($p < 0.05$) between hand grip strength and ball release velocity, highlighting that stronger grip strength contributes positively to higher ball speeds. This suggests that for young off-spin bowlers, enhancing hand grip strength could be a key factor in improving bowling performance.

Felton, P. J. (2015) has submitted a doctoral thesis which focused on the evaluation of a torque-driven simulation model designed to replicate the front foot contact phase in fast bowling. In this doctoral thesis, the researcher developed and evaluated a torque-driven simulation model focused on replicating the front foot contact (FFC) phase in fast bowling. The model was designed using torque profiles for various joints critical to bowling mechanics, including the front metatarsophalangeal (MTP) joint, ankle, knee, hips, shoulders, as well as the elbow and wrist of the bowling arm. To enhance accuracy, angle-time data for the back leg joints and the non-bowling arm elbow were also incorporated. The orientation of the trunk played a vital role in guiding the model, particularly in managing the orientation of massless segments and adjusting variable segment lengths. A genetic algorithm was used to optimize multiple components—such as torque activation timings, specific joint parameters (especially at the front MTP and bowling elbow), and initial setup conditions. The objective was to minimize the difference between simulated and actual recorded bowling movements. The outcomes showed that the simulated motion closely aligned with real-life data, confirming the model's high accuracy and effectiveness. This validated the simulation as a reliable tool for analyzing the biomechanics of fast bowling, particularly during the FFC phase.

Feros, S. A. (2015) have shown the determinants and development of the performance of bowling in Cricket in his doctoral theses. This study highlights the nuanced impact of using heavy-ball warm-ups in pace bowling. Initially, incorporating a heavier ball can temporarily impair bowling performance, most likely due to a disturbance in the natural segmental sequencing that is key to effective and efficient bowling mechanics. However, with regular practice and adaptation over time, bowlers can adjust to the altered load, leading to performance improvements. To avoid abrupt disruption, a gradual progression from heavy-ball to standard-ball deliveries within a training session is advised. Over the course of an eight-week structured and evidence-based training regimen involving heavy-ball drills, bowlers generally show modest increases in both peak and average bowling speeds. However, this increase in speed may come with a slight compromise in accuracy. Therefore, coaches and trainers must strike a balance—ensuring that while speed gains are encouraged, accuracy is not significantly diminished during the training process.

Singh, K., & Singh, R. (2015) published a research paper where they investigated the relationship between selected anthropometric variables and the velocity of the ball in pace bowlers within cricket. This study explored how certain anthropometric characteristics relate to ball velocity among 15 pace bowlers from Guru Ghasidas Vishwavidyalaya, Bilaspur. Using Pearson's Product Moment Correlation, the researchers analyzed the association between ball speed and four physical attributes: height, weight, arm length, and arm girth. Data analysis, conducted using SPSS (version 16.0), revealed statistically significant positive correlations between ball velocity and both height ($r = 0.645$, $p < 0.05$) and arm length ($r = 0.719$, $p < 0.05$). These results suggest that taller bowlers with longer arms may be better equipped to generate higher bowling speeds. In contrast, no significant relationship was found between ball velocity and body weight or arm girth, indicating that these factors may not play a critical role in influencing speed. The study underscores the importance of height and arm length as beneficial anthropometric traits for fast bowlers aiming to improve their performance.

Bala, B. (2014). had conducted a doctoral research on 50 national-level junior male cricketers (aged under 16 and under 19) in West Bengal aimed to assess differences in physical fitness, anthropometric measures, and psychological factors across age groups and playing positions. The study evaluated fitness parameters such as strength, agility, aerobic capacity, and flexibility, along with anthropometric characteristics like body weight, height, and limb lengths. Psychological attributes, including mental toughness and sports motivation, were also analyzed. The findings suggest that while physical and psychological factors are integral to cricket performance, individualized training regimens tailored to specific positional demands can further optimize a player's abilities and reduce injury risks.

Ferdinands, R. E. D., Sinclair, P. J., Stuelcken, M. C., & Greene, A. (2014) have analyzed the kinematics and kinetics associated with the rear leg drive in fast bowling and to investigate the relationship between these variables and ball release speed. This study examined the biomechanical contributions of rear leg movement to wrist speed in fast bowling, involving 18 young fast bowlers from the Cricket New South Wales development squad (mean age: 17.2 ± 1.7 years). Using a high-precision Cortex 2.0 motion analysis system operating at 200 Hz, the researchers recorded detailed movement data during the bowling action. They employed bivariate Pearson's correlation via SPSS to explore relationships between wrist speed and several rear leg kinematic and kinetic variables. Key findings revealed statistically significant correlations between wrist speed and certain rear leg movements. Specifically, mean thigh extension angular velocity ($r = 0.606$, $p = 0.008$), thigh adduction angular velocity at back foot contact ($r = 0.515$, $p = 0.029$), and the maximum change in knee extension angular velocity ($r = 0.559$, $p = 0.016$) were positively associated with wrist speed. These results suggest that rear leg motion during the delivery stride plays a meaningful role in generating speed. Importantly, the study found that rear leg drive was not primarily the result of strong muscular effort or active torque generation. Instead, it appears to be influenced by more passive, controlled movement patterns, particularly involving hip and knee motion in multiple planes. This insight has practical implications for coaching, suggesting that developing efficient rear leg mechanics may involve refining timing and coordination more than brute strength.

Ghosh, J. and Chatterjee, S. (2014) have conducted a study on relationship of selected anthropometric variables to pace bowling in cricket. In this study, the researchers have selected 20 university level pace bowlers from the University of Burdwan, West Bengal, age ranging from 18 to 20. They have chosen the anthropometric variables of Leg Length, Arm Length, Foot length, Shoulder width and Wrist girth. They found that the length of arm and leg help a pace bowler to generate a greater amount of momentum as well as proper line and length.

Johnstone, J. A., Mitchell, A. C., Hughes, G., Watson, T., Ford, P. A., & Garrett, A. T. (2014) have prepared a review study on athletic profile of the fast bowlers in cricket. This review critically explores the expanding field of physiological research related to fast bowling in cricket, particularly focusing on findings from both controlled simulations and actual match scenarios. It aims to bridge the gap between academic insight and practical application for strength and conditioning professionals working with fast bowlers. The review highlights a lack of comprehensive and sport-specific resources currently available to practitioners, which limits their ability to design evidence-based training programs. It identifies limitations in previous research, especially concerning ecological validity, and underscores the need for studies that reflect the real-world physical demands of cricket, including workload variations across different game formats (Test, ODI, T20). With advancements in mobile technology and wearable monitoring systems, there is now an opportunity to conduct more relevant and long-term studies that capture in-match physiological data. These tools can help quantify workloads and better understand the stress placed on bowlers during competitive play. The review concludes by encouraging the integration of such technologies into future research, with the ultimate goal of improving injury prevention strategies and performance enhancement in fast bowling.

Spratford, W. et al. (2014) have done research to assess the effectiveness of using peak outward acceleration (POA) measured by an inertial sensor on the wrist to identify the ball release point in cricket bowling, a key factor when evaluating illegal actions. This study assessed the reliability of a wrist-worn sensor in measuring the point of ball release (POA) among 21 spin and fast bowlers from nine different countries during the ICC Under-19 Cricket World Cup. Bowlers executed standard deliveries while wearing the sensor, and the results were compared against a validated Motion Analysis Ball Release (MABR) protocol to evaluate accuracy. The findings revealed a very high correlation ($R^2 = 0.98$) between the POA captured by the sensor and the MABR data. Additionally, a Bland–Altman plot showed that all trials fell within acceptable agreement limits, reinforcing the validity of the sensor-based measurements. The study concluded that POA, as measured by the wrist sensor, is a reliable and accurate marker of ball release timing in cricket. Furthermore, the application of a simple regression equation can fine-tune this measurement, making it a practical and efficient alternative to more complex traditional biomechanical setups. This has significant implications for real-time performance monitoring and coaching in competitive cricket environments.

Crewe, H., Campbell, A., Elliott, B., & Alderson, J. (2013) have conducted a study aiming to examine how bowling technique. The study investigated how bowling technique and lumbar spine loading evolve over the course of an 8-over spell in adolescent fast bowlers, and examined which biomechanical factors might contribute to increased risk of low back injuries. A total of 40 adolescent bowlers participated, with their bowling actions analyzed using three-dimensional motion capture technology. Interestingly, the results revealed no significant changes in either bowling technique or lumbar loading across the duration of the spell, indicating that young fast bowlers are generally able to maintain consistent technique and physical output. However, specific kinematic factors were found to be linked to increased lumbar loading. These included a more extended front knee at delivery, higher ball release speeds, and greater shoulder counterrotation — all of which were significantly associated with increased lumbo-pelvic stress, particularly in the form of peak transverse rotation moments and anterior-posterior shear forces acting on the spine. These biomechanical patterns suggest that while technique might remain consistent across spells, certain movement characteristics can elevate stress on the lower back, potentially contributing to injury risk over time. The study highlights the importance of monitoring and managing these risk factors in adolescent bowlers. It also recommends future research to further explore the link between lumbar load, injury incidence, and other contributing factors, in order to better inform injury prevention strategies in fast bowling.

Worthington, P.J. et al. (2013) have made another experiment to identify the key technical aspects that distinguish the fastest cricket bowlers. This study analyzed kinematic data from 20 elite male fast bowlers to better understand the technical elements that influence ball release speed. The focus was on 11 biomechanical parameters previously identified as relevant to pace generation. Among these, four key variables emerged as the most significant predictors of ball release speed, collectively accounting for 74% of the variation in performance among the bowlers. The bowlers who achieved the highest ball speeds shared common technical traits: they executed a faster run-up, maintained a straighter front knee at front foot contact, demonstrated greater upper trunk flexion as they approached ball release, and delayed their arm circumduction (circular arm movement) during the delivery stride. These biomechanical features appear to play a crucial role in maximizing speed at the point of release. The findings have practical relevance for coaches and talent scouts, offering clear biomechanical markers that could be targeted in training programs to enhance performance, as well as used in the identification of potential fast bowling talent. The study emphasizes the importance of not only physical conditioning but also technical refinement to achieve elite-level bowling speeds.

Worthington, P. J., King, M. A., & Ranson, C. A. (2012) were found in a research paper to explore how the technique of the front leg influences peak ground reaction forces during the delivery stride of fast bowling. This research focused on the biomechanics of front foot contact in fast bowling, a critical phase linked to performance and injury risk. Using three-dimensional motion capture and force plate data, the study analyzed 20 elite male fast bowlers to evaluate how run-up speed and front leg technique influence ground reaction forces during the delivery stride. Eight key kinematic parameters were assessed, along with measurements of peak vertical and horizontal ground reaction forces and the time taken to reach those peak values. The results showed considerable variation among the bowlers. On average, bowlers experienced peak vertical forces equivalent to 6.7 times their body weight and horizontal braking forces around 4.5 times body weight. The time to reach peak force in both directions was approximately 0.03 seconds, suggesting an intense and rapid loading phase. Importantly, the orientation and mechanics of the front leg at the point of landing were found to significantly affect these forces. Bowlers who displayed a larger plant angle (more extended leg position) and a heel strike landing experienced lower peak forces and slightly longer durations to reach peak force. These technical characteristics could reduce the mechanical stress on the lumbar spine, potentially lowering the risk of developing lower back injuries. The study highlights the influence of front foot biomechanics on both performance and injury prevention, suggesting that technical modifications—such as promoting heel strike and optimizing leg orientation—may be beneficial for long-term fast bowling health and effectiveness.

Ferdinands, R. E. (2011) has analyzed the segmental kinetic energies for the cricket bowlers. This study investigated how the kinetic link principle operates in fast bowling, specifically how energy is transferred from the body's larger segments to the smaller ones to generate ball speed. Thirty-four fast bowlers, averaging just over 22 years old, were analyzed using 3D motion capture. They were divided into four speed categories: slow-medium, medium, medium-fast, and fast. The analysis showed that faster bowlers generally had greater segmental kinetic energy, although the fast group didn't show a significant energy increase compared to the medium-fast group.

Interestingly, while there were no clear differences in the sequencing of body segment movement across speed groups, all bowlers followed a consistent proximal-to-distal energy transfer pattern. This means energy was first generated in the trunk (torso), then transferred down through the arm to the hand and ball during the final acceleration phase. The findings suggest that regardless of a bowler's speed, effective energy transfer starting from the core and moving outward is a key component of fast bowling technique. This emphasizes the importance of core strength and trunk rotation in bowling performance and could help inform coaching strategies aimed at optimizing speed while maintaining safe biomechanics.

Hussain, I. et al. (2011) tried to explore whether cricket bowlers can enhance wrist and ball release speed through internal rotation of the upper arm, even while adhering to rules limiting elbow straightening during delivery. While a perfectly rigid arm is considered impractical, current regulations allow up to 15° of elbow extension. Using a two-link model of the bowling arm, the researchers analyzed how internal upper arm rotation affects wrist speed based on data from cricket and baseball. The results showed a significant increase in wrist speed through internal rotation, indicating that bowlers who maintain a fixed elbow position can still generate higher ball speeds by utilizing upper arm rotation.

Zhang, Y. Unka, J. and Liu, G. (2011) have prepared a research paper on Cricket Bowler's Joint Rotations and its effect on Ball Release Speed. This study aimed to investigate how upper body segmental rotations impact ball release speed in cricket fast bowling and whether forceful trunk flexion contributes to improved speed and accuracy. Using a Vicon motion capture system, eight male fast bowlers were analyzed under three different conditions: sub-maximal effort, maximal effort, and maximal effort with intentional trunk flexion. Results showed that ball release speed was highest during the condition involving trunk flexion, which followed a clear proximal-to-distal sequencing pattern—starting from the torso and moving outwards to the arm and hand. However, this increase in speed came with a slight reduction in accuracy, suggesting a trade-off between power and precision. Among all body segments, upper arm rotation contributed most significantly to ball speed, followed by torso and thoracic rotation, pelvic rotation, pelvic linear velocity, and lastly, the forearm and hand. These findings emphasize the critical role of upper body mechanics, particularly arm and torso rotation, in maximizing bowling performance. At the same time, they point to the need for controlled trunk movement to maintain accuracy.

Wormgoor, S., Harden, L., & Mckinon, W. (2010) conducted a research work to determine the Biomechanical, Anthropometric, and Isokinetic strength predictors for high ball release speeds in cricket fast bowlers. This study investigated the key physical and technical factors associated with ball release speed in 28 elite fast bowlers. Participants were evaluated for their anthropometric profiles and both concentric and eccentric isokinetic strength in important knee and shoulder muscle groups. To analyze bowling technique, six high-speed cameras and Ariel Performance Analysis System software were used to capture and examine their fastest and most accurate deliveries. The results highlighted several significant correlations between technical elements and ball release speed. Bowlers who demonstrated greater front leg knee extension at the moment of release were able to generate higher ball speeds, suggesting the importance of a firm front leg in transferring momentum. Additionally, those with greater shoulder rotation away from the batsman at front foot strike, a higher ankle position during the delivery stride, and stronger shoulder extension also delivered faster balls. Interestingly, while these individual variables were linked to ball speed, they could not be combined into a single predictive model. This contrasts with findings from studies on less experienced bowlers, implying that elite bowlers may use a variety of techniques to achieve high performance. In summary, the study emphasizes that specific technical and strength-related factors play a role in fast bowling success, but their influence may vary depending on the skill level of the bowler.

Wormgoor, S., Harden, L., & McKinon, W. (2008) had made a research work focusing on the key factors that contribute to high ball release speeds in senior cricket fast bowlers. This study examined 28 elite fast bowlers to determine which physical and technical factors influence ball release speed. Each bowler's morphology, isokinetic strength in the knees and shoulders, and bowling technique were assessed. High-speed cameras and motion analysis software captured and analyzed their fastest deliveries. The analysis revealed three key factors that significantly correlated with faster ball speeds: greater extension of the front leg at ball release, increased shoulder rotation away from the batsman at front foot strike, and stronger shoulder extensor muscles. Despite these strong individual correlations, the variables couldn't be integrated into a combined predictive model, indicating that performance patterns seen in elite bowlers may differ from those in less experienced players. This suggests that elite fast bowling technique is more individualized and complex, requiring nuanced assessment.

Stuelcken, M., Pyne, D., & Sinclair, P. (2007) made a research on Australian female and male cricket fast bowlers.. This study involved 52 fast bowlers—26 male and 26 female—and examined detailed anthropometric differences between the two groups. Measurements included height, weight, limb and segment lengths, breadths, girths, and skinfold thickness. Researchers also calculated derived values to evaluate fat distribution, relative body proportions, and body type classification (somatotype). Findings revealed that male bowlers were not only taller and heavier on average than female bowlers, but also had significantly greater limb lengths and overall body breadth and girth, indicating a generally larger and more muscular physique. In contrast, female bowlers showed higher levels of subcutaneous fat, as indicated by a significantly greater sum of skinfold measurements. Somatotype analysis further showed that female bowlers were more endomorphic (higher fat content) and less mesomorphic (less muscular) compared to their male counterparts. Notably, only male bowlers were found to possess body proportions that could be categorized as "large" relative to their height, highlighting a substantial difference in proportionality. These anthropometric differences are important as they may influence biomechanical efficiency, injury risk, and performance potential in fast bowling, and suggest that sex-specific training and conditioning approaches may be beneficial.

Pyne, D. B. et al. (2006) examined the relationships between anthropometric and isoinertial strength characteristics. This study compared physical and performance characteristics between two groups of male fast bowlers—24 senior first-class bowlers (average age 23.9 years) and 48 junior representative bowlers (average age 14.8 years)—to identify key predictors of peak bowling speed (Vpeak). The seniors bowled significantly faster on average (126.7 km/h) than the juniors (99.6 km/h), and they also exhibited superior physical traits, including higher muscle mass and better upper-body power as indicated by greater results in the bench press and deltoid throws. For junior bowlers, Vpeak was best predicted by a combination of static jump performance, upper-body strength (bench throw), body mass, muscle mass percentage, and height, with a very strong overall correlation ($r = 0.86$). In contrast, for senior bowlers, Vpeak showed the strongest associations with static jump and arm length (r = 0.74), highlighting the continued importance of lower-body explosiveness and limb dimensions at advanced levels. Interestingly, the one-legged countermovement jump was negatively correlated with Vpeak in both groups, suggesting that this particular movement may not translate effectively to bowling performance, or could reflect inefficient movement patterns. Overall, the study emphasizes the evolving physical demands as bowlers mature, where juniors benefit from general size and strength, while seniors rely more on refined lower-body power and biomechanical leverage.

Hanley, Brian & Lloyd, Ray & Bissas, Athanassios. (2005) conducted an investigation on male cricketers. In this study involving thirteen elite male fast bowlers—including international and county-level players—researchers used 3D motion capture and video analysis to explore how specific biomechanical variables relate to ball release speed. Out of 74 measured kinematic variables, five were found to significantly influence the velocity of ball release: run-up speed, trunk angular displacement, shoulder angular displacement, bowling arm angle at release, and foot alignment. The analysis revealed that faster run-ups, more extensive trunk and shoulder rotation, and a lower arm angle during release were all associated with higher delivery speeds. Furthermore, bowlers who avoided an overly “side-on” foot position at front foot contact were able to generate more trunk rotation, which in turn contributed to faster ball release. These findings suggest that by strategically improving these specific technical aspects—especially in the run-up and rotational mechanics—bowlers may enhance their performance. Importantly, the study highlights that these enhancements can be achieved without negatively affecting the overall efficiency or safety of the bowling action, offering valuable guidance for coaches aiming to fine-tune a bowler's technique.

Marshall, R. N., & Ferdinands, R. (2005) have prepared a review article on the elbow mechanism in cricket bowling. This article compared the biomechanics of the traditional straight-arm delivery with published analyses of bent-arm bowling, examining potential advantages and disadvantages in terms of ball speed, injury risk, and elbow joint kinetics. The data sources for this comparison included journal articles, a web page, and conference proceedings. Four articles focused on the kinematics of bent-arm bowling, while three papers provided data on the kinematics and/or kinetics of the bowling arm. Additionally, unpublished data on elbow kinetics in bowling were compared to findings on varus torques in throwing. The analysis revealed that varus and valgus torque on the elbow in straight-arm bowling are relatively low compared to throwing activities. However, the bent-arm technique allows bowlers to exploit upper-arm internal rotation, potentially increasing ball release speed. This, however, significantly raises varus stress on the elbow. As these torques are managed mainly by ligaments and capsular restraints, the risk of elbow injury is heightened. The study concludes that while the traditional straight-arm technique minimizes stress on the elbow, the bent-arm action, although legal, poses a greater risk of injury due to increased varus torques. This may necessitate additional restrictions on bowling frequency to mitigate the risk of elbow damage.

Petersen, C., Wilson, B., & Hopkins, W. (2004) investigated in a study, how training with overweight and underweight cricket balls affects fast-bowling speed and accuracy among senior club cricket bowlers. The participants were randomly divided into two groups: a traditional training group (n = 9), which used only regulation cricket balls weighing 156 grams, and a modified-implement training group (n = 7), which utilized a mix of overweight (ranging from 161 to 181 grams), underweight (ranging from 151 to 131 grams), and regulation balls. Both groups engaged in bowling training sessions three times per week for a duration of 10 weeks. Bowling speed was measured using a radar gun, recording 18 consecutive deliveries before, during, and after the training period. Additionally, video analysis was conducted to assess bowling accuracy by examining the first-bounce distance from the stumps. The initial mean bowling speed was recorded at 108 ± 5 km/h. Following the training, the modified-implement group experienced an average speed increase of 4.0 km/h, while the traditional group saw a smaller increase of 1.3 km/h. This resulted in a difference of 2.7 km/h between the groups, with 90% confidence limits ranging from 1.2 to 4.2 km/h. Regarding the practical significance of these changes, for a minimum worthwhile improvement of 5 km/h, the likelihood that the actual effect on bowling speed was beneficial, trivial, or harmful was assessed as 1.0%, 99%, and 50.1%, respectively. For bowling accuracy, the corresponding probabilities were 1%, 48%, and 51%. Ultimately, the findings indicate that the modified-implement training approach is not an effective strategy for enhancing the performance of club cricketers.

Loram, L. C. et al. (2003) aimed to explore knee biomechanics during bowling and the strength of the shoulder in fast-medium bowlers. This study focused on understanding how knee biomechanics and muscular strength in the knee and shoulder relate to ball release speed in fast-medium schoolboy bowlers. Twelve young male cricketers (average age 16.6 years) were assessed on several variables: the angle of the front knee at key points during the delivery stride (foot strike and ball release), and peak strength (torque) of the shoulder and knee joints. The key finding was that a straighter front knee—both at the moment of front foot strike and at ball release—was strongly associated with higher ball speeds ($r = 0.72$ and $r = 0.71$ respectively). This reinforces the idea that proper knee extension helps in transferring momentum efficiently through the kinetic chain during the bowling action. Interestingly, while one might expect muscle strength to play a significant role, the study did not find a meaningful correlation between ball speed and isolated shoulder or knee strength values. However, when knee kinematics (the angles) and shoulder torque were combined in a multiple regression model, they could effectively predict ball release speed (adjusted $r^2 = 0.85$), suggesting that it is the interaction of technique and strength—not strength alone—that better determines performance. These findings highlight the importance of technical coaching focused on optimal front leg positioning and coordination with upper body movement to enhance ball speed in developing bowlers.

Elliott, B., Wallis, R., Sakurai, S., Lloyd, D., & Besier, T. (2002) made a research paper on shoulder alignment in cricket fast bowling. This study investigated the accuracy of using two- and three-dimensional shoulder alignment estimates as proxies for thoracic spine alignment during the fast bowling action in cricket. Specifically, it compared these methods across three key phases of the delivery stride: back-foot impact, front-foot impact, and ball release. Using a six-camera Vicon motion capture system operating at 50 Hz, the researchers reconstructed thoracic alignment and measured shoulder alignment in both 3D (via the acromion processes) and 2D (via standard video footage). At back-foot impact, there was a strong association between thoracic spine alignment and shoulder alignment, with correlations of 0.97 for the 3D method and 0.87 for the 2D method. These high correlations persisted at front-foot impact, with values of 0.89 (3D) and 0.84 (2D). However, at ball release, the correlations weakened considerably to 0.58 (3D) and 0.41 (2D), with shoulder alignment diverging from thoracic alignment by approximately 10°. The 95% limits of agreement revealed increasing random errors at each phase: 9.5° at back-foot impact, 11.7° at front-foot impact, and 22.5° at ball release. These findings indicate that while both 2D and 3D shoulder alignment projections are reliable estimators of thoracic alignment during the initial phases of bowling, they become less accurate at ball release due to greater independent movement of the shoulders. This suggests that direct measurement of thoracic motion is necessary for precise biomechanical analysis at the point of delivery.

R. Portus, M., Sinclair, P. J., Burke, S. T., Moore, D. J. A., & Farhart, P. J. (2000) have conducted a study aiming to explore the impact of an 8-over bowling spell. Fourteen first-grade fast bowlers, with a mean age of 23 years, participated in the research. The physical capacities assessed included abdominal strength, trunk stability, and specific girth and skinfold measurements. The bowlers were filmed from both overhead and lateral angles at a frequency of 50 Hz to gather two-dimensional data on transverse plane shoulder alignment and sagittal plane knee joint angle during the delivery stride. Ball speed was measured using a radar gun, while accuracy was evaluated based on the impact point of each delivery on a zoned scoring target aligned with the batter’s stumps. Findings indicated that shoulder counter-rotation did not exhibit significant changes between overs 2 and 8 across all bowlers. However, it was significantly correlated with a more front-on shoulder orientation at back foot impact. When analyzing only the front-on fast bowlers ($n = 5$), a significant increase in shoulder counter-rotation was observed between overs 2 and 8. Throughout the bowling spell, ball speed remained consistent, while accuracy demonstrated some non-significant variations. Notably, shoulder counter-rotation was significantly related to accuracy scores during the latter half of the 8-over spell. Additionally, chest girth and body composition were significantly correlated with ball release speed at various points during the spell, highlighting the importance of physical capacities in maintaining performance.

S. Glazier, P. et al. (2000) have gone through a study which aimed to investigate the relationships between anthropometric and kinematic variables and ball release speed in fast-medium collegiate bowlers. Nine bowlers were filmed and analyzed in 3D, with ball release speed measured using a validated radar system. A strong correlation was found between horizontal velocity during the pre-delivery stride and ball release speed, suggesting that effective use of run-up momentum influenced release speed. In contrast, the angular velocity of the right humerus showed a weaker correlation. Despite not analyzing wrist action, significant correlations were observed between ball release speed and both shoulder-to-wrist length and total arm length. The study suggests that differences in release speed among the bowlers may be explained by variations in arm length from the shoulder joint to the release point.

Bartlett, R.M. et al. (1996) have worked on the biomechanics of fast bowling in men's cricket: a review. This review summarizes key biomechanical findings related to fast bowling in men's cricket, concentrating on three primary areas: techniques that enhance ball release speed, the aerodynamics of swing bowling, and the link between fast bowling and lower back injuries. It highlights that while fast ball release is crucial for performance, no definitive technique components have been conclusively linked to higher ball speeds. The authors recommend that future research should focus on individual-specific mechanics and the broader dynamics of the bowler's body. Regarding swing bowling, the review explains that the principle of differential boundary layer separation underlies both conventional and reverse swing. However, it emphasizes the need for more detailed investigation into the ball's aerodynamic behavior and how asymmetries influence swing. On the injury front, the review identifies a strong association between lower back injuries and the use of a mixed bowling technique, which combines elements of front-on and side-on actions in a way that increases spinal stress. As a result, the authors recommend targeted screening and intervention strategies to mitigate injury risk, alongside developing advanced biomechanical models of the lower back to better understand injury mechanisms and improve prevention efforts.

SUMMARY OF REVIEW

The reviewed studies collectively examined the relationship between biomechanical, anthropometric, kinematic, and physical fitness factors in cricket pace bowling, emphasizing the key elements that influence ball release velocity and contribute to overall bowling performance. It indicates that ball release velocity in cricket pace bowling is influenced by a combination of anthropometric, kinematic, and physical fitness parameters, though the strength and consistency of these relationships vary.

Anthropometric Parameters

Among anthropometric factors, variables such as upper arm length, forearm length, and arm span have demonstrated moderate positive correlations with ball speed in some studies. For instance, Lyons et al. (2023) reported a correlation of r = 0.61 for arm length, suggesting that longer limb segments may enhance lever mechanics and rotational force. However, other studies like that of Goswami et al. (2016) found negligible correlations, implying that technique and training may modulate these anthropometric advantages. Similarly, leg segment lengths and standing reach height showed inconsistent results, though they may influence stride and release mechanics indirectly.

Kinematic Parameters

Kinematic variables were more strongly and consistently associated with ball release velocity. Notably, final run-up velocity showed a strong positive correlation with ball release speed in several studies (e.g., r = 0.75, Lyons et al., 2023; r = 0.728, Glazier et al., 2000), emphasizing the importance of approach speed. Bound height and stride length varied in their influence. Ball release height and angle also showed some predictive value, with shoulder angle at ball release strongly correlated (r = 0.95, Lyons et al., 2023). Joint angles at both front foot contact (FFC) and ball release (BR) were highlighted as critical, though correlations varied: for example, knee angle at BR showed r = 0.52 (Wormgoor et al., 2010), while hip and shoulder joint movements between FFC and BR reflected meaningful contributions to speed generation (e.g., shoulder flexion r = 0.636, Hanley et al., 2005). Flexion transitions—like knee or hip flexion from FFC to BR—were particularly relevant in studies focused on motion sequencing.

Physical Fitness Parameters

Several physical fitness measures showed moderate to strong correlations with ball release velocity. Core stability (e.g., r = 0.736, Anand et al., 2017), upper body flexibility (e.g., r = 0.726, Sisodia & Bagchi, 2017), and sprinting speed (e.g., r = -0.482 for 30m sprint time, Kiely et al., 2021) were positively associated with faster bowling. Upper body power, as measured by the medicine ball throw test, and back/leg strength had limited supportive evidence. Arm strength was assessed by Goswami et al (2016), and was reported insignificant but strong positive relation and suggested to contribute to increase ball release velocity.

Overall, the review of related literature supports that kinematic factors, especially final run-up velocity, joint angles, and ball release height, show the strongest and most consistent relationships with ball release velocity. Anthropometric characteristics and physical fitness components, while individually less predictive, contribute significantly when integrated into a comprehensive biomechanical and physiological profile of pace bowlers. In summary, the evidence suggests that while anthropometric traits provide foundational physical advantages, it is the kinematic execution and physical fitness capacity, particularly related to speed, power, and joint movement efficiency, that most strongly determine ball release velocity in pace bowling.

CHAPTER - III

3. METHODOLOGY:

3.1. Selection of Subjects:

Twelve healthy female pace bowlers who have performed in state level tournaments, with no severe previous injury were selected as the subjects for the study. The age of the subjects ranged from 18 to 28 years. They have trained themselves under the guidance of qualified coaches in different academy and all of them must have had the representation in the state level tournament at least once within the last 5 years and they were active participants in the game during the time of data collection for the purpose of study.

3.2. Selection of the Variables:

The following variables were measured to conduct the research-

3.2.1. Demographic Details:

i. Age

ii. Height

iii. Weight

3.2.2. Dependent Variables:

i. Ball release velocity

3.2.3. Independent Variables:

A. Anthropometric parameters:

i. Upper arm length (Acromiale-radiale)

ii. Forearm length (Radiale-stylion radiale)

iii. Hand length (Midstylion-dactylion)

iv. Arm span

v. Upper leg length (Trochanterion-tibiale laterale)

vi. Lower leg length (Tibiale laterale)

vii. Foot length

viii. Standing reach height

B. Kinematic parameters:

i. Run up length

ii. Run-up velocity at pre-delivery stride

iii. Bound height

iv. Final stride length

v. Ball release height

vi. Ball release angle

vii. Ankle joint angle at front foot contact (FFC)

viii. Knee joint angle at front foot contact (FFC)

ix. Hip joint angle at front foot contact (FFC)

x. Shoulder joint angle at front foot contact (FFC)

xi. Ankle joint angle at ball release (BR)

xii. Knee joint angle at ball release (BR)

xiii. Hip joint angle at ball release (BR)

xiv. Shoulder joint angle at ball release (BR)

xv. Ankle plantar flexion from FFC to BR

xvi. Knee flexion from FFC to BR

xvii. Hip flexion from FFC to BR

xviii. Shoulder flexion from FFC to BR

C. Physical Fitness Parameters:

i. Arm strength
ii. Back strength
iii. Leg strength
iv. Upper body power
v. Lower body power
vi. Core stability
vii. Speed
viii. Flexibility

3.3. Instruments and Tools:

For the collection and the analysis of the data following instruments and tools were used:

i. Stadiometer
ii. Weighing machine
iii. Segmometer
iv. Three cameras with tripod stands
v. Two white Screen
vi. Computer system
vii. Motion analysis software (Kinovea-0.9.5)
viii. Hand grip dynamometer
ix. Back and leg dynamometer
x. Standard cricket balls
xi. Well-equipped cricket pitch
xii. Flexometer
xiii. Medicine ball

xiv. Stopwatch

xv. Steel tape

xvi. Measuring tape

xvii. Lime dust

xviii. Nails

3.4. Procedure for the Administering the Test:

3.4.1. Demographic Details: The demographic details i.e. age, height and weight were recorded by using the following procedure:

i. Age:

To measure the age of a group of people, their birthdates, including the year, month, and day, were first collected either from their matriculation certificate or AADHAR card. The current date (28/03/2024) at the time of data collection was then noted for comparison. For each individual, the birth year was subtracted from the current year to provide a preliminary estimation of their age. Afterward, it was checked whether their birthday for that year had already passed. If the birth month and day had occurred or matched the current date, the age was recorded as the difference in years. However, if their birthday had not yet taken place, one year was subtracted from the calculated difference. Using this procedure, the accurate age for each subject was determined. For example, if someone was born on January 29, 2000, and the date of calculation was March 28, 2024, the age was recorded as (2024 – 2000) = 24 years. If someone was born on April 29, 2000, the age was adjusted to (24-1) = 23 years.

ii. Height:

To measure the height of the subjects, a stadiometer was used. Each subject was asked to stand upright with their heels, buttocks, and back against the measuring surface. They were instructed to look straight ahead with their head in a neutral position to avoid any slouching or tilting.

The height was then measured from the base of the feet to the top of the head in centimeter. After recording, the data were checked for accuracy, and any discrepancies were addressed through remeasurement.

Figure 1

Measurement of Height

iii. Weight:

To measure the weight of the subjects, a weighing machine was used to ensure accurate and consistent readings. Each subject was asked to remove any heavy clothing, shoes, or accessories that might affect the measurement. They were instructed to stand still on the weighing machine, distributing their weight evenly on both feet. The readings were recorded in kilograms (kg) to maintain uniformity across all subjects. The weighing machine was zeroed before each use to guarantee precise measurements.

Figure 2

Measurement of Weight

3.4.2. Anthropometric parameters:

Most of the anthropometric parameters were measured according to the book, “International Standards for Anthropometric Assessment”, published by International Society for Advancement of Kinanthropometry (ISAK). The actual procedure of collecting these data is described below:

i. Upper Arm Length (Acromiale-radiale):

In this study, the Acromiale and Radiale landmarks were first identified on each subject. The subjects were positioned in a relaxed standing posture, with their bowling arms (right) hanging naturally by their sides.

A segmometer was then used to measure the distance between the Acromiale and Radiale landmarks. One branch of the segmometer was placed on the Acromiale, and the other on the Radiale. The distance between these two points was recorded in centimeter as the upper arm length. (ISAK, 2001)

Figure 3

Measurement of Upper Arm Length

ii. Forearm Length (Radiale-stylion):

In this study, the distance between the Radiale and Stylion landmarks, which had been previously marked, was used to determine this measurement. The subjects were positioned in a relaxed stance with their bowling arms naturally hanging by their sides.

A segmometer was used for the measurement, with one branch placed on the Radiale and the other on the Stylion landmark. The length between these two landmarks was recorded in centimeter as the forearm length. (ISAK, 2001)

Figure 4

Measurement of Forearm Length

iii. Hand length (Midstylion-dactylion):

In this study, the hand length of the subjects was measured as the shortest distance between the Midstylion line and the Dactylion. The subjects were asked to stand in a relaxed position, with the fingers extended, but not hyperextended.

Using a segmometer, one branch was placed on the Midstylion line, while the other was positioned on the Dactylion, which is the most distal point of the third digit. The distance between these two points was recorded in centimeter as the hand length. (ISAK, 2001)

Figure 5

Measurement of Hand Length

iv. Arm Span:

In this study, the measurement was taken as the distance between the fingertips when the arms were fully outstretched. The subjects stood facing away from the wall, ensuring that their back and buttocks were in contact with the wall. The arms were extended horizontally to form a straight line.

Using a measuring tape, the distance from one furthest fingertip to the other was recorded in centimeter as the arm span. (Mohanty et al., 2001)

Figure 6

Measurement of Arm Span

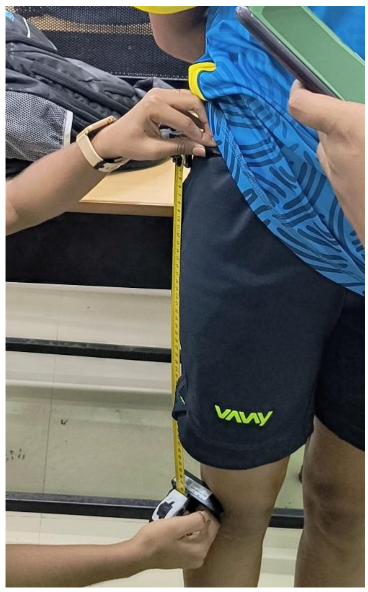
v. Upper Leg Length (Trochanterion-tibiale laterale):

In this study, the length of the thigh was measured by determining the distance between the marked Trochanterion and Tibiale laterale landmarks. The subjects stood with their feet together and their arms folded across their chest to maintain a stable posture.

Using a segmometer, one branch was placed on the Trochanterion, while the other was positioned on the Tibiale laterale site. The distance between these two landmarks was recorded in centimeter as the upper leg length. (ISAK, 2001)

Figure 7

Measurement of Upper Leg Length



vi. Lower Leg Length (Tibiale laterale height):

In this study, the length of the leg was measured by assessing the distance from the Tibiale laterale to the floor. The subjects stood straight on the floor and arms hanging naturally by their sides.

Figure 8

Measurement of Lower Leg Length

The fixed branch of the segmometer was positioned on the top surface of the floor, while the moving branch was placed on the marked Tibiale laterale site. The distance between the Tibiale laterale and the floor was recorded in centimeter as the lower leg length. (ISAK, 2001)

vii. Foot length:

Figure 9

Measurement of Foot Length

In this study, foot length was measured using a segmometer, assessing the distance between the Akropodion (the tip of the longest toe, either the first or second phalanx) and the Pternion (the most posterior point on the calcaneus). The subjects stood in a relaxed position with their feet comfortably apart and their weight evenly distributed, while their arms hung naturally by their sides.

The segmometer was used with minimal pressure applied to ensure accurate measurements without distorting the foot's natural shape. One branch of the segmometer was placed on the Akropodion, while the other was positioned on the Pternion. The recorded distance in centimeter between these two points was taken as the foot length. (ISAK, 2001)

viii. Standing Reach Height:

In this study, the standing reach height of the subjects was measured by using a steel tape. The subjects stood barefoot with their feet together, facing a flat wall, and their arms hanging naturally by their sides. They were instructed to stand as tall as possible, extending one arm fully overhead without lifting their heels off the ground.

The steel tape was used to measure the vertical distance from the floor to the tip of the middle finger on the fully extended arm. One end of the tape was placed on the floor, while the other end was aligned with the tip of the subject's middle finger at maximum reach. The recorded distance was taken as the standing reach height. (Johnson & Nelson, 1986)

Figure 10

Measurement of Standing Reach Height

3.4.3. Kinematic parameters:

All the kinematic data were drawn by analyzing and digitizing the video footage of the bowling action, recorded from three different place of right and left sagittal plane.

Recording of Movements:

Three high-speed video cameras (Camera 1: Nikon D7500, Camera 2: Canon 1200D and Camera 3: Canon 1200D) of 60 fps each were used for recording the video of the pace bowling technique. Camera-1 was positioned in right sagittal plane and perpendicular to the pitch focusing on the area of delivery stride. Camera-2 was placed in the left sagittal plane of the pitch in the same way as Camera-1 was placed to analyze the movements which were not visible from right side. Camera-3 was positioned in right sagittal plane and perpendicular to the run-up path, specifically focusing the area of the last 10 meters before the crease.

Figure 11

Illustration of Filming Environment

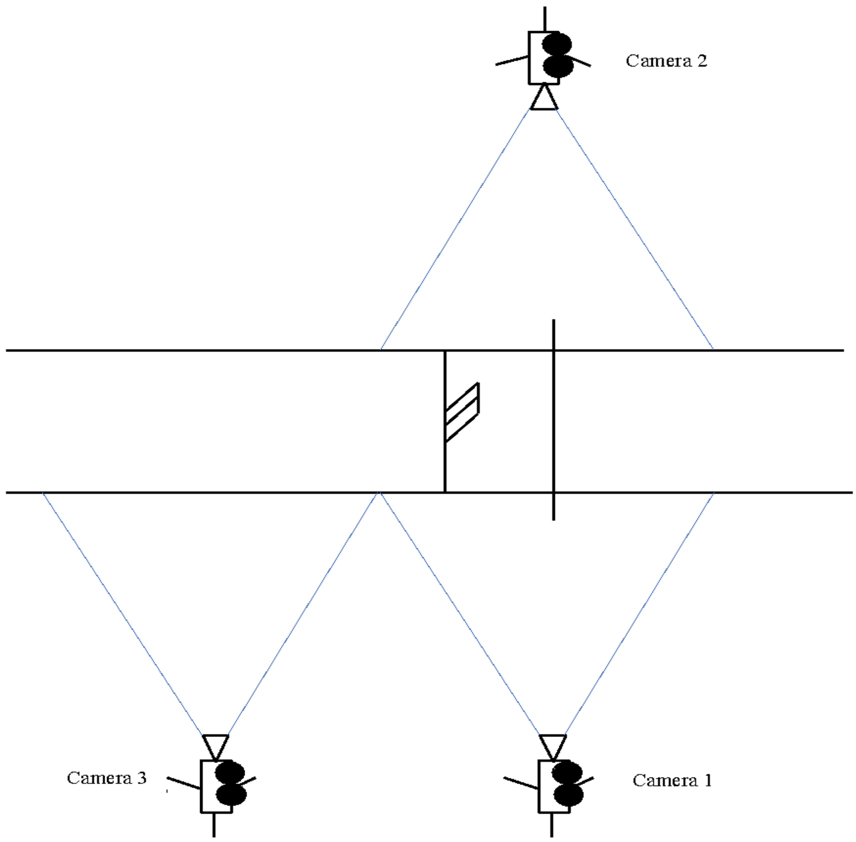


Figure 12

Photograph of Real Filming Environment

Figure 13
Warm Up Session of the Players

Before making videography of bowling action, the purpose of recording was briefly explained to the subjects for better understanding and to increase their motivation level. All the subjects were warmed-up for 10 minutes by stretching all major muscles groups for bowling. Then each subject has performed six (6) successful bowling into the valid area. A reference scale (Height: 1m and Width: 1.5m) was also recorded in the same video putting on the exact line of the movement for the purpose of length calibration at the time of video analysis. The movement of the subjects for executing the pace bowling action (technique) was recorded by using three fixed cameras. A successful bowling was defined as the ball in the legal delivery towards the stump (batsman side) on the pitch.

Method of Video Analysis for Kinematic Parameters: To measure the selected kinematic parameters the video footage was analyzed using Kinovea (0.9.5) Motion Analysis Software. The captured movement was transferred from the cameras to the computer and with the help of this motion analysis software, the pace bowling action of each subject was analyzed for collecting the kinematic data. For measuring all the length parameters, the reference scale was recorded in the beginning of the video. The length of the reference scale in the video was calibrated with its real length (1m x 1.5m) to get the real length of anything situated on the same position.

Figure 14

Reference Scale

For all the velocity parameter, frame rate (60 fps) of the video was used for calculating the time taken for any kind of displacement. The detail procedure of collecting Kinematic data has been given below:

i. Run-Up Length:

To determine the ideal run-up length for the subjects, a systematic approach was followed. Each bowler began by performing a series of warm-up deliveries to settle into their natural rhythm. Without any predetermined measurements, the cricketers were asked to bowl multiple times, allowing them to find a comfortable run-up distance that felt natural and conducive to effective delivery. Once a consistent pattern was observed in their approach, the starting point of each bowler's run-up was marked.

Using a measuring tape, the distance from the start point to the popping crease was measured for each cricketer. (Bailey et al., 2023)

Figure 15

Measurement of Run-Up Length

ii. Final Run-Up Velocity:

To measure the run-up velocity at the pre-delivery stride for all the subjects, using motion analysis software, the video footage was reviewed frame by frame. After take-off in the pre-delivery stride, when the body was travelling in the air, a point was marked at waist level. After forwarding three frames from this point, another point was marked in the same way. The distance between two points was measured by drawing a line (calibrated with the reference scale) to get the horizontal displacement of the body (waist region). Time taken for this displacement was calculated from the frame rate of the video. The run-up velocity was then determined by dividing the distance covered by the time taken. (Bull et al., 2024)

Figure 16

Measurement of Final Run-Up Velocity

iii. Bound Height:

To measure the bound height in cricket pace bowling, the difference in waist height between the take-off and peak of the bound was analyzed using video footage. Through video analysis software, two critical points were identified in the bound phase: the moment just before the bowler's feet left the ground (take-off), and the highest point reached during the leap (peak height). At each of these points, the waist height was marked and measured from the ground using calibrated line. The bound height was then calculated as the difference in waist height between the peak of the leap and the height just before take-off. (Bull et al., 2024)

Figure 17

Measurement of Bound Height

iv. Final Stride Length:

To measure the final stride length in cricket pace bowling, video analysis was used to capture the bowler's movements during the delivery stride. Using video analysis software, the points of contact for both the back foot and the front foot were identified as delivery stride. The distance between the point where the bowler's back foot first contacted the ground and the point where the front foot landed just before the ball was delivered was measured by drawing the calibrated line to get the final stride length. This measurement represented the horizontal distance covered by the bowler during the last stride of their delivery phase. (Feros et al., 2019)

Figure 18:

Measurement of Final Stride Length

v. Ball Release Height:

To measure the ball release height, the recorded video was analyzed. Video analysis software was utilized to slow down playback and mark key points, including the position of the ball and the release point on the bowler's hand. The vertical distance from the ground to the point of ball release was measured by the calibrated line and documented as ball release height for each trial. (Kiely et al., 2021)

Figure 19

Measurement of Ball Release Height

vi. Ball Release Angle:

To measure the ball release angle in cricket pace bowling, a systematic approach was followed. The key frame where the ball leaves the bowler's hand was identified, as this is the critical moment for measuring the release angle. In this frame, a horizontal reference line (parallel to the ground) was drawn, and the trajectory of the ball, immediately after it left the hand, was marked. The angle between the horizontal reference line and the ball's initial trajectory was then measured using the software's angle tool. For fast bowlers, this angle typically indicates a downward trajectory, as the ball is released with the intention of hitting the pitch in front of the batsman. If the angle was formed below the horizontal line (desirable in fast bowling), it was recorded as positive angle and if the angle was formed above the horizontal line, it was recorded as negative angle. (Manawadu et al., 2022)

Figure 20

Measurement of Ball Release Angle

vii. Ball Release Velocity:

To measure the ball release velocity in cricket bowling using video analysis, the exact moment when the ball left the bowler's hand was identified by isolating the frame in which the ball first became airborne, completely free from the hand. The next step involved marking the position of the ball in consecutive frames after release. By measuring the displacement of the ball between two frames and using the known frame rate (60 frames per second), the distance traveled by the ball over a specific time interval was calculated. Then, using the formula for velocity (Velocity=Displacement/Time), the ball release velocity was calculated. (Glazier et al., 2000; Felton et al., 2017; Lyons et al., 2023)

Figure 21

Measurement of Ball Release Velocity

viii. Ankle Joint Angle at Front Foot Contact (FFC):

To measure the ankle joint angle at front foot contact during delivery stride in cricket bowling, video analysis method was used. After the footage was imported into video analysis software, the exact frame where the bowler's front foot makes contact with the ground during the delivery stride was identified, as this is the critical moment for analysing the ankle joint angle. In this frame, key anatomical landmarks were marked: the ankle joint (typically using the malleolus as a reference point), and the toes. Next, a line was drawn from the toe to the ankle joint (representing the foot) and another from the ankle joint to the knee (representing the lower leg). The software's angle measurement tool was then used to calculate the angle formed between these two lines, which represents the ankle joint angle at front foot contact (FFC).

Figure 22

Measurement of Ankle Joint Angle at FFC

ix. Knee Joint Angle at Front Foot Contact (FFC):

To measure the knee joint angle at front foot contact during final stride in cricket bowling, recorded video was analyzed using video analysis software. The key frame where the bowler's front foot first contacts the ground was identified, as this is the essential moment for assessing the knee joint angle. In this frame, anatomical reference points were marked on the bowler's body: the hip, knee joint, and ankle. To measure the knee joint angle, two lines were drawn: one from the hip to the knee (representing the thigh) and another from the knee to the ankle (representing the lower leg). The software's angle measurement tool was then used to calculate the angle between these two lines, representing the knee joint angle at the moment of front foot contact (FFC). (Glazier et al., 2000; Feros et al., 2019; Lyons et al., 2023)

Figure 23

Measurement of Knee Joint Angle at FFC

x. Hip Joint Angle at Front Foot Contact (FFC):

To measure the hip joint angle at front foot contact in final stride during cricket bowling, a precise procedure was followed for video analysis. The exact frame where the front foot first contacts the ground during the delivery stride was identified, as this is the crucial moment for analysing the hip joint angle. In this frame, key anatomical landmarks were marked: the shoulder, hip joint, and knee. Two lines were drawn: one from the shoulder to the hip (representing the upper body) and another from the hip to the knee (representing the thigh). The software's angle measurement tool was then used to calculate the angle between these two lines, which represents the hip joint angle at the moment of front foot contact (FFC).

Figure 24

Measurement of Hip Joint Angle at FFC

xi. Shoulder Joint Angle at Front Foot Contact (FFC):

To measure the shoulder joint angle at front foot contact during the delivery stride of cricket pace bowling, a structured approach was followed. After recording the video footage of delivery, it was imported into video analysis software. The key frame where the bowler's front foot first contacts the ground during the delivery stride was identified, as this is the critical moment to assess the shoulder joint angle. In this frame, specific anatomical points were marked: the shoulder joint, the elbow, and the trunk (or torso). To measure the shoulder joint angle, two lines were drawn: one line from the shoulder to the elbow (representing the upper arm) and another line along the trunk, from the shoulder towards the pelvis (representing the upper body). Using the software's angle measurement tool, the angle between these two lines was calculated, representing the shoulder joint angle at the moment of front foot contact (FFC). (Worthington et al., 2013)

Figure 25

Measurement of Shoulder Joint Angle at FFC

xii. Ankle Joint Angle at Ball Release (BR):

The ankle joint angle at ball release during cricket bowling was measured using a video analysis technique. The specific frame where the ball left the bowler's hand was pinpointed, as this is the key moment for evaluating the ankle joint angle. The subsequent steps followed the same procedure as those used for assessing the ankle joint angle at front foot contact (FFC).

Figure 26

Measurement of Ankle Joint Angle at BR

xiii. Knee Joint Angle at Ball Release (BR):

To measure the knee joint angle at ball release during cricket bowling, the recorded video footage was meticulously analyzed using Kinovea video analysis software. The precise frame where the ball leaves the bowler's hand was identified, as this moment is crucial for accurately assessing the knee joint angle. The same method previously applied to evaluate the knee joint angle at front foot contact (FFC) was then followed. (Thander & Prasad, 2019; Feros et al., 2019; Worthington et al., 2013)

Figure 27

Measurement of Knee Joint Angle at BR

xiv. Hip Joint Angle at Ball Release (BR):

The hip joint angle at ball release during cricket bowling was measured through a detailed video analysis process. After capturing the video, the footage was imported into video analysis software. The critical frame, where the ball leaves the bowler's hand, was identified, as this moment is essential for analysing the hip joint angle. The same method was then applied as used for measuring the hip joint angle at front foot contact (FFC).

Figure 28

Measurement of Hip Joint Angle at BR

xv. Shoulder Joint Angle at Ball Release (BR):

A detailed and systematic video analysis method was employed to measure the shoulder joint angle at ball release during cricket pace bowling. The critical frame, capturing the exact moment the ball leaves the bowler's hand, was identified, as this moment is pivotal for accurately evaluating the shoulder joint angle. The same detailed procedure was used, which was used to assess the hip joint angle at front foot contact (FFC). (Worthington et al., 2013)

Figure 29

Measurement of Shoulder Joint Angle at BR

xvi. Ankle Plantar Flexion from FFC to BR:

Plantar flexion referred to the motion where the foot pointed downward, increasing the angle between the foot and the shin. The angles from the two key frames—front foot contact (FFC) and ball release (BR)—were analyzed to determine the degree of ankle plantar flexion. As the mean angle at BR was larger than at FFC, indicating that the foot pointed more downward at ball release, this signified plantar flexion. The difference between the two angles provided the extent of plantar flexion during the bowling action.

xvii. Knee Flexion from FFC to BR:

Knee flexion is the process of folding the knee, which involves decreasing the angle between the thigh and the lower leg. By comparing the knee angles at FFC and BR, the degree of knee flexion was calculated. The difference in angle between these two frames indicates how much the knee flexed from front foot contact to ball release. (Kiely et al., 2021)

xviii. Hip Flexion from FFC to BR:

Hip flexion refers to the bending of the hip joint, which decreases the angle between the thigh and the upper body. By comparing the hip angle at FFC and at BR, the degree of hip flexion can be calculated. The difference in angle between these two frames (FFC and BR) indicates how much the hip flexes from front foot contact to ball release. (Kiely et al., 2021)

xix. Shoulder Flexion from FFC to BR:

Shoulder flexion refers to the forward movement of the upper arm relative to the trunk, decreasing the angle between the upper arm and the torso. The degree of shoulder flexion is determined by comparing the angle at FFC (typically a more extended) to the angle at BR (when the shoulder is more flexed as the arm moves forward). The difference in these two angles indicates the degree of shoulder flexion from FFC to BR. (Hanley et al., 2005; Worthington et al., 2013)

3.4.4. Physical Fitness Parameters:

To measure the selected physical fitness parameters, the subjects were gone through some specific tests as follows:

i. Arm Strength Test:

In this study, arm strength was measured using a hand grip dynamometer, following the procedures outlined by B. L. Johnson and J. K. Nelson (1986) in Practical Measurements for Evaluation in Physical Education. The subjects were stood comfortably with their elbow flexed at approximately 90 degrees, and the forearm was positioned in a neutral state. The dynamometer was adjusted to fit the subject's hand, ensuring the grip handle was positioned to align with the middle of the fingers for optimal performance.

Figure 30

Measurement of Arm Strength

The subjects were then instructed to squeeze the dynamometer with maximum effort for a few seconds, while avoiding body movement or compensatory actions. The force exerted was recorded in kilograms. To ensure reliability, three trials were conducted for each subject, with adequate rest between each attempt. The highest recorded value was taken as the final measure of arm strength. (Johnson & Nelson, 1986; Goswami et al., 2016)

ii. Back Strength Test:

Back strength was measured using a back and leg dynamometer, following the guidelines provided by B. L. Johnson and J. K. Nelson (1986) in Practical Measurements for Evaluation in Physical Education and D. K. Kansal in Test and Measurement in Sports and Physical Education. The subjects stood on the base platform of the dynamometer with their feet shoulder-width apart, ensuring a stable stance. The handle of the dynamometer was adjusted to the height of the subject's knees to measure back strength specifically.

Figure 31

Measurement of Back Strength

The subjects were instructed to bend trunk slightly at the waist while keeping their knee straight, gripping the dynamometer handle securely with both hands. They were then asked to exert maximum force by pulling the handle upward using their back muscles without lifting their heels off the ground. The force generated was recorded in kilograms. Three trials were conducted for each subject with rest intervals between attempts, and the highest value was taken as the final measure of back strength. (Johnson & Nelson, 1986)

iii. Leg Strength Test:

Leg strength was also measured using a back and leg dynamometer. The subjects stood on the base platform of the dynamometer with their feet shoulder-width apart and their knees slightly bent. To focus on leg strength, the dynamometer handle was adjusted to the appropriate height near the subjects' thighs.

Figure 32

Measurement of Leg Strength

The subjects were instructed to keep their back straight and legs bent slightly at the knees. They were then asked to exert maximum force by straightening their legs and pushing upward against the handle, applying pressure through their legs without using their back or arms.

The force exerted was measured in kilograms and recorded. Each subject performed three trials, with adequate rest between attempts, and the highest value was taken as the final leg strength measurement. (Johnson & Nelson, 1986)

iv. Overhead Medicine Ball Throw Test (Forward) for Upper Body Power:

Figure 33

Overhead Medicine Ball Throw Test

In this study, upper body power was measured using the Overhead Medicine Ball Throw (Forward). The subjects were positioned standing behind a marked throwing line, with their feet shoulder-width apart for stability. A standard medicine ball, weighing 2 kg was used for the test.

The subjects were instructed to hold the medicine ball with both hands and bring it behind their head while keeping their elbows slightly bent. With a forceful movement, they were asked to throw the ball forward and overhead as far as possible, using a combination of their upper body and core muscles for power generation. The feet remained stationary during the throw to isolate upper body power.

The distance from the throwing line to the point where the ball first touched the ground was measured in meters. Each subject performed three trials, and the longest throw was recorded as the final measure of upper body power. (Salonia et al., 2004)

v. Vertical Jump Test for Lower Body Power:

In this study, lower body power was measured using the Vertical Jump Test. The test was conducted to assess the explosive power of the lower body muscles.

Figure 34

Vertical Jump Test

The subjects were instructed to stand next to a vertical wall with their feet flat on the ground and their dominant arm fully extended upward. The height of the subject's reach, referred to as the standing reach height, was marked on the wall. After this, the subjects were asked to perform a vertical jump from a stationary, upright position, using both legs to propel themselves upward as high as possible. They were instructed to swing their arms and bend their knees to generate maximum force.

At the peak of the jump, the subjects touched the wall with their dominant hand, and the highest point reached was marked. The difference between the standing reach height and the height achieved during the jump was recorded as the vertical jump height, measured in centimeters. Each subject performed three trials, with the best jump recorded as the measure of lower body power. (Bailey et al., 2023)

vi. Prone Hold Test for Core Stability:

Core stability was measured using the Prone Hold Test. This test assesses the endurance of the core muscles, which are essential for maintaining posture and stability during physical activities.

Figure 35

Prone Hold Test

The subjects were instructed to assume the prone hold position, commonly known as the plank. In this position, they supported their body weight on their forearms and toes, keeping the elbows directly under the shoulders and the body in a straight line from head to heels. The subjects were required to maintain this posture without any sagging or arching of the back.

The test was timed from the moment the subject assumed the correct plank position until they could no longer maintain proper form. The total time (in seconds) that the subject was able to hold the position was recorded as their core stability score. Each subject performed one trial, and their hold time was used as the final measure of core stability. (Anand et al., 2017)

vii. 20m Speed Test:

In this study, speed was measured using the 20m Speed Test. This test evaluates the subject's sprinting speed over a short distance, which is crucial in many sports and physical activities.

The subjects were instructed to stand behind a marked starting line in a ready position. The course consisted of a 20-meter straight distance, clearly marked with start and finish lines. Upon the signal to start, the subjects sprinted from the starting line to the finish line as fast as possible. A stopwatch, was used to accurately measure the time it took each subject to complete the 20 meters.

The time was recorded in seconds, and each subject performed two trials, with adequate rest between attempts. The fastest time recorded was taken as the subject's final speed score. (Eler & Eler, 2018; Bala, 2014)

Figure 36

20m Speed Test

viii. Sit and Reach Test for Flexibility:

In this study, flexibility was measured using the Sit and Reach Test. This test assesses the flexibility of the lower back and hamstrings, which are important for overall functional mobility.

The subjects were instructed to sit on the floor with their legs fully extended, feet flat against a sit-and-reach box, and knees straight. They were asked to place one hand over the other and slowly reach forward as far as possible along the measuring scale attached to the sit-and-reach box, keeping their knees flat on the ground. The reach had to be held for at least two seconds to ensure a valid measurement.

The distance reached beyond the toes (or behind, if unable to reach the toes) was recorded in centimeters. Each subject performed the test three times, and the best of the three attempts was recorded as the final measure of flexibility. (Johnson & Nelson, 1986)

Figure 37

Flexometer for Sit and Reach Test

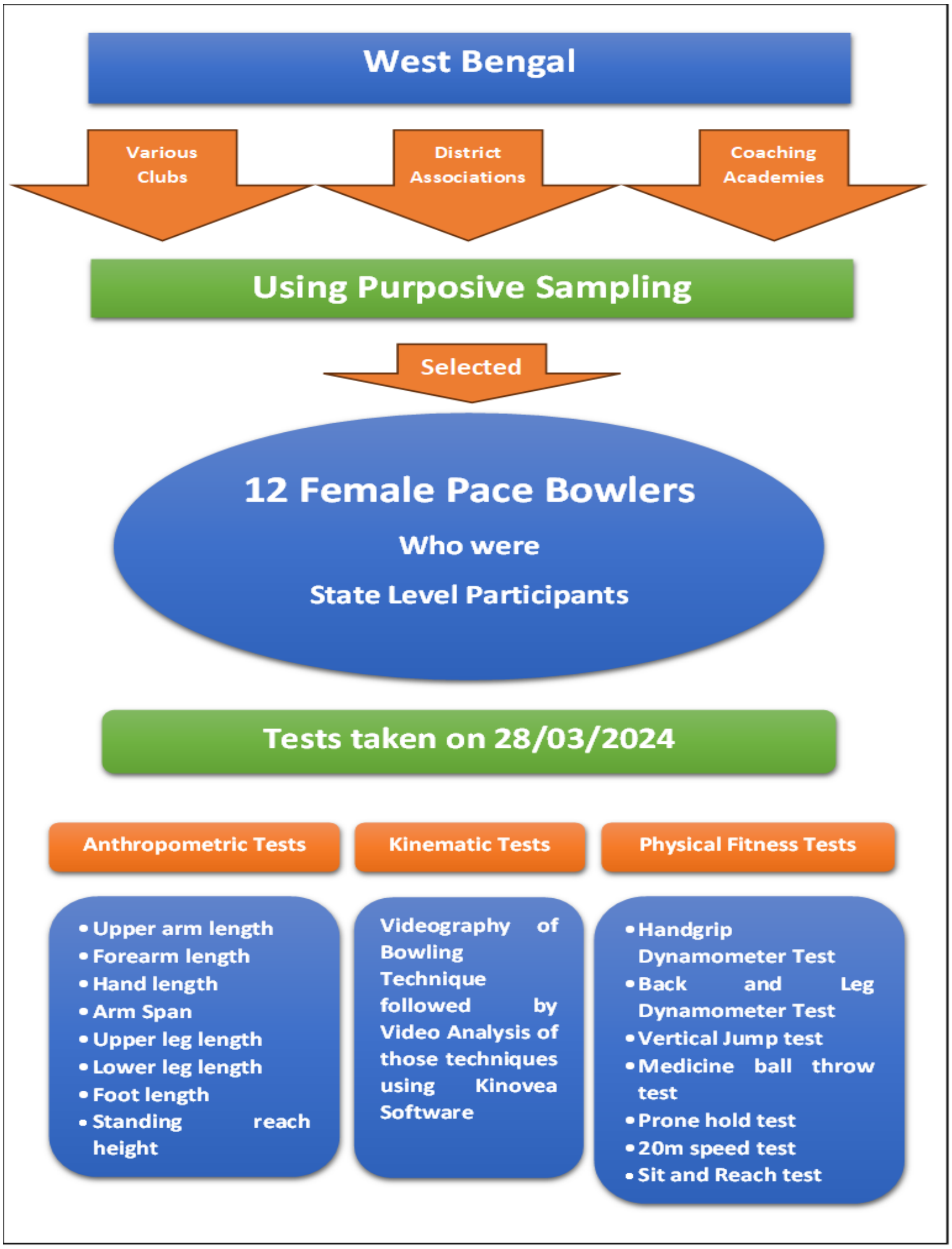
3.5. Design of the Study:

After visiting various coaching camp of Kolkata and contacting over the telephone to various coaches from various coaching camp from all over the state (West Bengal), twelve healthy female pace bowlers were selected, aged between 18 and 28, who had previously competed at state level tournaments at least once in last 5 years and till they are active players. They were selected as the subjects through purposive sampling method and were invited for contributing in this research work by sharing their valuable data with us spontaneously. The arrangement for data collection was made in the playground of Jadavpur university on 28/03/2024 in the presence and under the guidance of all the members of RAC and it was executed in an errorless way.

A comprehensive set of variables were measured, including demographic details, anthropometric parameters, kinematic parameters, and various physical fitness parameters. All anthropometric measurements adhered to the "International Standards for Anthropometric Assessment" guidelines published by the International Society for Advancement of Kinanthropometry (ISAK). The kinematic data were captured through three strategically placed high-speed cameras (Camera 1: Nikon D7500, Camera 2: Canon 1200D and Camera 3: Canon 1200D) recording at 60 fps, which allowed for a detailed analysis of the bowling technique from different angles. Prior to recording, subjects were informed about the purpose of the study to enhance their motivation, followed by a 10-minute warm-up. Each bowler executed six valid deliveries, and a reference scale was included in the video for length calibration during analysis. The recorded footage was then processed with motion analysis software to extract kinematic data, with specific reference lengths calibrated to real measurements. Physical fitness parameters were assessed through various standardized tests such as arm strength test by Handgrip Dynamometer, back and leg strength by Back and Leg Dynamometer, Vertical Jump test, Medicine ball throw test, Prone hold test, 20m speed test, Sit and Reach test etc. The whole process is illustrated in Figure 38.

Figure 38

Illustration of Design of the Study



3.6. Statistical Procedure:

Descriptive means, standard deviations, and ranges of all variables were calculated and evaluated. Pearson's product moment correlation and regression analysis were used to analyze relationship among the variables. MS Excel and SPSS statistical software was used for the statistical analysis.

3.7. Level of Significance:

The level of significance was set at 0.05 level of significance for testing the null hypothesis in the study.

CHAPTER - IV

4. ANALYSIS OF DATA AND RESULTS OF THE STUDY:

This chapter presents the statistical analysis of data related to anthropometric, kinematic, and physical fitness variables collected from 12 female pace bowlers who have participated in state-level tournaments in West Bengal. It also includes a discussion of the findings and the testing of the research hypotheses.

4.1. Findings:

Test of Normality: Before going through any statistical procedure, the normality of the data set was tested by Shapiro-Wilk Test (when the best deliveries were considered, N=12) and Kolmogorov-Smirnova Test (when all the deliveries were considered, N=72) through SPSS software and all the data were found to be distributed normally in the data set. Further statistics were then performed such as descriptive statistics (Mean, SD and Range), Pearson's product moment correlation and linear regression analysis (when all the deliveries were considered, N=72).

The details of demographic, anthropometric, kinematic and physical fitness measurements of the subjects are presented here.

Table 1

Descriptive Statistics of Demographic Details of the Subject

Demographic Details	N	Minimum	Maximum	Mean	Std. Deviation
Age (Year)	12	18.00	28.00	21.67	±3.47
Height (cm.)	12	162.00	168.00	164.13	±1.79
Weight (Kg.)	12	43.00	70.00	56.25	±8.58

The Table 1 represent a statistical summary of demographic details, including age, height, and weight, for a sample of 12 individuals. The data on age revealed that the participants ranged from 18 to 28 years old, with an average age of 21.67 years and a standard deviation of 3.47 years. This indicated that the sample primarily consisted of young adults with moderate variability in age. Regarding height, the participants' measurements ranged from 162 cm to 168 cm, with a mean of 164.13 cm and a low standard deviation of 1.79 cm, suggesting that the group had relatively uniform height. In contrast, weight showed greater variability, ranging from 43 kg to 70 kg, with an average weight of 56.25 kg and a standard deviation of 8.58 kg. This reflected diversity in the participants' physical build, possibly influenced by factors such as lifestyle or diet. Overall, the data highlighted a youthful demographic with consistent height and varied weight, providing a clear profile of the sample group for further analysis.

Table 2

Descriptive Statistics of Anthropometric Variables of the Subjects

Anthropometric Variables	N	Minimum	Maximum	Mean	Std. Deviation
Upper arm length (cm.)	12	27.00	33.10	29.56	±1.96
Forearm length (cm.)	12	20.20	25.90	23.65	±1.72
Hand length (cm.)	12	17.20	20.00	18.76	±1.03
Arm span (cm.)	12	143.00	167.00	157.50	±6.22
Upper leg length (cm.)	12	42.90	51.50	48.12	±2.29
Lower leg length (cm.)	12	37.00	44.50	40.05	±2.14
Foot length (cm.)	12	22.90	26.00	24.24	±0.85
Standing reach height (cm.)	12	187.00	214.50	204.96	±7.86

The Table 2 provides statistical information about anthropometric variables of the subjects. The data for upper arm length showed a range from 27.00 cm to 33.10 cm, with a mean value of 29.56 cm and a standard deviation of ±1.96 cm, indicating slight variability among participants. Forearm length varied between 20.20 cm and 25.90 cm, with an average of 23.65 cm and a standard deviation of ±1.72 cm, suggesting moderate consistency. Hand length was relatively uniform, ranging from 17.20 cm to 20.00 cm, with a mean of 18.76 cm and a standard deviation of ±1.03 cm.

The arm span ranged from 143.00 cm to 167.00 cm, with an average value of 157.50 cm and a standard deviation of ±6.22 cm, showing broader variability. Upper leg length, with a range of 42.90 cm to 51.50 cm, averaged 48.12 cm and had a standard deviation of ±2.29 cm, indicating moderate variation. Lower leg length was observed between 37.00 cm and 44.50 cm, with a mean of 40.05 cm and a standard deviation of ±2.14 cm, reflecting some diversity within the group. Foot length was consistent, ranging from 22.90 cm to 26.00 cm, with a mean of 24.24 cm and a low standard deviation of ±0.85 cm. Lastly, standing reach height spanned from 187.00 cm to 214.50 cm, with a mean of 204.96 cm and a standard deviation of ±7.86 cm, indicating considerable variability.

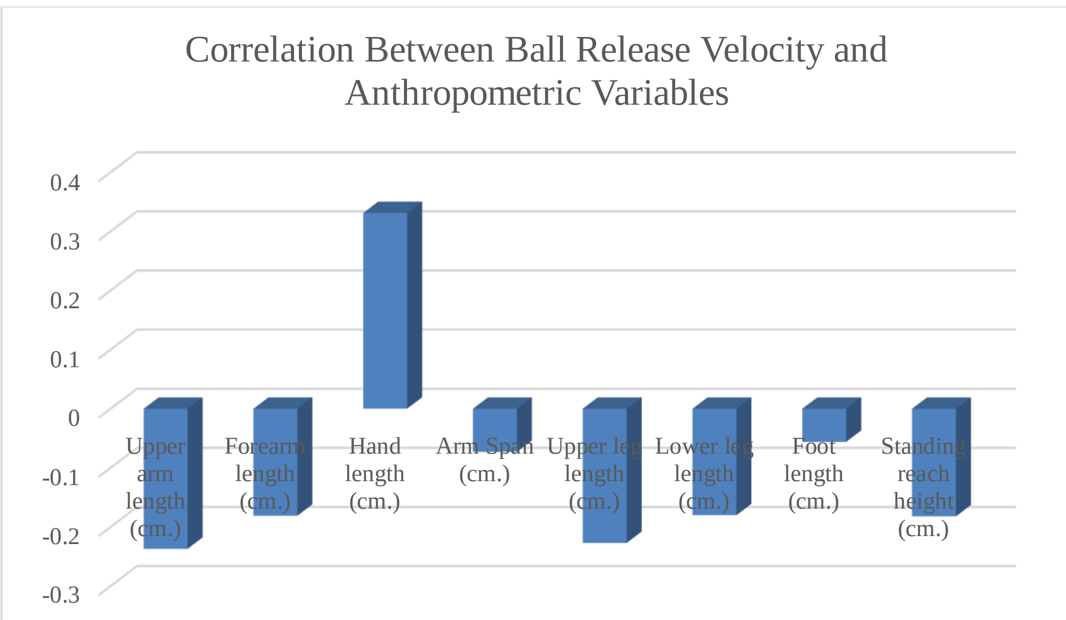
Table 3

Correlation between Ball Release Velocity and Anthropometric Variables

Anthropometric Variables	N	Correlation Coefficient with Ball release velocity (m/s.)	Sig. (2-tailed)
Upper arm length (cm.)	12	-0.237	0.458
Forearm length (cm.)	12	-0.181	0.573
Hand length (cm.)	12	0.331	0.293
Arm span (cm.)	12	-0.073	0.821
Upper leg length (cm.)	12	-0.227	0.478
Lower leg length (cm.)	12	-0.180	0.577
Foot length (cm.)	12	-0.056	0.863
Standing reach height (cm.)	12	-0.182	0.572

Figure 39

Graphical Representation of Correlation between Ball Release Velocity and Anthropometric Variables



The Table 3 and Figure 39 show the relationship between anthropometric variables and ball release velocity of the subjects. Each variable was represented by a Pearson correlation coefficient and its associated significance value.

For upper arm length, the correlation coefficient was -0.237 with a significance value of 0.458, indicating a weak negative relationship that was not statistically significant. Similarly, forearm length showed a correlation of -0.181 and a p-value of 0.573, suggesting a negligible and non-significant association. Hand length, however, had a positive correlation of 0.331 with a p-value of 0.293, which was also not statistically significant but indicated a slightly stronger association compared to other variables.

Arm span presented a weak negative correlation of -0.073, with a high p-value of 0.821, indicating no significant relationship. Upper leg length and lower leg length showed weak negative correlations of -0.227 and -0.180, respectively, with p-values of 0.478 and 0.577, reflecting minimal and non-significant associations. Foot length exhibited a correlation of -0.056 with a p-value of 0.863, suggesting no meaningful relationship. Lastly, standing reach height had a correlation of -0.182 and a p-value of 0.572, further indicating a weak and non-significant negative association.

Overall, none of the anthropometric variables in this analysis exhibited statistically significant correlations with ball release velocity. These findings suggested that the examined physical measurements may have had limited influence on ball release velocity within the sample. Further research with larger samples would have been necessary to provide deeper insights into these relationships.

Table 4

Descriptive Statistics of Kinematic Variables Measured on Best Ball Deliveries (n = 12)

Kinematic variables	N	Minimum	Maximum	Mean	Std. Deviation
Ball release velocity (m/s.)	12	21.23	26.28	24.32	±1.73
Run up length (m.)	12	12.15	18.87	14.67	±2.15
Final run-up velocity (m/s.)	12	2.85	5.18	4.27	±0.72
Bound height (cm.)	12	3.53	21.48	11.00	±5.18
Final stride length (cm.)	12	83.01	141.58	119.55	±17.40
Ball release height (cm.)	12	156.10	187.55	170.97	±10.07
Ball release angle (degree)	12	-10.20	6.20	0.41	±4.42
Ankle joint at FFC (Degree)	12	93.10	150.70	114.18	±18.07
Knee joint at FFC (Degree)	12	154.50	175.80	165.35	±6.33
Hip joint at FFC (Degree)	12	111.90	149.10	126.35	±10.47
Shoulder joint at FFC (Degree)	12	269.30	344.60	311.58	±20.18
Ankle joint at BR (Degree)	12	97.60	139.60	120.28	±13.85
Knee joint at BR (Degree)	12	124.80	198.90	169.07	±23.17
Hip joint at BR (Degree)	12	71.90	124.90	105.33	±15.91
Shoulder joints at BR (Degree)	12	176.70	214.30	195.62	±11.64
Ankle plantar Flexion from FFC to BR	12	-18.80	34.40	6.11	±18.16
Knee flexion from FFC to BR	12	-31.20	38.50	-3.72	±20.30
Hip flexion from FFC to BR	12	8.20	40.00	21.02	±10.17
Shoulder flexion from FFC to BR	12	80.00	148.60	115.96	±19.38

The Table 4 summarized data of kinematic variables that have been chosen to investigate the influence on ball release velocity during pace bowling. The ball release velocity ranged from 21.23 to 26.28 m/s, with a mean of 24.32 m/s (SD = ± 1.73), indicating moderate variability among participants, while the final run-up velocity ranged from 2.85 to 5.18 m/s, with a mean of 4.27 m/s (SD = ± 0.72), reflecting differences in approach strategies and momentum generation. The run-up length varied between 12.15 and 18.87 meters, averaging 14.67 meters (SD = ± 2.15). The ball release height ranged from 156.10 to 187.55 cm (mean = 170.97 cm, SD = ± 10.07), and the ball release angle ranged between -10.20° and 6.20° (mean = 0.41°, SD = ± 4.42), highlighting variations in release mechanics and suboptimal angles for some participants.

Joint angles at front foot contact (FFC) and ball release (BR) revealed substantial biomechanical variability. For instance, the ankle joint angles ranged from 93.10° to 150.70° at FFC and 97.60° to 139.60° at BR, while the knee joint angles were varied from 154.50° to 175.80° at FFC and 124.80° to 198.90° at BR. The hip joint angles ranged from 111.90° to 149.10° at FFC and 71.90° to 124.90° at BR. Notably, the shoulder joint angles displayed considerable variation, especially at FFC, where they ranged from 269.30° to 344.60° (mean = 311.58°, SD = ±20.18). At BR, it is from 176.70° to 214.30° (mean = 195.62°, SD = ±11.64), reflecting its critical role in release mechanics.

The range of motion (ROM) between FFC and BR showed diverse contributions to performance. Ankle plantar flexion ranged from -18.80° to 34.40° (mean = 6.11°, SD = ±18.16), and knee flexion exhibited minimal average change (mean = -3.72°, SD = ±20.30) but significant individual variation. Similarly, hip flexion ranged from 8.20° to 40.00° (mean = 21.02°, SD = ±10.17), and shoulder flexion showed substantial ROM (80.00° to 148.60°, mean = 115.96°, SD = ±19.38). These findings highlighted the considerable variability in kinematic performance, shaped by individual differences in anthropometry, skill levels, and physical conditioning, which can collectively influence ball release mechanics.

Table 5

Correlation between Ball Release Velocity and Kinematic Variables Measured on Best Ball Deliveries (n = 12)

Kinematic Variables	N	Correlation Coefficient with Ball release velocity (m/s.)	Sig. (2-tailed)
Run up length (m.)	12	0.199	0.536
Final Run-up velocity (m/s.)	12	0.325	0.303
Bound height (cm.)	**12**	**-0.587***	**0.045**
Final stride length (cm.)	12	0.002	0.995
Ball release height (cm.)	12	0.06	0.854
Ball release angle (Degree)	12	0.194	0.546
Ankle joint at FFC (Degree)	12	-0.034	0.917
Knee joint at FFC (Degree)	12	0.424	0.170
Hip joint at FFC (Degree)	12	0.228	0.477
Shoulder joint at FFC (Degree)	12	0.001	0.998
Ankle joint at BR (Degree)	**12**	**0.727****	**0.007**
Knee joint at BR (Degree)	**12**	**0.604***	**0.038**
Hip joint at BR (Degree)	12	0.062	0.847
Shoulder joints at BR (Degree)	12	-0.386	0.215
Ankle Plantar Flexion from FFC to BR	**12**	**0.588***	**0.045**
Knee Flexion from FFC to BR	12	-0.557	0.060
Hip Flexion from FFC to BR	12	0.137	0.672
Shoulder Flexion from FFC to BR	12	0.233	0.466
** Correlation is significant at the 0.01 level (2-tailed).			
* Correlation is significant at the 0.05 level (2-tailed).			

The Table 5 represents the correlation analysis between kinematic variables and ball release velocity which reveals key biomechanical insights into factors influencing bowling performance. Among the variables, ankle joint at ball release (BR) demonstrated the strongest positive and significant correlation (r = 0.727, p = 0.007), underscoring the critical role of ankle positioning at the point of release in optimizing velocity. Similarly, the knee joint at BR showed a significant positive correlation (r = 0.604, p = 0.038), highlighting the importance of knee alignment for effective force transfer during the bowling action.

Ankle plantar flexion from front foot contact (FFC) to ball release (BR) also exhibited a significant positive correlation (r = 0.588, p = 0.045), indicating that dynamic ankle movement contributes to enhanced ball release velocity. Although the increase in knee flexion from front foot contact (FFC) to ball release (BR) showed a negative correlation that was close to statistical significance (r = -0.557, p = 0.060), it still suggests that lower limb mechanics play a crucial role to increase ball release velocity.

Conversely, bound height showed a significant negative correlation (r = -0.587, p = 0.045), suggesting that higher vertical displacement during the bound phase might detract from horizontal momentum and reduce ball release velocity. This finding aligns with the principle that excessive vertical motion in a predominantly horizontal skill can diminish performance efficiency.

Other variables, such as run-up length (r = 0.199, p = 0.536), final run-up velocity (r = 0.325, p = 0.303), final stride length (r = 0.002, p = 0.995), ball release height (r = 0.060, p = 0.854), ball release angle (r = 0.194, p = 0.546), knee joint angle at FFC (r = 0.424, p = 0.170), hip joint angle at FFC (r = 0.228, p = 0.477) and BR (r = 0.062, p = 0.847), shoulder joint angle at FFC (r = 0.001, p = 0.998), hip flexion (r = 0.137, p = 0.672) from FFC to BR and shoulder flexion from FFC to BR showed positive but statistically insignificant correlations. Similarly, shoulder joint angle at BR (r = -0.386, p = 0.215) and ankle joint angle at FFC (r = -0.034, p = 0.917) showed negative but statistically insignificant correlations. These insignificant correlations highlight that not all kinematic factors have a direct or consistent impact on velocity.

Figure 40

Graphical Representation of Correlation between Ball Release Velocity and Kinematic Variables Measured on Best Ball Deliveries (n = 12)

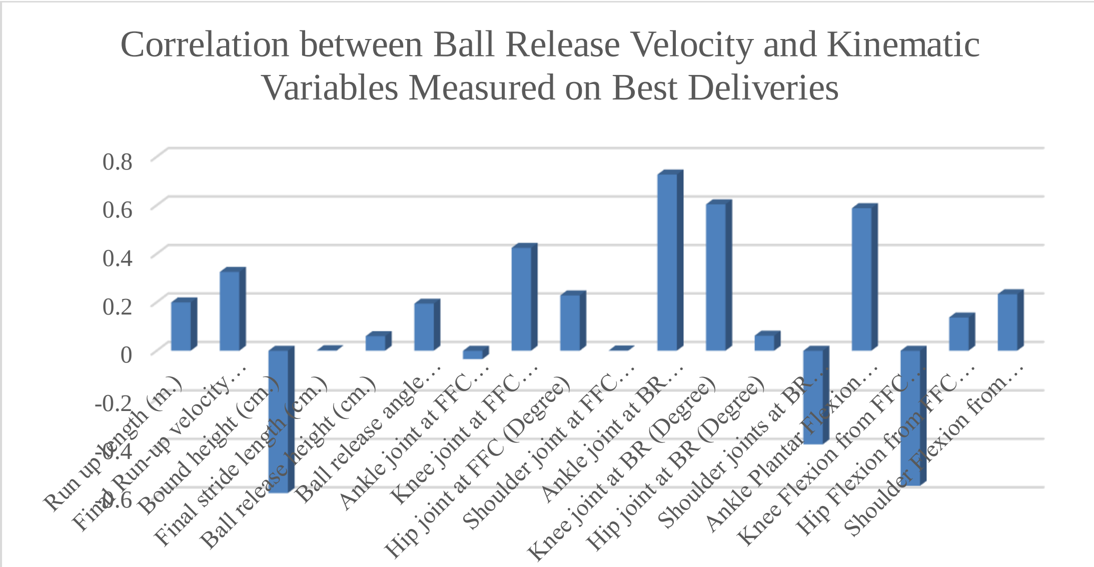


Figure 41

Graphical Representation of Correlation between Bound Height and Ball Release Velocity Measured on Best Ball Deliveries (n = 12)

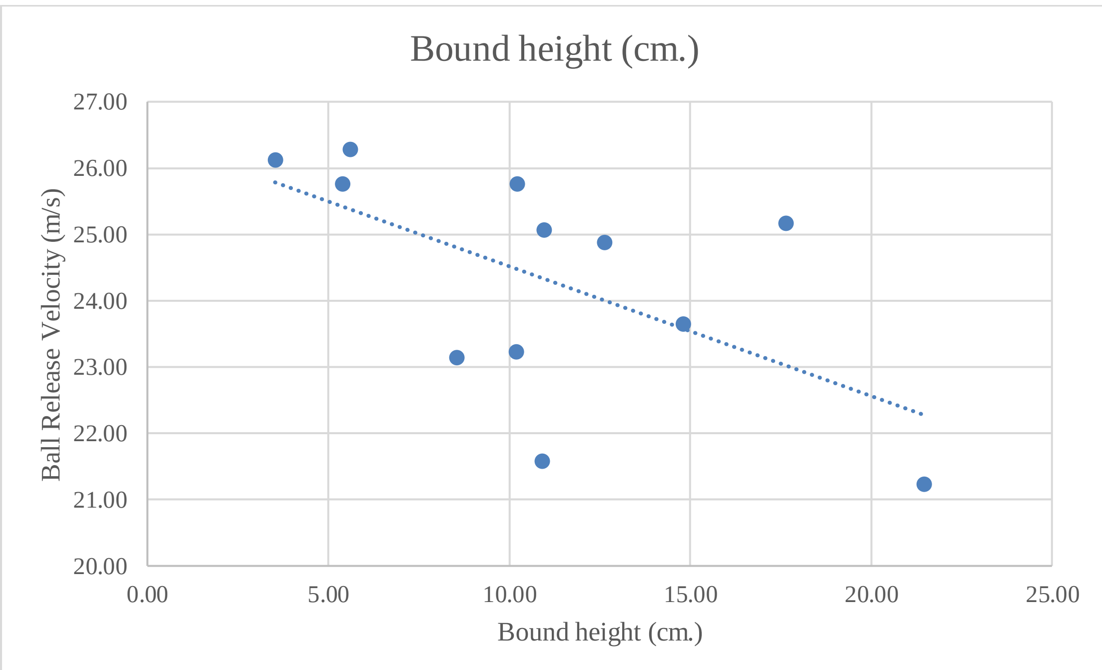


Figure 42

Graphical Representation of Correlation between Ankle Joint Angle at BR and Ball Release Velocity Measured on Best Deliveries (n = 12)

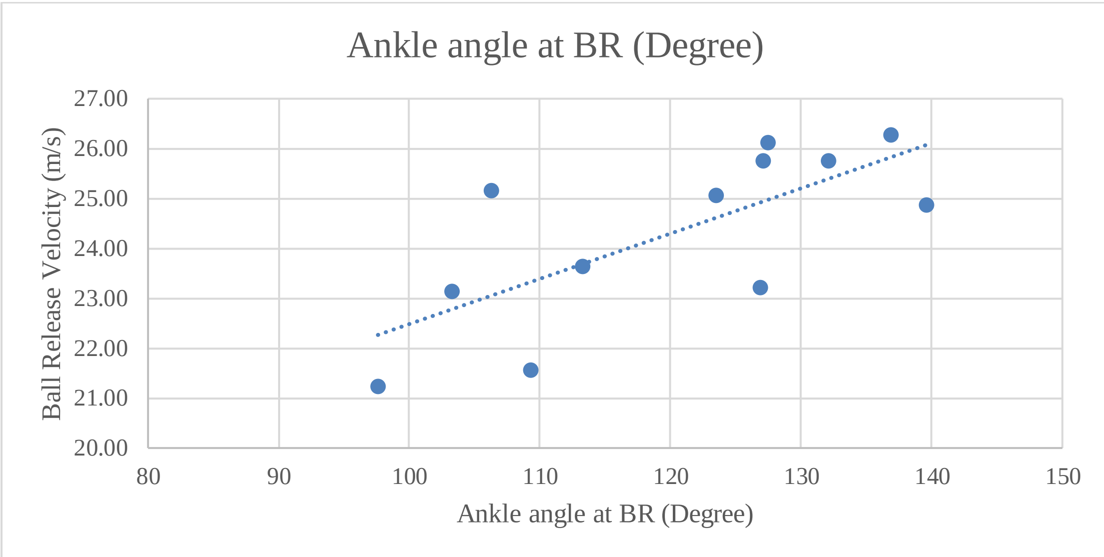


Figure 43:

Graphical Representation of Correlation between Knee Joint Angle at BR and Ball Release Velocity Measured on Best Ball Deliveries (n = 12)

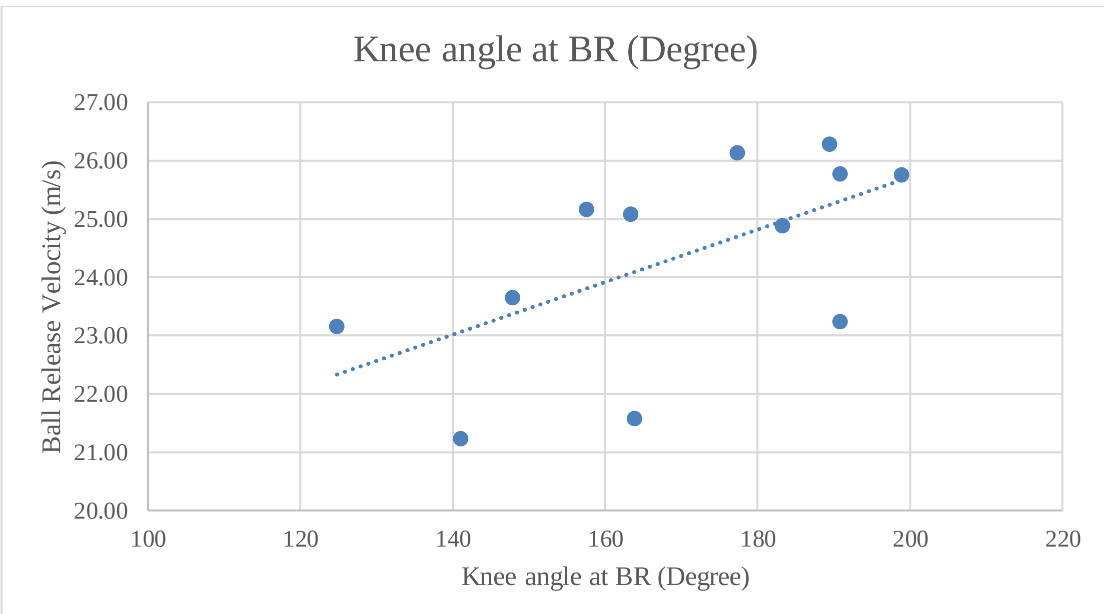


Figure 44

Graphical Representation of Correlation between Ankle Planter Flexion from FFC to BR and Ball Release Velocity Measured on Best Ball Deliveries (n = 12)

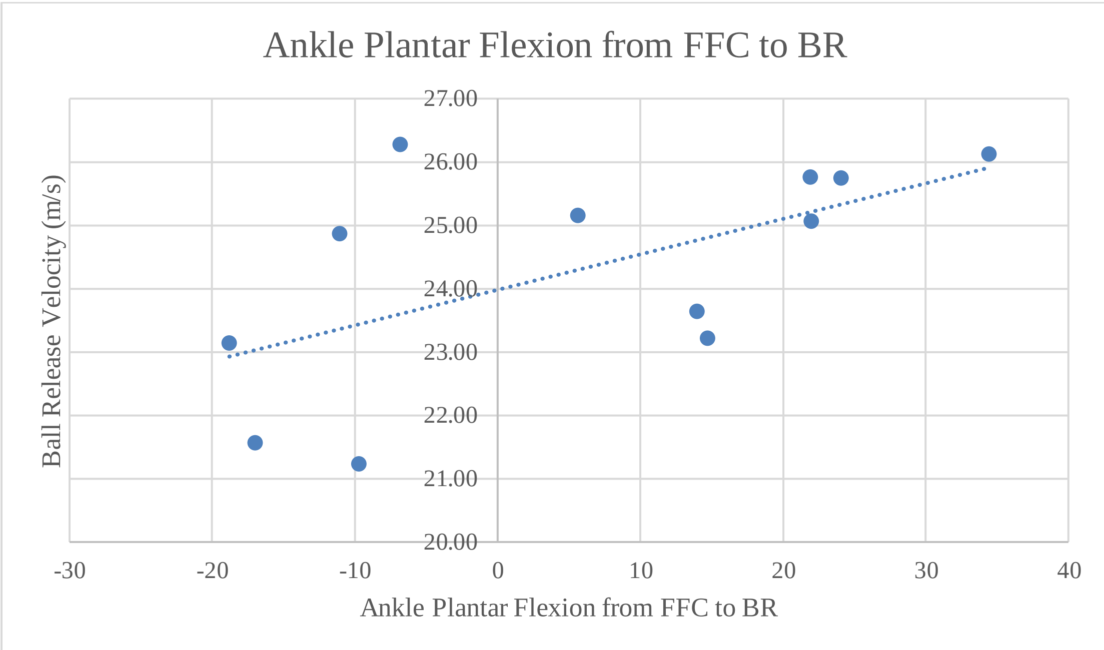


Table 6

Descriptive Statistics of Kinematic Variables Measured on All Ball Deliveries (n = 72)

Kinematic variables	N	Minimum	Maximum	Mean	Std. Deviation
Ball release velocity (m/s.)	72	19.60	26.28	23.69	±1.78
Final run-up velocity (m/s.)	72	2.53	5.50	4.27	±0.74
Bound height (cm.)	72	2.59	21.75	11.07	±4.90
Final stride length (cm.)	72	81.46	143.13	118.18	±15.91
Ball release height (cm.)	72	155.43	196.17	170.31	±9.10
Ball release angle (degree)	72	-13.80	6.20	-0.98	±4.50
Ankle angle at FFC (Degree)	72	87.00	153.70	112.96	±18.04
Knee angle at FFC (Degree)	72	152.10	181.80	165.41	±6.47
Hip angle at FFC (Degree)	72	107.50	149.10	125.32	±10.09
Shoulder angle at FFC (Degree)	72	257.10	349.70	312.86	±18.53
Ankle angle at BR (Degree)	72	93.40	144.50	120.28	±13.18
Knee angle at BR (Degree)	72	118.80	202.80	167.98	±22.93
Hip angle at BR (Degree)	72	71.90	127.80	103.51	±14.88
Shoulder angle at BR (Degree)	72	176.70	225.20	199.19	±13.15
Ankle plantar Flexion from FFC to BR (Degree)	72	-30.40	45.20	7.32	±17.76
Knee flexion from FFC to BR (Degree)	72	-34.50	41.00	-2.57	±19.68
Hip flexion from FFC to BR (Degree)	72	0.50	40.00	21.81	±9.64
Shoulder flexion from FFC to BR (Degree)	72	77.60	148.60	113.67	±16.22

The kinematic variables, in the Table 6, highlight key biomechanical aspects of the bowling motion across a total of 72 bowling deliveries of 12 subjects (6 deliveries of each subject), offering insights into how body mechanics contribute to ball release velocity and overall bowling performance. The mean ball release velocity was 23.69 m/s, with a moderate range (19.60–26.28 m/s) and variability (SD = 1.78), reflecting differences in subjects' skill levels and mechanics.

The final run-up velocity (mean = 4.27 m/s, SD = 0.74) was relatively consistent, indicating uniformity in approach speed during the throw. The bound height (mean = 11.07 cm, SD = 4.90) showed substantial variability, with values ranging from 2.59 cm to 21.75 cm, reflecting differences in explosive leg power and centre of gravity adjustments during pre-delivery phase. The final stride length (mean = 118.18 cm, SD = 15.91) and ball release height (mean = 170.31 cm, SD = 9.10) exhibited moderate variability, highlighting the influence of physical attributes and technique in achieving optimal bowling velocity.

The ball release angle had a mean of -0.98° (SD = 4.50), with a range from -13.80° to 6.20°, indicating that most subjects released the ball with a slight upward trajectory, potentially to enhance control or adjustment to hit the ball in the target (good length area) with a slower bowling speed. Joint angles at final foot contact (FFC) and ball release (BR) phases displayed varying levels of variability: ankle angles at FFC (mean = 112.96°, SD = 18.04) and BR (mean = 120.28°, SD = 13.18), knee angles at FFC (mean = 165.41°, SD = 6.47) and BR (mean = 167.98°, SD = 22.93), hip angles at FFC (mean = 125.32°, SD = 10.09) and BR (mean = 103.51°, SD = 14.88), and shoulder angles at FFC (mean = 312.86°, SD = 18.53) and BR (mean = 199.19°, SD = 13.15). These values highlight the complexity of body alignment and motion during bowling.

Joint movements from FFC to BR, including ankle plantar flexion (mean = 7.32°, SD = 17.76), knee flexion (mean = -2.57°, SD = 19.68), hip flexion (mean = 21.81°, SD = 9.64), and shoulder flexion (mean = 113.67°, SD = 16.22), demonstrated significant variability, reflecting differences in subjects' technique and physical conditioning.

Table 7

Correlation between Ball Release Velocity and Kinematic Variables Measured on All Ball Deliveries (n = 72)

Kinematic variables	N	Correlation coefficient with ball release velocity (m/s.)	Sig. (2-tailed)
Final run-up velocity (m/s.)	**72**	**0.373****	**0.001**
Bound height (cm.)	**72**	**-0.537****	**0.000**
Final stride length (cm.)	72	0.143	0.232
Ball release height (cm.)	**72**	**-0.283***	**0.016**
Ball release angle (Degree)	**72**	**0.712****	**0.000**
Ankle angle at FFC (Degree)	72	0.049	0.683
Knee angle at FFC (Degree)	**72**	**0.365****	**0.002**
Hip angle at FFC (Degree)	72	0.192	0.106
Shoulder angle at FFC (Degree)	72	-0.126	0.290
Ankle angle at BR (Degree)	**72**	**0.693****	**0.000**
Knee angle at BR (Degree)	**72**	**0.572****	**0.000**
Hip angle at BR (Degree)	**72**	**0.264***	**0.025**
Shoulder angle at BR (Degree)	**72**	**-0.458****	**0.000**
Ankle plantar flexion from FFC to BR (Degree)	**72**	**0.465****	**0.000**
Knee flexion from FFC to BR (Degree)	**72**	**-0.547****	**0.000**
Hip flexion from FFC to BR (Degree)	72	-0.207	0.081
Shoulder flexion from FFC to BR (Degree)	72	0.227	0.055
** Correlation is significant at the 0.01 level (2-tailed).			
* Correlation is significant at the 0.05 level (2-tailed).			

In the Table 7, the correlation analysis between kinematic variables and ball release velocity of a total 72 bowling deliveries of 12 participants (6 deliveries of each participant) reveals several significant relationships that highlight the biomechanical factors influencing bowling performance. Final run-up velocity exhibited a moderate positive correlation with ball release velocity (r = 0.373, p = 0.001), emphasizing the importance of maintaining a high approach speed to generate momentum. Conversely, bound height showed a significant negative correlation (r = -0.537, p = 0.000), indicating that excessive vertical displacement during the bound phase can detract from horizontal energy transfer, thereby reducing velocity.

Interestingly, ball release height showed a small but significant negative correlation (r = -0.283, p = 0.016), suggesting that a higher release point does not necessarily translate to greater velocity.

The ball release angle demonstrated a strong positive correlation with ball release velocity (r = 0.712, p = 0.000), underscoring its critical role in optimizing the trajectory for maximum speed. Similarly, the knee angle at FFC (r = 0.365, p = 0.002), ankle angle at BR (r = 0.693, p = 0.000) and knee angle at BR (r = 0.572, p = 0.000) showed significant positive correlations as well as shoulder angle at BR (r = -0.458, p = 0.000) showed significant negative correlations, highlighting the importance of joint alignment and positioning at the point of release in achieving optimal bowling velocity. Additionally, hip angle at BR showed a weaker but still significant positive correlation (r = 0.264, p = 0.025), further supporting the role of hip mechanics.

Ankle plantar flexion from FFC to BR was positively correlated with ball release velocity (r = 0.465, p = 0.000), indicating that dynamic ankle movement contributes to the generation of ball release velocity. On the other hand, knee flexion from FFC to BR was negatively correlated (r = -0.547, p = 0.000) with ball release velocity.

Other variables, such as final stride length (r = 0.143, p = 0.232), ankle angle at FFC (r = 0.049, p = 0.683), hip angle at FFC (r = 0.192, p = 0.106), shoulder angle at FFC (r = -0.126, p = 0.290), hip flexion from FFC to BR (r = −0.207, p = 0.081), and shoulder flexion from FFC to BR (r = 0.227, p = 0.055), showed weaker or statistically insignificant correlations, suggesting their role might be less direct or more context-dependent.

Figure 45

Graphical Representation of Correlation between Ball Release Velocity and Kinematic Variables Measured on All Ball Deliveries (n = 72)

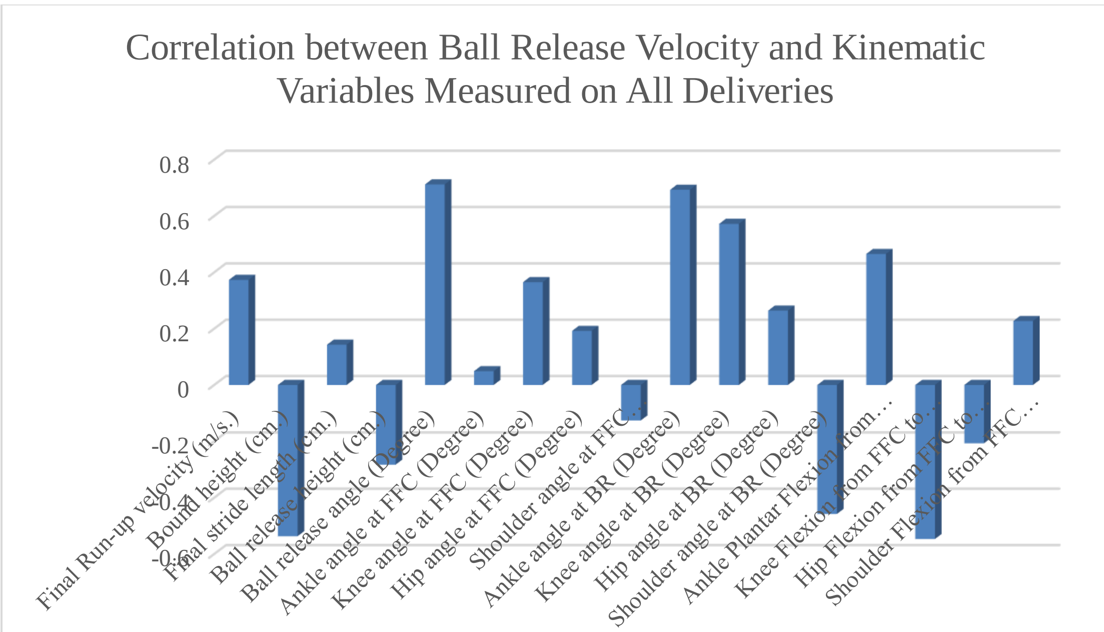


Figure 46

Graphical Representation of Correlation between Ball Release Velocity and Final Run-up Velocity Measured on All Ball Deliveries (n = 72)

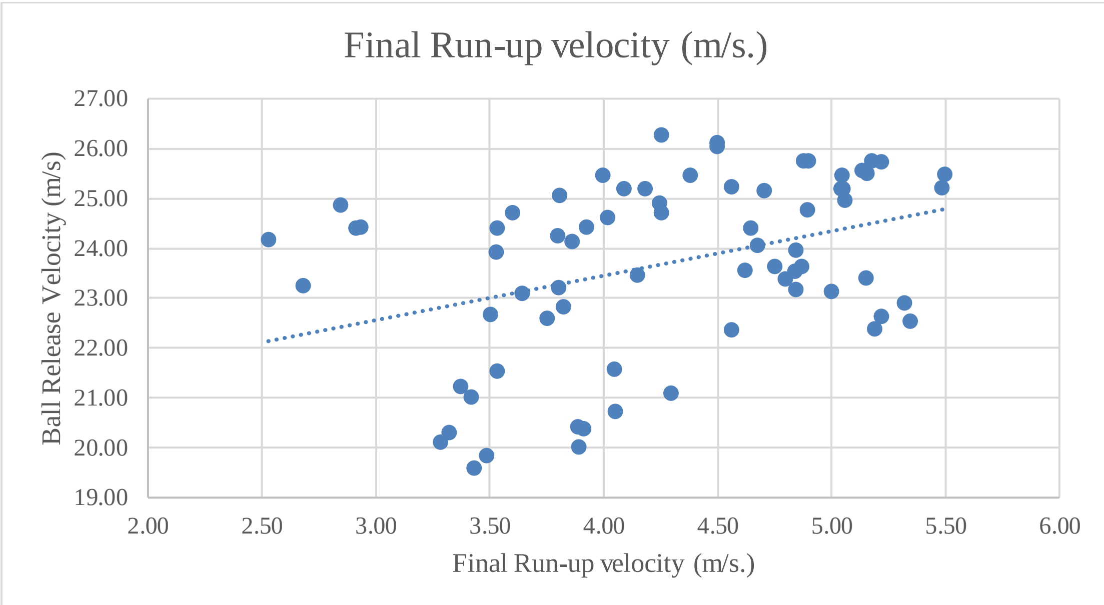


Figure 47

Graphical Representation of Correlation between Ball Release Velocity and Bound Height Measured on All Ball Deliveries (n = 72)

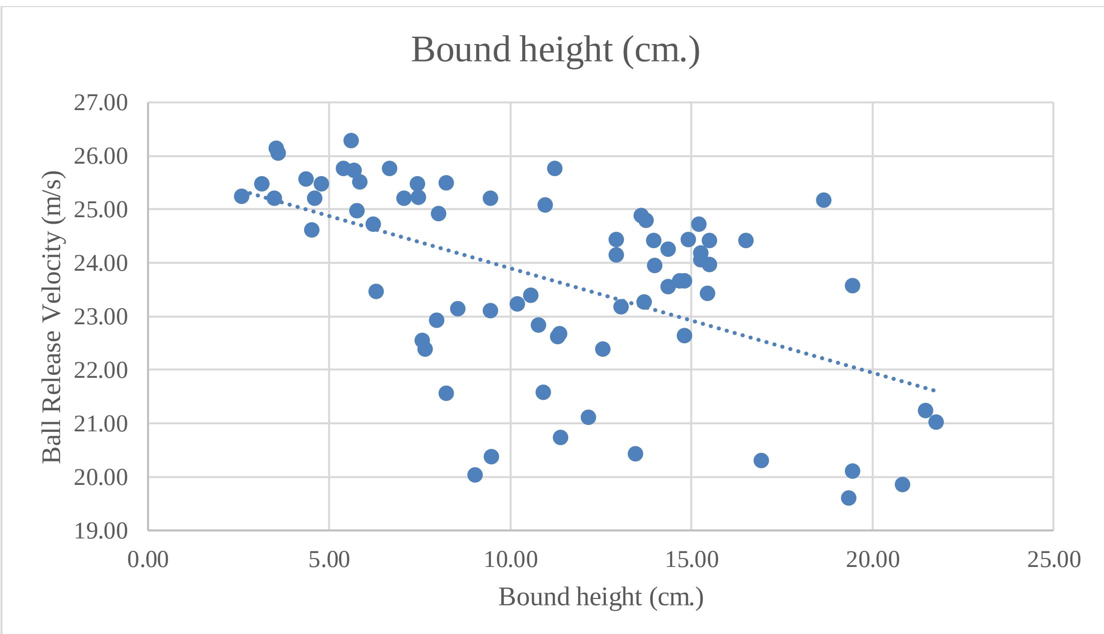


Figure 48

Graphical Representation of Correlation between Ball Release Velocity and Ball Release Height Measured on All Ball Deliveries (n = 72)

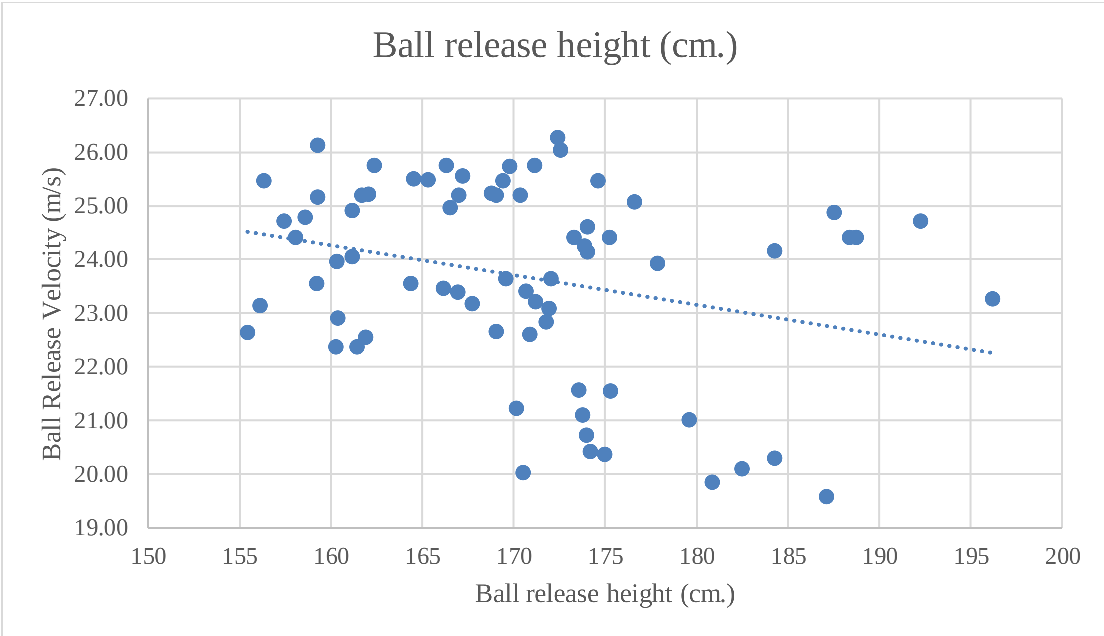


Figure 49:

Graphical Representation of Correlation between Ball Release Velocity and Ball Release Angle Measured on All Ball Deliveries (n = 72)

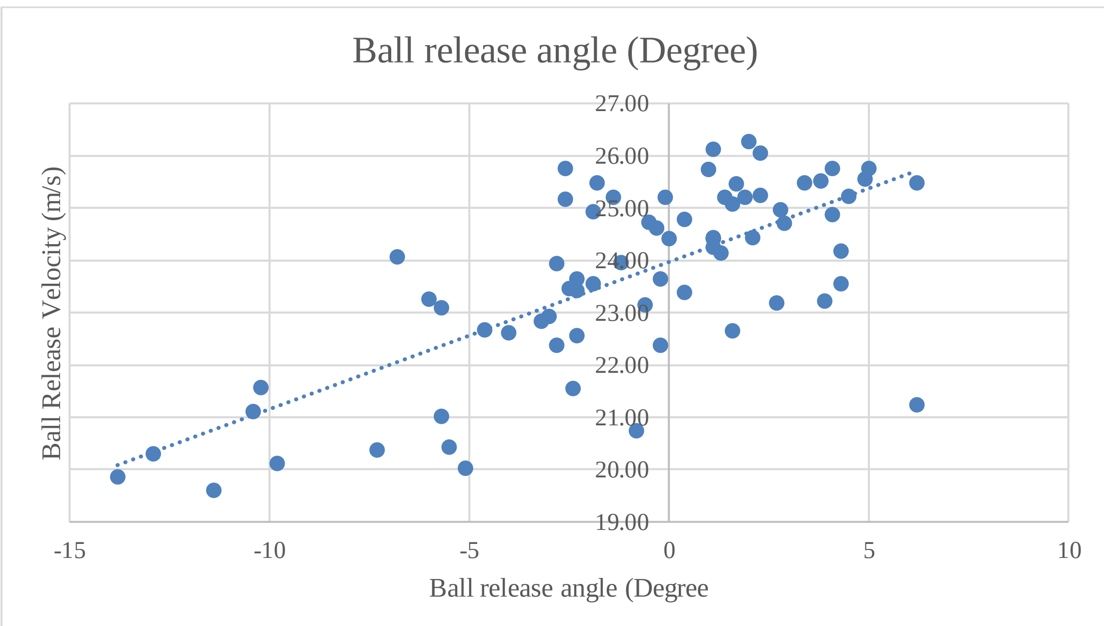


Figure 50

Graphical Representation of Correlation between Ball Release Velocity and Knee Angle at FFC Measured on All Ball Deliveries (n = 72)

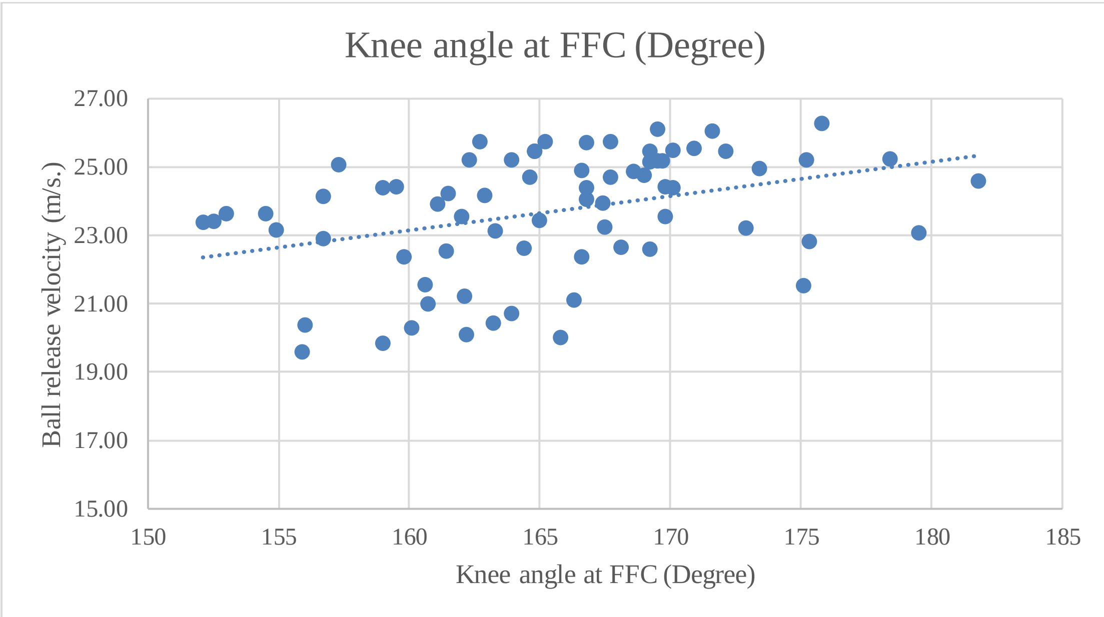


Figure 51

Graphical Representation of Correlation between Ball Release Velocity and Ankle Joint Angle at BR Measured on All Ball Deliveries (n = 72)

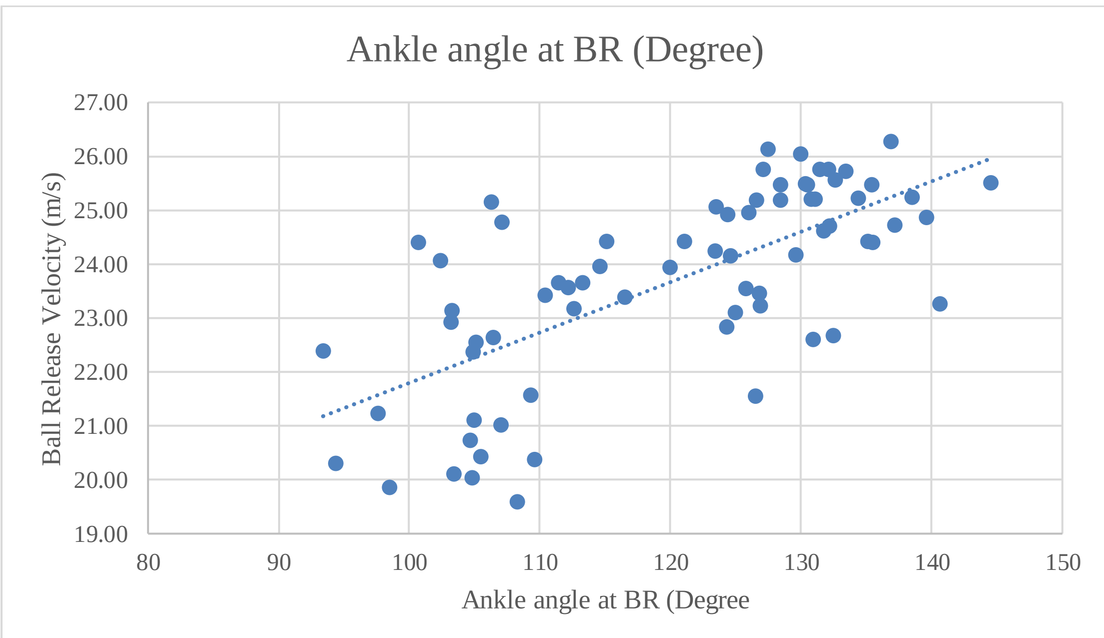


Figure 52

Graphical Representation of Correlation between Ball Release Velocity and Knee Joint Angle at BR Measured on All Ball Deliveries (n = 72)

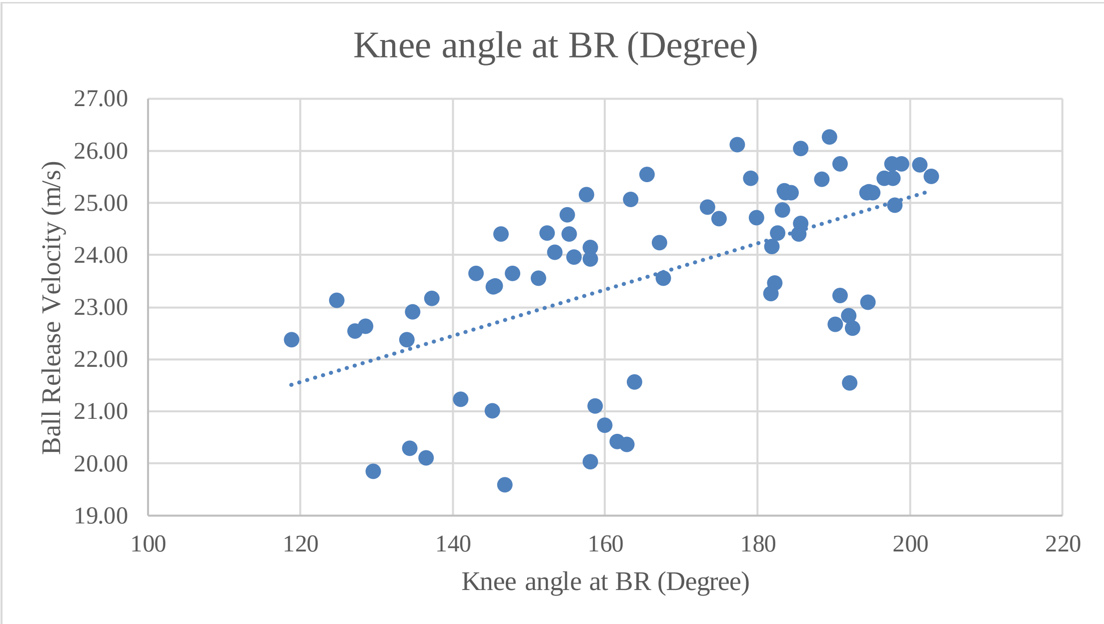


Figure 53

Graphical Representation of Correlation between Ball Release Velocity and Hip Joint Angle at BR Measured on All Ball Deliveries (n = 72)

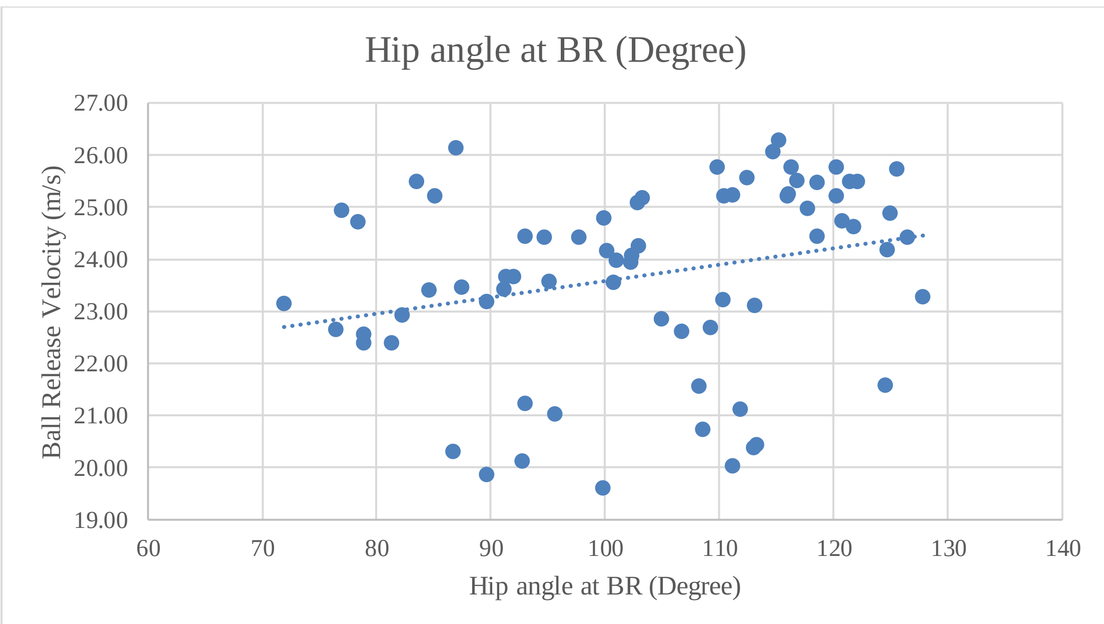


Figure 54

Graphical Representation of Correlation between Ball Release Velocity and Shoulder Joint Angle at BR Measured on All Ball Deliveries (n = 72)

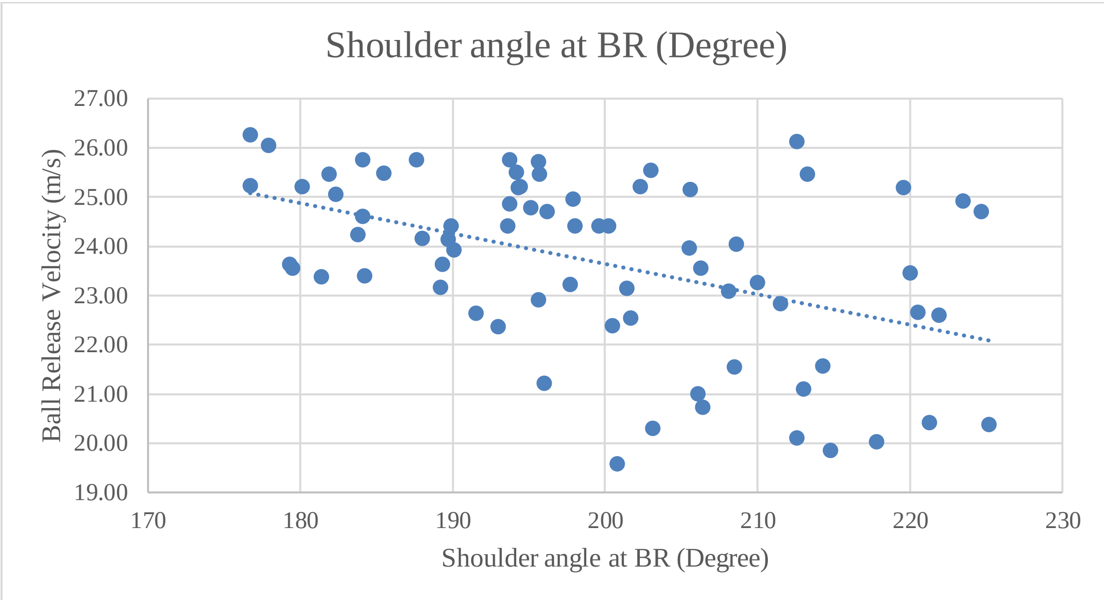


Figure 55

Graphical Representation of Correlation between Ball Release Velocity and Ankle Planter Flexion from FFC to BR Measured on All Ball Deliveries (n = 72)

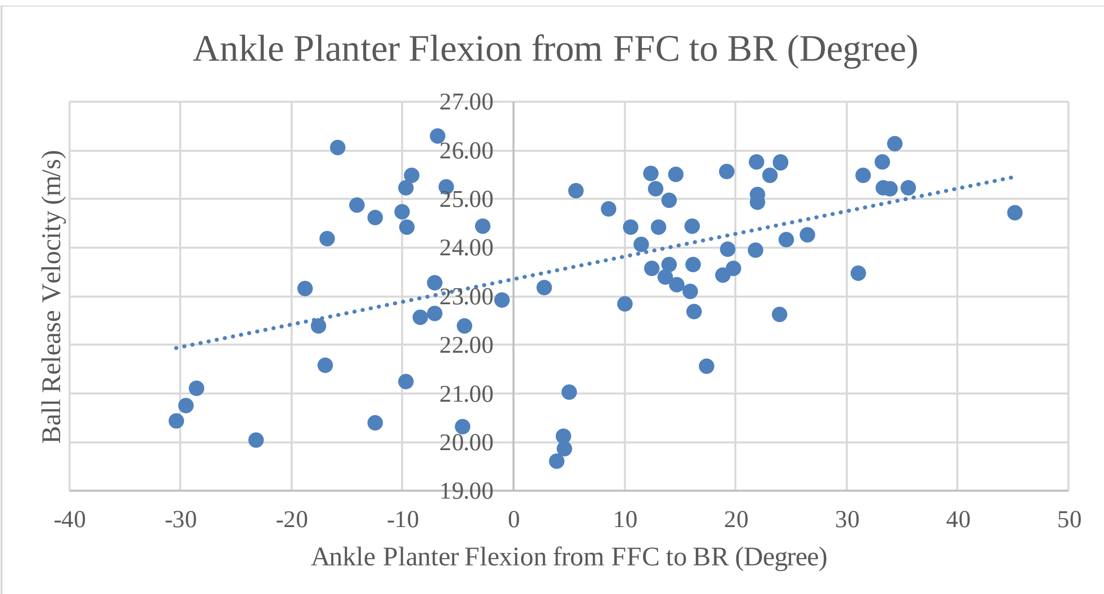


Figure 56

Graphical Representation of Correlation between Ball Release Velocity and Knee Flexion from FFC to BR Measured on All Ball Deliveries (n = 72)

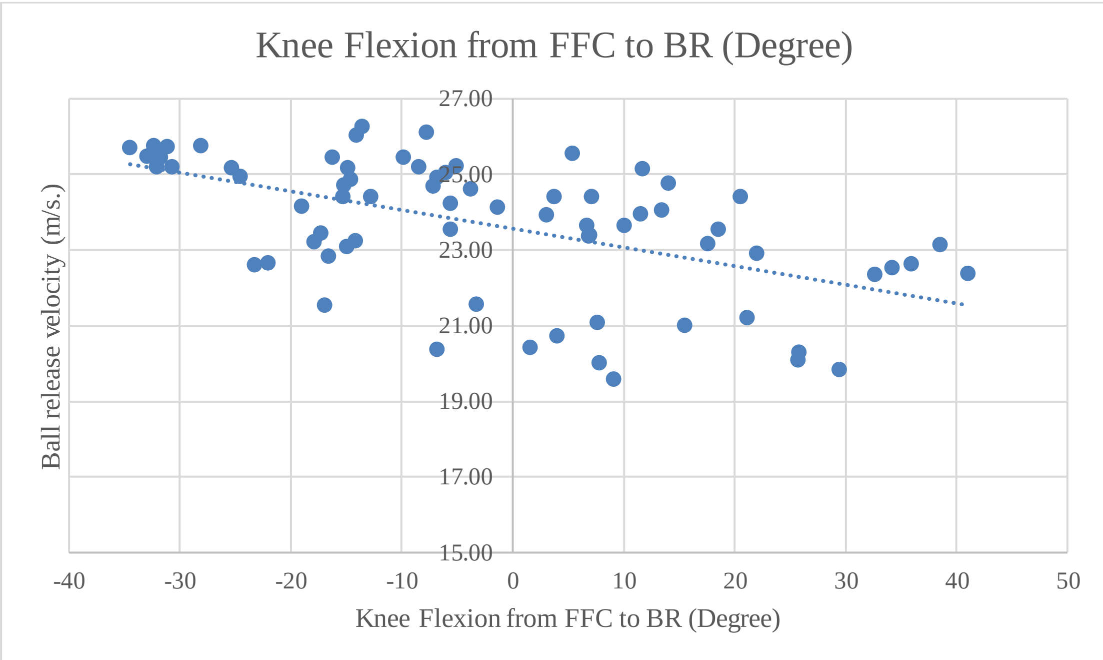


Table 8

Model Summery of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.935	0.873	0.845	0.69930

The Table 8 shows the regression analysis summary which provided insights into the model's ability to predict the dependent variable (ball release velocity) using the selected independent variables.

The R value (R = 0.935) indicated a very strong correlation between the predicted and actual values of the dependent variable, suggesting a high degree of accuracy in the model's predictions. The R Square value (R^2 = 0.873) revealed that 87.3% of the variance in ball release velocity is explained by the independent variables included in the model. This high percentage indicated that the model captures the key factors influencing the ball release velocity.

The Adjusted R Square (Adj. R^2 = 0.845) accounted for the number of predictors in the model, providing a more conservative estimate of its explanatory power. This value remained high, confirming the robustness of the model even after considering the number of variables.

The Standard Error of the Estimate (Std. Error = 0.69930) represented the average distance between the actual data points and the regression line. A lower value indicated higher precision in the model's predictions.

Table 9

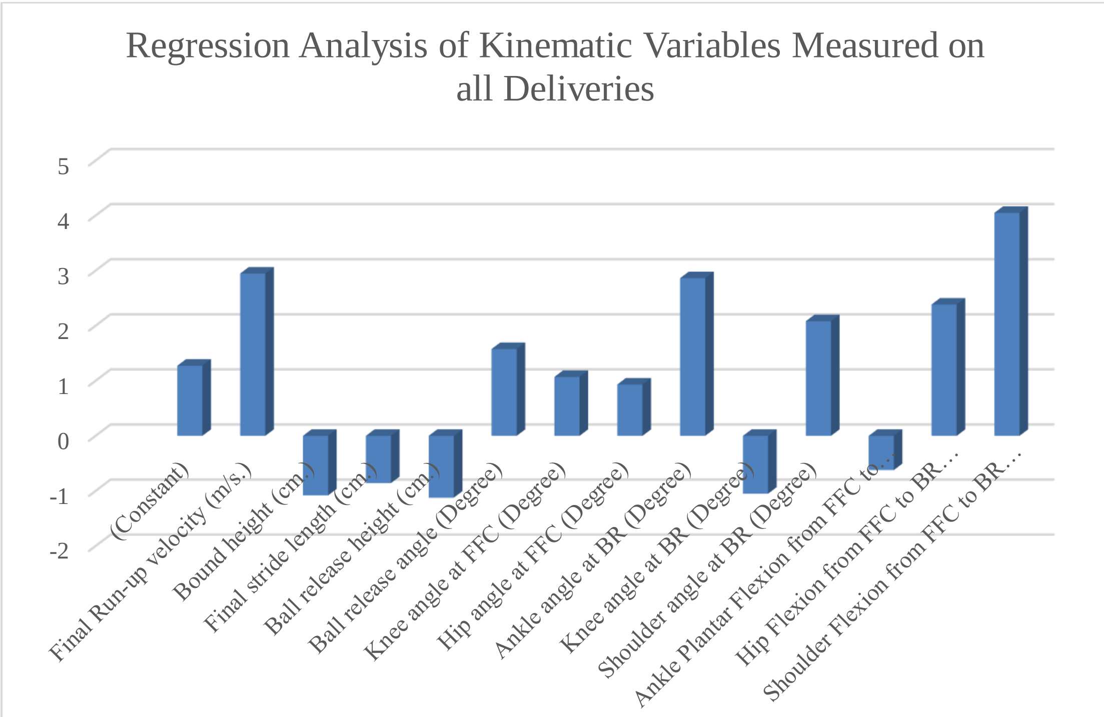
Coefficient of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	10.860	8.529		1.273	0.208
Final Run-up velocity (m/s.)	**0.887**	**0.301**	**0.371**	**2.946**	**0.005**
Bound height (cm.)	-0.035	0.032	-0.095	-1.080	0.285
Final stride length (cm.)	-0.016	0.018	-0.141	-0.857	0.395
Ball release height (cm.)	-0.033	0.029	-0.169	-1.123	0.266
Ball release angle (Degree)	0.056	0.035	0.141	1.576	0.120
Ankle angle at FFC (Degree)	-	-	-	-	-
Knee angle at FFC (Degree)	0.027	0.025	0.097	1.070	0.289
Hip angle at FFC (Degree)	0.029	0.031	0.163	0.932	0.355
Shoulder angle at FFC (Degree)	-	-	-	-	-
Ankle angle at BR (Degree)	**0.059**	**0.021**	**0.440**	**2.864**	**0.006**
Knee angle at BR (Degree)	-	-	-	-	-
Hip angle at BR (Degree)	-	-	-	-	-
Shoulder angle at BR (Degree)	-0.011	0.011	-0.083	-1.050	0.298
Ankle Plantar Flexion from FFC to BR (Degree)	**0.020**	**0.010**	**0.204**	**2.082**	**0.042**
Knee Flexion from FFC to BR (Degree)	-0.009	0.015	-0.100	-0.621	0.537
Hip Flexion from FFC to BR (Degree)	**0.049**	**0.020**	**0.264**	**2.384**	**0.020**
Shoulder Flexion from FFC to BR (Degree)	**0.025**	**0.006**	**0.228**	**4.048**	**0.000**

Note: Ankle Ange at FFC, Shoulder Angle at FFC, Knee Angle at BR and Hip angle at BR were excluded by the software due to collinearity of data with another variable.

Figure 57

Graphical Representation of Regression Analysis of Kinematic Variables Measured on All Ball Deliveries (n = 72)



The Table 9 and Figure 57 of multiple linear regression analysis indicate that several kinematic variables significantly contribute to the dependent variable, while others do not. Among the predictors, final run-up velocity (B = 0.887, p = 0.005) emerges as a key factor, demonstrating a strong positive effect on performance. This suggests that higher approach speed is crucial in optimizing the outcome. Additionally, ankle angle at ball release (B = 0.059, p = 0.006) and shoulder flexion from front foot contact (FFC) to ball release (BR) (B = 0.025, p = 0.001) also play significant roles, with the latter showing the strongest statistical significance. These findings emphasize the importance of joint mechanics in effective performance execution.

Other significant predictors include ankle plantar flexion from FFC to BR ($B = 0.020$, $p = 0.042$) and hip flexion from FFC to BR ($B = 0.049$, $p = 0.020$), both of which contribute positively. These results highlight the role of dynamic lower limb movements in influencing the outcome.

However, several variables, including bound height, final stride length, ball release height, and ball release angle, were found to be statistically insignificant ($p > 0.05$), suggesting that they do not meaningfully impact performance in this model. Similarly, knee angle at FFC, hip angle at FFC, shoulder angle at BR and knee flexion from FFC to BR failed to show significant contributions.

Ankle angle at FFC, shoulder angle at FFC, knee angle at BR and hip angle at BR were excluded by the statistical software (SPSS) due to collinearity of data with another variable.

Table 10

Compiled Table of Correlation and Regression Analysis of Kinematic Variables with Ball Release Velocity Measured on Best Ball Deliveries (n = 12) and All Ball Deliveries (n = 72)

Kinematic Variables	Measured on best deliveries (n = 12)		Measured on all deliveries (n = 72)			
	Correlation		Correlation		Regression	
	r	p	r	p	t	p
Run up length (m.)	0.199	0.536	-	-	-	-
Final Run-up velocity (m/s.)	0.325	0.303	**0.373****	**0.001**	**2.946**	**0.005**
Bound height (cm.)	**-0.587***	**0.045**	**-0.537****	**0.000**	-1.080	0.285
Final stride length (cm.)	0.002	0.995	0.143	0.232	-0.857	0.395
Ball release height (cm.)	0.06	0.854	**-0.283***	**0.016**	-1.123	0.266
Ball release angle (Degree)	0.194	0.546	**0.712****	**0.000**	1.576	0.120
Ankle joint at FFC (Degree)	-0.034	0.917	0.049	0.683	-	-
Knee joint at FFC (Degree)	0.424	0.17	**0.365****	**0.002**	1.070	0.289
Hip joint at FFC (Degree)	0.228	0.477	0.192	0.106	0.932	0.355
Shoulder joint at FFC (Degree)	0.001	0.998	-0.126	0.290	-	-
Ankle joint at BR (Degree)	**0.727****	**0.007**	**0.693****	**0.000**	**2.864**	**0.006**
Knee joint at BR (Degree)	**0.604***	**0.038**	**0.572****	**0.000**	-	-
Hip joint at BR (Degree)	0.062	0.847	**0.264***	**0.025**	-	-
Shoulder joints at BR (Degree)	-0.386	0.215	**-0.458****	**0.000**	-1.050	0.298
Ankle Plantar Flexion from FFC to BR	**0.588***	**0.045**	**0.465****	**0.000**	**2.082**	**0.042**
Knee Flexion from FFC to BR	-0.557	0.06	**-0.547****	**0.000**	-0.621	0.537
Hip Flexion from FFC to BR	0.137	0.672	-0.207	0.081	**2.384**	**0.020**
Shoulder Flexion from FFC to BR	0.233	0.466	0.227	0.055	**4.048**	**0.000**

The Table 10 revealed the overview of significant kinematic variables based on three statistical measures: correlation on best deliveries, correlation on all deliveries, and regression on all deliveries. The final run-up velocity was significant in both the correlation on all deliveries and the regression analysis. Bound height was significant in the correlation on both best and all deliveries, while ball release height and ball release angle were significant in the correlation on all deliveries. Knee joint at FFC also showed significance in the correlation on all deliveries. The ankle joint at ball release (BR) was significant in all three analyses: correlation on best deliveries, correlation on all deliveries, and regression. Both the knee joint at BR and shoulder joint at BR were significant in the correlation on all deliveries. Additionally, Ankle plantar flexion from FFC to BR was significant in all three statistics, while knee flexion from FFC to BR was significant in the correlation on all deliveries. Hip flexion from FFC to BR was significant in regression, and shoulder flexion from FFC to BR was significant in regression as well.

On the other hand, variables such as run-up length, final stride length, ankle joint at FFC, hip joint at FFC, and shoulder joint at FFC were not significant in any of the three statistical measures.

Table 11

Descriptive Statistics of Physical Fitness Variables

Physical fitness variables	N	Minimum	Maximum	Mean	Std. Deviation
Arm strength (kg.)	12	27.10	36.30	32.13	±2.36
Back strength (kg.)	12	44.00	55.00	51.08	±3.65
Leg strength (kg.)	12	44.00	55.00	50.58	±4.03
Upper body power (mtr.)	12	6.72	8.02	7.31	±0.41
Lower body power (cm.)	12	24.50	41.00	32.50	±4.91
Core stability (sec.)	12	75.00	251.65	143.59	±52.10
Speed (m/sec.)	12	4.59	5.88	5.25	±0.37
Flexibility (cm.)	12	30.50	38.00	35.13	±2.23

The Table 11 presents the descriptive statistics for various physical fitness variables, including measures of strength, endurance, power, speed, and flexibility, providing a comprehensive profile of participants' fitness levels across 12 individuals.

The arm strength test recorded a mean value of 32.13 kg, with a range from 27.10 to 36.30 kg and a standard deviation (SD) of ±2.36, indicating relatively consistent upper body strength among participants. The back strength test showed a mean of 51.08 kg (SD = ±3.65), ranging from 44.00 to 55.00 kg, and the leg strength test had a mean of 50.58 kg (SD = ±4.03), both reflecting moderate variability in overall muscular strength.

The prone hold test, which measures core endurance, exhibited considerable variability, with a mean of 143.59 seconds (SD = ±52.10) and values ranging from 75.00 to 251.65 seconds. The medicine ball throw test, indicative of upper body power, showed a mean distance of 7.31 meters (SD = ±0.41), with participants scoring between 6.72 and 8.02 meters.

The vertical jump test, assessing lower body explosive power, had a mean of 32.50 cm (SD = ±4.91) with scores ranging from 24.50 to 41.00 cm, demonstrating variability in jump height capabilities. The 20-meter speed test, used to evaluate short-distance sprinting speed, recorded a mean speed of 5.25 m/seconds (SD = ±0.37), with speed ranging from 4.59 to 5.88 m/seconds, indicating moderate consistency in participants' sprinting performance. Lastly, flexibility, measured in centimetres, had a mean score of 35.13 cm (SD = ±2.23), with participants ranging from 30.50 to 38.00 cm, reflecting relatively consistent flexibility levels.

Table 12

Correlation between Ball Release Velocity and Physical Fitness Variables

Physical fitness variables	N	Correlation coefficient with ball release velocity (m/s.)	Sig. (2-tailed)
Arm strength (kg.)	**12**	**0.610***	**0.035**
Back strength (kg.)	12	0.411	0.185
Leg strength (kg.)	**12**	**0.616***	**0.033**
Upper body power- medicine ball throwing distance (mtr.)	**12**	0.213	0.506
Lower body power- vertical jump height (cm.)	12	0.415	0.179
Core stability- prone hold timing (sec.)	12	**0.577***	**0.050**
Speed (m/sec.)	**12**	**0.581***	**0.048**
Flexibility (cm.)	**12**	**0.646***	**0.023**
* Correlation is significant at the 0.05 level (2-tailed).			

The Table 12 and Figure 58 presents the correlation analysis between physical fitness variables and ball release velocity, highlighting the relationship and statistical significance of each fitness component in contributing to performance. The analysis is based on 12 observations, with correlation coefficients (r) and significance levels (p) reported for each variable.

Among the variables, arm strength showed a significant positive correlation ($r = 0.610$, $p = 0.035$), indicating that participants with greater arm strength tended to achieve higher ball release velocities. Similarly, leg strength exhibited a significant positive correlation ($r = 0.616$, $p = 0.033$), suggesting that stronger leg muscles contribute to better force generation during the bowling motion.

The prone hold test, which measures core stability and endurance, also showed a significant positive correlation ($r = 0.577$, $p = 0.050$), emphasizing the importance of core stability in facilitating effective transfer of force during the bowling process. Flexibility demonstrated the strongest positive correlation (r =0.646, p = 0.023), highlighting the critical role of flexibility in achieving optimal joint range of motion for efficient bowling mechanics.

In contrast, the 20-meter speed test revealed a significant negative correlation with ball release velocity (r = 0.581, p = 0.048), indicating that faster sprint times are associated with higher ball release velocities. This suggests that speed, as a dynamic physical attribute, complements bowling velocity by enabling greater momentum generation during the run-up phase.

The other variables, including back strength (r = 0.411, p = 0.185), medicine ball throw test (r = 0.213, p = 0.506), and vertical jump test (r = 0.415, p = 0.179), showed positive but statistically insignificant correlations, suggesting their secondary or indirect contributions to ball release velocity.

Figure 58

Graphical Representation of Correlation between Ball Release Velocity and Physical Fitness Variables

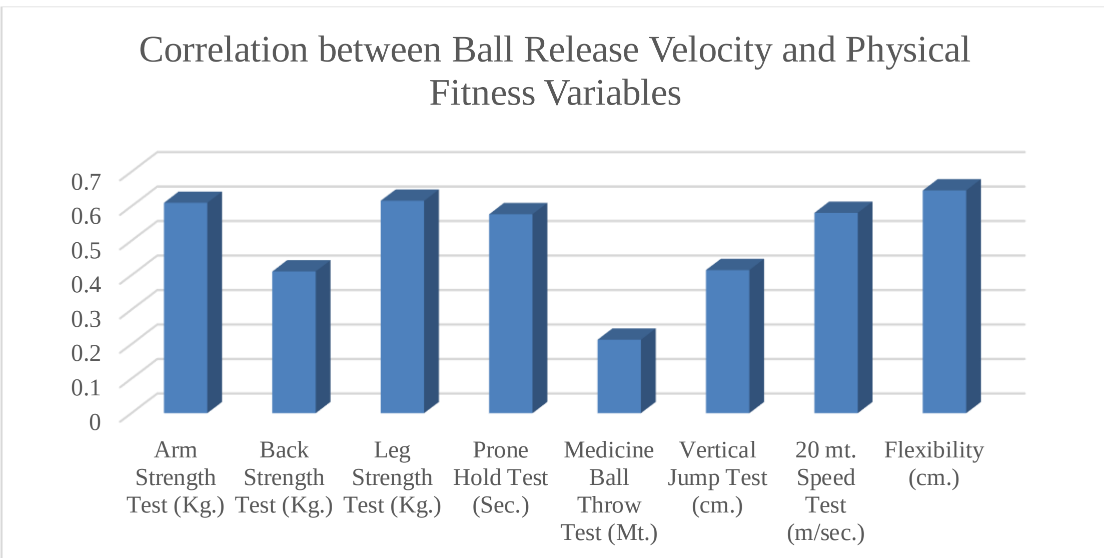


Figure 59

Graphical Representation of Correlation between Ball Release Velocity and Arm Strength of the Subjects

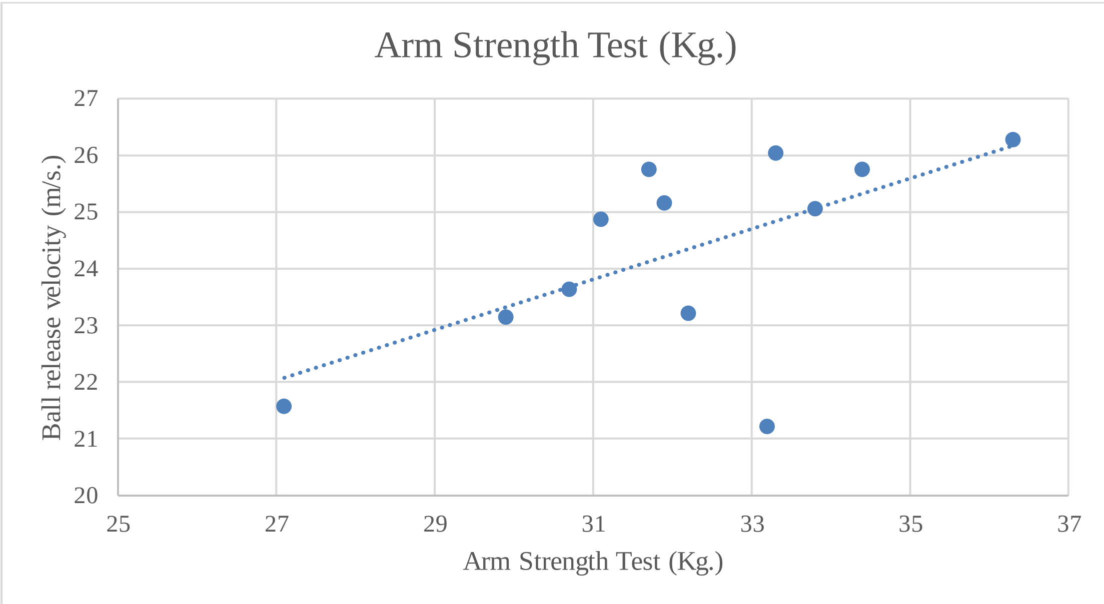


Figure 60

Graphical Representation of Correlation between Ball Release Velocity and Leg Strength of the Subjects

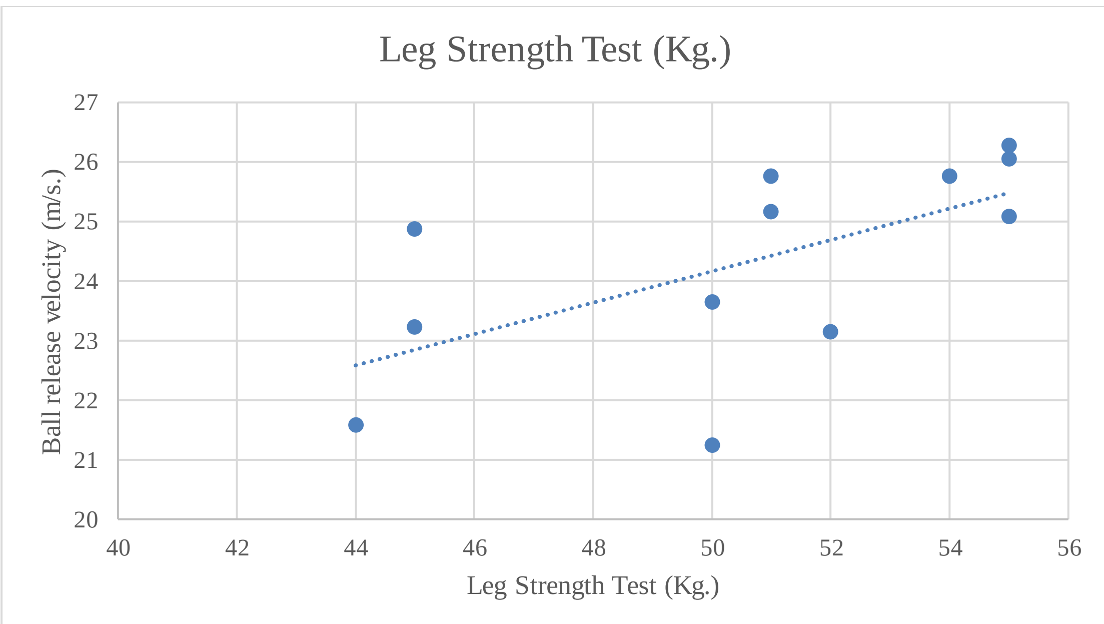


Figure 61

Graphical Representation of Correlation between Ball Release Velocity and Core Stability of the Subjects

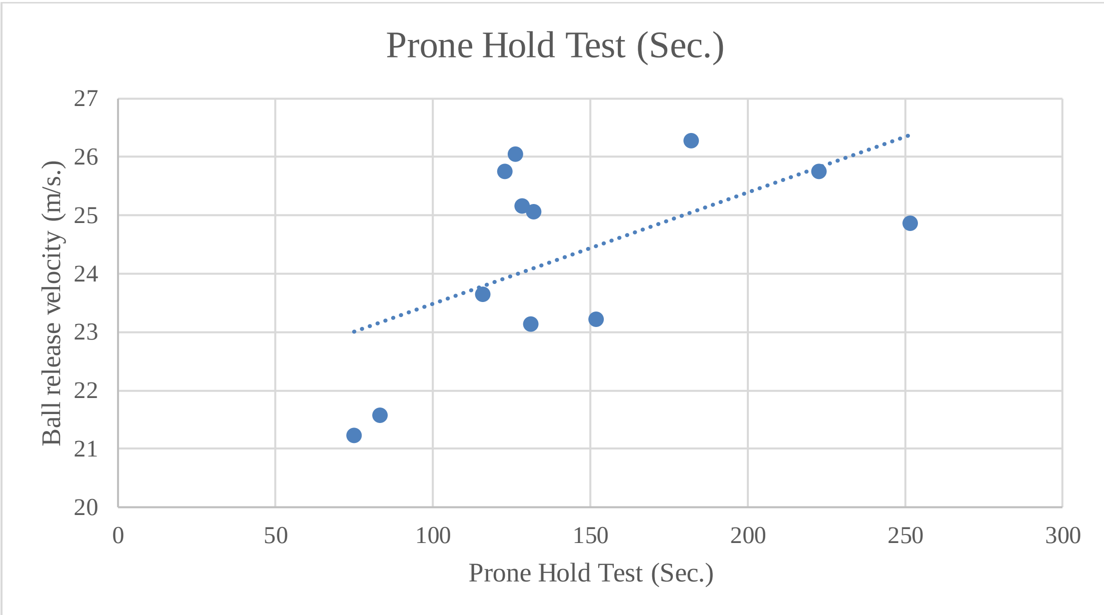


Figure 62

Graphical Representation of Correlation between Ball Release Velocity and Speed of the Subjects

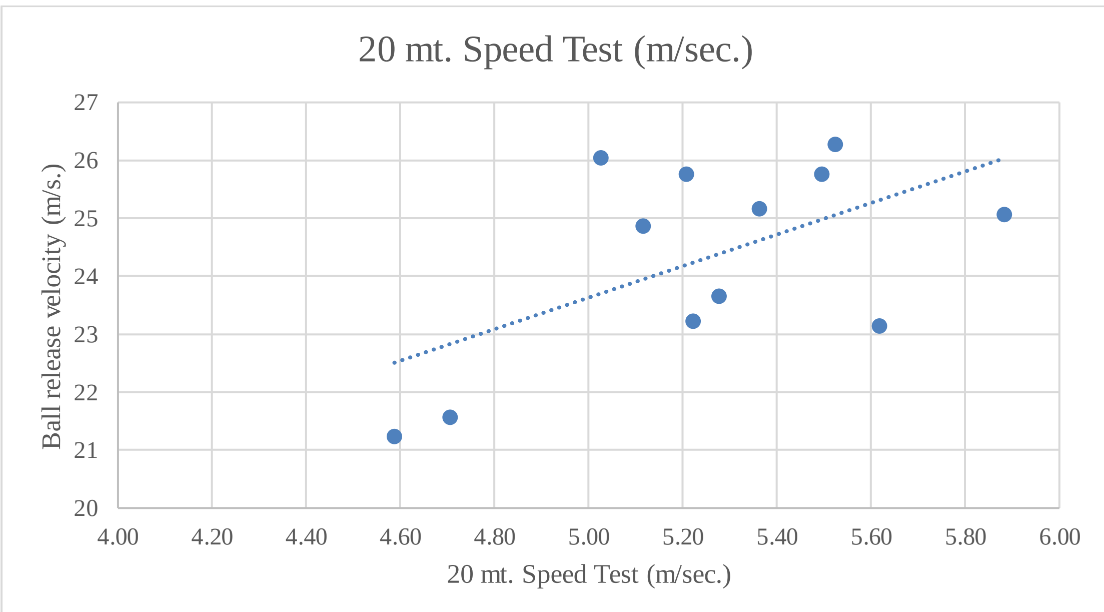
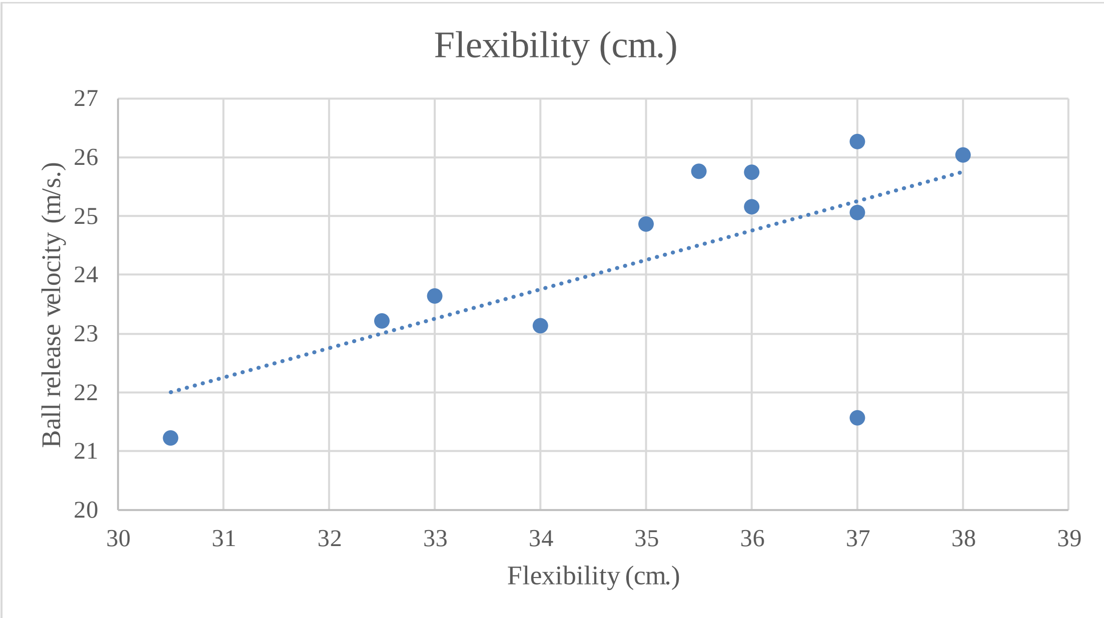


Figure 63

Graphical Representation of Correlation between Ball Release Velocity and Flexibility of the Subjects



4.2. Discussion of findings:

4.2.1. Anthropometric Variables:

Though larger body dimensions, such as arm length and height, are often associated with increased velocity in many studies, results of the present study suggest that these anthropometric measurements do not have any direct relation with ball release velocity.

This may be due to the complex interaction between variables such as fitness, strength, and technique. For instance, strength and power, which are crucial for generating high velocity, may not have been sufficiently developed in the participants, leading to poor performance despite favourable body dimensions. It also may highlight the complexity of performance in ball release velocity, where anthropometric dimensions alone are insufficient without proper technique and strength.

Furthermore, the small sample size of 12 participants could have contributed to the insignificant correlation due to individual outliers or specific participant characteristics that skewed the results.

Similarly, Loram et al. (2005) and Wormgoor et al. (2010) also found insignificant relation between ball speed and any anthropometric variables. In another study, Goswami, S. et al. (2016) reported insignificant negative relation (77.03 ± 11.67, $r = -0.019$) with arm the length and positive relation (19.53 ± 0.79, $r = 0.030$) with hand length.

4.2.2. Kinematic Variables:

Final Run-up Velocity:

Final run-up velocity (Best: 4.27 ± 0.72, All: 4.27 ± 0.74) showed a significant positive correlation with ball release velocity ($r = 0.373$, $p = 0.001$) and was a significant predictor in the regression analysis ($B = 0.887$, $t = 2.946$, $p = 0.005$). This finding aligns with the biomechanical principle of momentum transfer, where a faster approach speed allows the bowler to generate greater linear momentum, which is transferred through the kinetic chain. This energy, when efficiently converted into angular momentum during delivery, contributes to higher ball release velocity. Effective technique ensures minimal energy loss, optimizing this transfer and enhancing performance.

Lyons, C. et al. (2023) also found the significant positive relation (5.05 ± 0.61, r = 0.75, p = 0.01) between final run-up velocity and ball release velocity among female cricketers.

Glazier, P. S. et al. (2000) also found similar result (5.9 ± 0.7 m/s, r = 0.728, p = 0.05) between these two variables among male cricketers.

Bound Height:

A significant negative correlation was found between bound height (Best: 11 ± 5.18, All: 11.07 ± 4.90) and ball release velocity measured on the best deliveries (r = -0.587, p = 0.045) as well as all deliveries (r = -0.480, p = 0.000). This suggests that excessive vertical displacement during the bound phase disrupts the forward horizontal momentum required for optimal delivery. Biomechanical principles highlight that, unnecessary vertical motion increases energy dissipation and reduces the efficiency of the kinetic chain. Maintaining a controlled bound height ensures the bowler remains balanced and preserves horizontal momentum, contributing to higher ball velocity.

In a previous study, Bull, H. G. et.al. (2024) also found negative correlation (1.27 ± 0.07 m, r = -0.004) between jump height and ball release speed.

Ball Release Height:

Ball release height (Best: 170.97 ± 10.07, All: 170.31 ± 9.10) showed a significant negative correlation with ball release velocity (r = -0.283, p = 0.016) and was a significant predictor (B = -0.058, p = 0.024). A lower release height may allow for better control and energy transfer from the body to the ball. Biomechanical principles suggest that maintaining a compact and efficient posture at release minimizes energy loss, enabling greater velocity.

These findings support the results of Kiely, N. et al. (2021) who reported a negative relation between ball release height (1.97 ± 0.11m, $r = -0.222$, $p = 0.346$) and ball release velocity among male cricketers.

Previously, Thander, A. et al. (2019) also reported the negative relation (1.93 ± 0.08, $r = -0.494$) between ball release height and ball release velocity among male cricketers.

Ball Release Angle:

The ball release angle (Best: 0.41 ± 4.42, All: -0.98 ± 4.50) had a strong positive correlation with ball release velocity ($r = 0.712$, $p = 0.000$) measured on all deliveries, highlighting its importance in optimizing the projectile trajectory. A well-calibrated release angle ensures that the ball follows a path conducive to maximum velocity while maintaining accuracy. This finding aligns with biomechanical principles emphasizing the importance of optimizing joint kinematics to achieve the desired release angle.

In a previous study, Manawadu, K., et al. (2022), reported various type ball release angles of male cricketers depending on the length of the ball i.e. Yorker = 1.9 ± 1.8, Stock = 5.3 ± 1.4 and Bouncer = 13.0 ± 2.7.

But no previous study was found correlating between these two variables to compare with this study.

Knee Joint Angle at Front Foot Contact (Degree):

The significant correlation ($r = 0.365$ $p = 0.002$) between knee joint at FFC (165.41 ± 6.47) and ball release velocity measured on all deliveries, suggests that the knee angle at front foot contact plays a significant role in influencing the ball release velocity. In cricket bowling, the angle of the knee at FFC affects the overall stability, power generation, and efficiency of the bowler's kinetic chain.

A larger knee angle at FFC typically indicates a more powerful and controlled position, where the bowler has maximized their use of the lower body muscles. This allows for greater energy transfer from the legs through the torso and arms, resulting in higher ball release velocity.

Though Glazier, P. S., et.al. (2000) and Thander, A., et.al. (2019) found insignificant negative correlation between the variables among male cricketers, but this finding aligns with the result of Lyons, C., et al. (2023) who found significant positive relations (167.0 ± 2.9, r = 0.49, p = 0.13) between these two variables among the female cricketers.

Ankle Angle at Ball Release (Degree):

A significant relation was found between ankle angle (Best: 120.28 ± 13.85, All: 120.28 ± 13.18) and ball release velocity in both the case i.e. measured on best deliveries (r = 0.727, p = 0.007) as well as measured on all deliveries (r = 0.693, p = 0.00). Also, the ankle angle is a strong predictor (B = 0.059, t = 2.864, p = 0.006) of ball release velocity in the regression analysis.

The ankle joint acts as a critical point of stability and force transmission. According to the principle of ground reaction forces (Newton's Third Law), a well-aligned ankle maximizes the transfer of force from the lower body to the upper body. This alignment ensures effective energy transfer, enhancing ball release velocity.

No previous study was found correlating between these two variables to compare with this study.

Knee Angle at Ball Release (Degree):

The significant correlation between knee angle at BR (Best: 169.07 ± 23.17, All: 167.98 ± 22.93) and ball release velocity in both measured on best deliveries ($r = 0.604$, $p = 0.038$) as well as measured on all deliveries ($r = 0.572$, $p = 0.000$) indicates that the more extended Knee at BR helps to increase the ball release velocity.

The knee serves as a stabilizer and force amplifier during ball release. Proper knee extension at release provides a strong base, allowing for effective force transfer through the kinetic chain. This aligns with principles of biomechanics, where stable and efficient joint motion enhances energy output.

In the previous studies, though Thander, A., et.al. (2019) found insignificant negative relation (166.6 ± 7.25, $r = -0.53$), this result is similar to the result of Wormgoor, et.al. (2010) who found a positive significant relation (150.7 ± 17.1, $r = 0.52$, $p = 0.005$).

Hip Angle at Ball Release (Degree):

The result shows a significant positive relation ($r = 0.264$, $p = 0.025$) of hip angle at BR (103.51 ± 14.88) with ball release velocity measured on all deliveries. It suggests that larger hip angle drives to increase ball release velocity.

The hips are a key pivot point in the kinetic chain, enabling the transfer of rotational energy generated by the lower body to the upper body. According to biomechanical principles, proper hip extension contributes to torque generation, which increases ball velocity.

No previous study was found correlating between these two variables to compare with this study.

Shoulder Angle at Ball Release (Degree):

The negative significant relation (r = -0.458, p = 0.000) between shoulder angle at BR (199.19 ± 13.15) and ball release velocity suggest that more flexed shoulder at the time of ball release helps to increase ball release velocity.

The shoulder plays a vital role in transferring rotational energy from the torso to the arm. More flexed shoulder at the time of ball release ensures that the angular velocity of the arm is maximized, allowing for efficient energy transfer to the ball. This is supported by the principle of summation of forces, where each segment of the body contributes to the overall velocity.

Although, Lyons, C., et.al. (2023) and Thander, A., (2019) found positive relations between shoulder angle at BR and ball release velocity, this result aligns with the result of Hanley, Brian et.al. (2005). who reported a negative significant relation (r = -0.558) between the variables among the male cricketers.

Ankle Plantar Flexion from FFC to BR (Degree):

Ankle plantar flexion from FFC to BR (Best: 6.11 ± 18.16, All: 7.32 ± 17.76) was found to be significantly correlated with ball release velocity in all the way i.e. correlation measured on best deliveries (r = 0.588, p = 0.045), correlation measured on all deliveries (r = 0.465, p = 0.000) and regression analysis measured on all deliveries (B = 0.020, t = 2.082, p = 0.042)

Plantar flexion at the ankle facilitates an explosive push-off during the transition from front foot contact (FFC) to ball release (BR). According to biomechanical principles, this movement increases the generation of vertical ground reaction forces, which are redirected into horizontal force to accelerate the ball.

In a study, Bali, S. L., & Thomas, R. (2010) concluded that ankle planter flexion moment is an important factor to increase ball release speed in cricket bowling.

Knee Flexion from FFC to BR (Degree):

The result shows significant negative relation ($r = -0.547$, $p = 0.000$) between knee flexion from FFC to BR (-2.57 ± 19.68) and ball release velocity measured on all deliveries, which indicates the less flexion of knee at the time of ball release is advantageous for ball release velocity.

Flexion of knee at the time of delivery provides a strong base, but excessive flexion can absorb the horizontal momentum of body, which break the kinetic chain. This aligns with principles of biomechanics, where stable and efficient joint motion enhances energy output.

The result aligns with the results of Wormgoor, S., et.al. (2008) ($r = - 0.465$ $P = 0.013$), Kiely, N., et.al. (2021) ($r = -0.075$, $p = 0.752$) and Wormgoor, S., et.al. (2010) ($r = -0.47$, $p = 0.013$). All of them have reported negative correlation between these variables.

Hip Flexion from FFC to BR (Degree):

Hip flexion from FFC to BR (21.81 ± 9.64) was found to be a significant predictor ($B = 0.049$, $t = 2.384$, $p = 0.02$) of ball release velocity in the regression analysis. it indicates more flexion of hip joint during delivery (FFC to BR) facilitates the ball release velocity.

Hip flexion during the transition from FFC to BR facilitates the proper alignment of the lower body and allows for the optimal transfer of energy from the legs to the upper body. As the hip flexes, it helps generate torque and prepares the body for the final drive into the ball, leading to higher ball release speeds.

In a previous study, Lyons, C., et.al. (2023) have reported an insignificant negative correlation ($r = -0.19$, $p = 0.57$) between the variables among female cricketers. But Kiely, N., et.al. (2021) reported positive relation ($r = 0.411$, $p = 0.072$) in their study.

In another study, Hanley, Brian et.al. (2005) also reported positive relation ($r = 0.642$) between Trunk angular displacement and ball release velocity.

Shoulder Flexion from FFC to BR (Degree):

The shoulder flexion from FFC to BR (113.67 ± 16.22) was also found to be a significant predictor ($B = 0.025$, $t = 4.048$, $p = 0.000$) of ball release velocity, which suggests that more flexed arm during the delivery phase drives to increase ball release velocity.

Shoulder flexion is critical for generating angular velocity in the arm. During the delivery phase, shoulder flexion involves the forward motion of the arm, creating potential energy. This energy is then released as the arm accelerates forward, propelling the ball. According to angular motion principles, greater shoulder flexion during the bowling stride leads to increased angular velocity at the shoulder joint, which leads to increased ball velocity.

This result supports the result of Hanley, Brian et.al. (2005) where they found positive relation ($r = 0.636$) between shoulder angular displacement and ball release velocity.

Other Kinematic Parameters (Not Statistically Correlated with Ball Release Velocity):

The non-significant relations were found with run-up length, final stride length, ankle joint at FFC, hip joint at FFC, and shoulder joint at FFC in correlation with ball release velocity. Ball release velocity is influenced more by force application, energy transfer, and coordination between body segments rather than static joint positions or stride parameters. Kiely et al. (2021) also found insignificant relation between delivery stride length and ball speed, though Feros et al. (2019) found significant result between them. While a longer run-up or stride may contribute to momentum generation, their direct impact on velocity depends on how efficiently the bowler utilizes these movements. Similarly, joint angles (except knee) at front foot contact (FFC) may vary based on individual flexibility, strength, and bowling technique, making them less reliable indicators of release velocity. The critical phases for generating speed occur later in the delivery, particularly during arm acceleration and follow-through, reducing the direct influence of these variables. Additionally, the small sample size (N = 12) may have limited statistical power, making it more challenging to detect significant correlations.

4.2.3. Physical Fitness Variables:

Arm Strength:

A strong positive correlation ($r = 0.61$, $p = 0.035$) was found between arm strength (32.13 ± 2.36 kg) and ball release velocity, which indicates stronger arm can generate faster ball release velocity.

Arm strength is crucial for generating the necessary force during the bowling action. A stronger arm provides better control over the ball and greater capacity for delivering high velocity. The force-velocity relationship in biomechanics suggests that greater muscle strength in the upper body enhances the ability to accelerate the arm quickly, leading to higher ball release speeds. A stronger arm contributes to more efficient energy transfer through the kinetic chain from the lower body to the ball, improving the release velocity.

Similar result (47.43 ± 4.17, r = 0.405) was reported by Goswami, S., et.al. (2016) among male cricketers.

Leg Strength:

Leg strength (50.58 ± 4.03 kg) was found to be positively correlated (r = 0.616, p = 0.033) with ball release velocity, which says that it is an important factor of ball release velocity.

Leg strength plays a critical role in generating force during the bowling stride. Strong legs allow for greater ground reaction forces (according to Newton's Third Law), which are essential for propelling the body forward and transferring energy into the ball. Leg power directly affects the speed of the run-up, the force applied during the stride, and the efficiency of the kinetic chain. Strong leg muscles provide a stable foundation, allowing the upper body to generate the necessary velocity for the ball release.

No previous study was found correlating between these two variables to compare with this study.

Core Stability:

Core stability, measured through the prone hold test (143.59 ± 52.10 sec), also showed a significant positive correlation ($r = 0.577$, $p = 0.050$). The prone hold test evaluates core stability, which is essential for maintaining balance and posture during the bowling action. A strong core provides better torque generation and force transfer through the trunk to the arms and legs. Core strength helps maintain proper alignment and coordination during the delivery phase, preventing energy loss and ensuring the maximum transfer of power from the lower body to the ball. The role of the core in the kinetic chain is critical for generating optimal ball release velocity.

This result aligns with the result (256.27 ± 82.00, $r = 0.736$, $p = 0.0001$) of Anand, P. C., et.al. (2017) conducted among male cricketers.

Speed:

Interestingly, the 20-meter speed test (5.25 ± 0.37 m/s) revealed a significant correlation ($r = 0.581$, $p = 0.048$), indicating that faster sprint times are associated with higher ball release velocities. The 20-meter speed test assesses sprinting speed, which is directly linked to the ability to accelerate quickly and generate high levels of momentum. Faster sprints contribute to increased run-up velocity, which, when properly transferred through the kinetic chain, enhances ball release velocity. According to biomechanical principles, faster running speeds translate to greater horizontal velocity, allowing for more effective energy transfer to the ball.

Kiely, N., et.al. (2021) also reported the similar result (4.32 ± 0.18 sec, $r = -0.482$, $p = 0.031$) where 30-meter sprint time was negatively correlated.

Flexibility:

Flexibility (35.13 ± 2.23 cm) emerged as the strongest predictor ($r = 0.646$, $p = 0.023$) of ball release velocity among the physical fitness variables. Flexibility, particularly in the shoulders, hips, and legs, allows for a greater range of motion during the bowling action. Increased flexibility helps optimize joint movements, ensuring that the full kinetic chain is utilized efficiently. With greater flexibility, the bowler can achieve better angles and positions during the stride and ball release, maximizing energy transfer and ball speed. The principle of joint mobility highlights that a more flexible bowler can generate more effective movements, leading to higher ball release velocities.

A similar result (9.74 ± 2.64 inch, $r = 0.726$) was reported by Sisodia, A. et.al. (2017).

Other Physical Fitness Parameters (Not Statistically Correlated with Ball Release Velocity):

The correlation coefficient of ball release velocity with back strength, upper body power, and lower body power were found non-significant. While strength and power are important for overall athletic performance, ball release velocity is more dependent on timing, sequencing of movements, and efficient energy transfer rather than isolated muscular strength. Simply having greater back strength or upper and lower body power does not guarantee higher velocity if the kinetic chain is not effectively utilized. Insignificant relation between vertical jump height and ball speed was also reported by Kiely et al. (2021). Bowling speed is influenced by neuromuscular coordination, joint stability, and explosive movement patterns, rather than raw strength alone. Additionally, the contribution of strength and power may vary among bowlers depending on their technique, making these factors less consistently correlated with velocity. Furthermore, the small sample size (n = 12) may have reduced the statistical power, making it harder to detect significant relationships between these variables and ball release velocity.

4.3. Testing of Hypothesis:

$H_0$1: It was hypothesized that, there will be no significant influence of selected anthropometric parameters namely, upper arm length (acromiale-radiale), forearm length (radiale-stylion radiale), hand length (midstylion-dactylion), arm span, upper leg length (trochanterion-tibiale laterale), lower leg length (tibiale laterale), foot length and standing reach height on ball release velocity in cricket bowling. As no significant effect of any anthropometric variable was found on ball release velocity, the first null hypothesis ($H_0$1) of this study previously mentioned was accepted.

$H_0$2: It was also hypothesized that, there will be no significant influence of selected kinematic parameters i.e. Run up length, final run-up velocity, bound height, final stride length, ball release height, ball release angle, angle of segmental joints at front foot contact (ankle, knee, hip, shoulder), angle of segmental joints at ball release (ankle, knee, hip, shoulder), flexion of segmental joints from front foot contact to ball release (ankle, knee, hip, shoulder) on ball release velocity in cricket bowling. But the significant effects were found for most of the kinematic variables (final run-up velocity, ball release angle, knee joint angle at front foot contact as well as ball release**,** ankle joint angle at ball release, hip joint angle at ball release, ankle planter flexion from front foot contact to ball release, hip flexion from foot contact to ball release, shoulder flexion from foot contact to ball release, bound height, ball release height, shoulder joint angle at ball release, and knee flexion from FFC to BR) on ball release velocity. So, the second null hypothesis ($H_0 2$) of this study previously mentioned was mostly rejected and partially accepted.

$H_0$3: Lastly it was hypothesized that, there will be no significant influence of selected physical fitness parameters like arm strength, back strength, leg strength, upper body power, lower body power, core stability, speed, flexibility on ball release velocity in cricket bowling. As the significant effects were found for most of the physical fitness variables (arm strength, leg strength, core stability, speed and flexibility) on ball release velocity, the third null hypothesis ($H_0 3$) of this study previously mentioned was mostly rejected and partially accepted.

CHAPTER - V

5. SUMMARY, CONCLUSION AND RECOMMENDATION:

5.1 Summary:

Cricket, originating in England, is now popular in countries like India, Australia, and Pakistan. Played between two teams of eleven, the game revolves around batting, bowling, and fielding, with the main goal being to score more runs than the opponent. It is played in three formats: Test (five days), One Day Internationals (50 overs), and Twenty20 (20 overs).

The history section highlights the sport's origins in 16th-century England, with the first recorded match in 1697. The Marylebone Cricket Club (MCC), founded in 1787, played a critical role in formalizing the game by drafting the Laws of Cricket and overseeing its global development. Based at Lord’s Cricket Ground, the MCC remains a prestigious institution dedicated to preserving cricket’s traditions while supporting its modern growth.

Women's cricket dates back to the 18th century, with the first international Test played between England and Australia in 1934. Key milestones include the inaugural Women's World Cup in 1973 and the introduction of T20 cricket in 2009, both of which boosted the sport’s popularity.

In India, women’s cricket began gaining structure in the 1970s, with the national team playing its first Test in 1976. Milestone moments include reaching the World Cup finals in 2005 and 2017, the latter sparking a surge in public interest. The

Women’s Premier League (WPL), launched in 2023, has provided more opportunities and financial backing for players. The BCCI has since increased investments in infrastructure, contracts, and media coverage, helping raise the profile of the sport.

Bowling in women’s cricket mirrors the fundamentals of the men's game, with bowlers using fast, swing, and spin techniques. Icons like Jhulan Goswami and Sophie Ecclestone have elevated the standards of fast and spin bowling. T20 formats have encouraged bowlers to innovate with slower balls and yorkers. Although women bowlers now receive better coaching and exposure through leagues and international tournaments, disparities in resources persist. Continued investment and support remain key to further developing female bowling talent and ensuring equality in the sport's future.

Coaching methods for women should differ from men due to anatomical and physiological differences, as suggested by Felton and King (2017). These differences affect kinematic variables in pace bowling, and therefore, training must be tailored specifically for female athletes.

While extensive research exists for men’s cricket, studies on women’s cricket, especially in bowling, remain limited. Among the few available, Lyons et al. (2023) found that increased height and larger bowling shoulder angles enhance ball release speed, and Bailey et al. (2023) linked run-up velocity with ball speed in elite female pace bowlers. Despite these findings, the research is still insufficient to fully understand women's pace bowling.

Recognizing this gap, the present researcher aims to explore factors influencing ball release velocity in women's cricket, as it is a vital component of a bowler's performance and overall game effectiveness.

In the present study, the researcher aimed to identify the key factors that determine ball release velocity in women's pace bowling. These factors include anthropometric characteristics, kinematic parameters, and physical fitness components. Guided by this objective, the researcher has entitled the Ph.D. thesis as "FACTORS DETERMINING BALL RELEASE VELOCITY OF WOMEN PACE BOWLERS IN CRICKET."

The study aimed to investigate the factors influencing ball release velocity in women pace bowlers by analysing three key areas:

1. Anthropometric variables such as limb lengths, arm span, foot length, and standing reach height, and how they relate to ball release velocity.

2. Kinematic parameters including run-up characteristics, stride and bound metrics, joint angles, and body segment movements during key phases of the bowling action.

3. Physical fitness attributes like strength (arm, back, leg), power (upper and lower body), core stability, speed, and flexibility in relation to their impact on ball release speed.

The objective was to understand how these physiological, biomechanical, and fitness factors contribute to performance in women's pace bowling.

The reviewed literature indicates that ball release velocity in cricket pace bowling is influenced by a combination of anthropometric, kinematic, and physical fitness parameters, although the strength of these relationships varies across studies. Among anthropometric variables, limb dimensions such as upper arm length, forearm length, and leg length showed moderate positive correlations with ball speed in some cases (Lyons et al., 2023), though other studies reported negligible associations (Goswami et al., 2016), suggesting that technique may mediate these effects. Kinematic variables demonstrated stronger and more consistent associations, with final run-up velocity emerging as a key predictor of ball release speed (Lyons et al., 2023; Glazier et al., 2000). Additional kinematic factors such as ball release height, shoulder angle at release, and joint flexion transitions from front foot contact (FFC) to ball release (BR)—particularly at the hip, knee, and shoulder—were also identified as important contributors (Hanley et al., 2005; Wormgoor et al., 2010). In terms of physical fitness, parameters like core stability (Anand et al., 2017), upper body flexibility (Sisodia & Bagchi, 2017), and sprint speed (Kiely et al., 2021) were significantly correlated with ball velocity. Arm strength and leg power were also noted as supportive factors, enhancing movement efficiency and joint control.

In the present study, twelve healthy female pace bowlers were selected as subjects. These participants were between 18 and 28 years of age and had experience playing at the state level, having represented their respective states at least once within the last five years. All the bowlers were actively involved in cricket during the time of data collection and were training under certified coaches at various cricket academies. None of them had any severe past injuries that could impact their performance or the study outcomes.

To conduct the research effectively, several variables were selected. The demographic details included age, height, and weight of the participants. The dependent variable in the study was ball release velocity, which was considered the key performance indicator. The independent variables were categorized into three main groups: anthropometric, kinematic, and physical fitness parameters.

The anthropometric parameters included upper arm length (acromiale–radiale), forearm length (radiale–stylion radiale), hand length (midstylion–dactylion), arm span, upper leg length (trochanterion–tibiale laterale), lower leg length (tibiale laterale), foot length, and standing reach height.

The kinematic parameters consisted of run-up length, run-up velocity during the pre-delivery stride, bound height, final stride length, ball release height, and ball release angle. Additionally, joint angles were analyzed at two key phases: front foot contact (FFC) and ball release (BR). These included the ankle, knee, hip, and shoulder joint angles at both FFC and BR. The study also examined the changes in joint positions between FFC and BR, specifically ankle plantar flexion, knee extension, hip flexion, and shoulder extension.

Lastly, the physical fitness parameters assessed in the study were arm strength, back strength, leg strength, upper body power, lower body power, core stability, speed, and flexibility. These comprehensive variables were chosen to explore their potential influence on the ball release velocity in women pace bowlers, with the aim of identifying significant performance determinants.

In the present study, statistical analysis was carried out using both Microsoft Excel and SPSS software. Descriptive statistics, including means, standard deviations, and ranges, were computed for all selected variables to provide a basic understanding of the data distribution. To examine the relationships among the variables, Pearson's product moment correlation was employed. Furthermore, regression analysis was conducted to determine the predictive value of the independent variables on the dependent variable, i.e., ball release velocity. The level of significance for testing the null hypothesis was set at 0.05, ensuring that any observed relationships were statistically meaningful within this confidence level.

The result revealed that there were no significant effects of any anthropometric variable on ball release velocity. The result also revealed that the positive significant effects were found for most of the kinematic variables (final run-up velocity, ball release angle, knee joint angle at front foot contact as well as ball release**,** ankle joint angle at ball release, hip joint angle at ball release, ankle planter flexion from front foot contact to ball release, hip flexion from foot contact to ball release, and shoulder flexion from foot contact to ball release) on ball release velocity. Besides the positive effects, bound height, ball release height, shoulder joint angle at ball release, and knee flexion from FFC to BR have negative effects on ball release velocity. In case of physical fitness, arm strength, leg strength, core stability, speed and flexibility influence ball release velocity positively.

5.2 Conclusion:

On the basis of the results and discussions of anthropometric variables, kinematic variables and physical fitness variables, the following conclusions may be drawn:

Anthropometric Variables:

i. The selected anthropometric parameters of women pace bowlers do not influence the ball release velocity significantly.

Kinematic Variables:

i. A higher final run-up velocity contributes to an increase in ball release velocity in women's cricket pace bowling.
ii. A greater ball release angle enhances the ball release velocity in women's cricket pace bowling.
iii. A larger knee joint angle at front foot contact and ball release improves ball release velocity in women's cricket pace bowling.
iv. A greater ankle joint angle at ball release aids in increasing ball release velocity in women's cricket pace bowling.
v. A wider hip joint angle at ball release facilitates the ball release velocity in women's cricket pace bowling.
vi. Increased ankle plantar flexion from front foot contact to ball release leads to a higher ball release velocity in women's cricket pace bowling.
vii. Greater hip flexion from front foot contact to ball release contributes to improved ball release velocity in women's cricket pace bowling.

viii. Increased shoulder flexion from front foot contact to ball release helps in achieving higher ball release velocity in women's cricket pace bowling.

ix. A reduced bound height supports to increase in ball release velocity in women's cricket pace bowling.

x. A lower ball release height enhances ball release velocity in women's cricket pace bowling.

xi. A smaller shoulder joint angle at ball release aids in increasing ball release velocity in women's cricket pace bowling.

xii. Lesser knee flexion from front foot contact to ball release results in higher ball release velocity in women's cricket pace bowling.

Physical Fitness Variables:

i. Greater arm strength of women pace bowlers has positive impact on ball release velocity in women's cricket pace bowling.

ii. Enhanced leg strength contributes to higher ball release velocity in women's cricket pace bowling.

iii. Improved core stability supports an increasement in ball release velocity in women's cricket pace bowling.

iv. Higher running speed of women pace bowlers helps to boost ball release velocity in women's cricket pace bowling.

v. Better flexibility of women pace bowlers positively affects ball release velocity in women's cricket pace bowling.

5.3 Recommendation:

It is recommended that –

i. The result of the study may be considered by National Cricket Academy (NCA) in the training method for female cricketers to enhance the quality of bowling in women cricket.
ii. The result of the study may be used by the coaching academies to categorize cricketers from very beginning stage and coaching accordingly.
iii. The result of the study may be adopted by the schools and colleges to make prognosis of the beginners about their cricketing future.
iv. The result of the study may be used by the Physical Education teachers to identify the talent and to improve the performance of the students.
v. The result of the study may be useful for all the women cricketers from the beginners.
vi. A similar study may be conducted using more sophisticate cameras and more advanced motion analysis software.
vii. A similar study may be conducted using variables other than those used in this study.
viii. A similar study may be conducted using subjects of age group other than used in this study.
ix. A similar study may be under taken with a large number of subjects.
x. Same study may be conducted with the players of different level other than that used in this study.
xi. A similar study may be undertaken on the male subjects of different level.

xii. Further studies may be under taken involving the relationship of the anthropometric, kinematic and physical fitness parameters between male and female players.

BIBLIOGRAPHY:

Anand, P. C., Khanna, G. L., Chorsiya, V., & Geomon, T. (2017). Relationship of core stability with bowling speed in male cricket medium and medium fast bowlers. *Al Ameen J Med Sci*, *10*(3), 225-228.

Anand, P. C., Khanna, G. L., Chorsiya, V., & Rana, A. (2017). Relationship between shoulder strength and bowling speed in cricket bowlers. *Journal of Exercise Science & Physiotherapy, 13*(1), 81-86.

Arumugam, S., Perumal, S., Raman, S. A., Ayyadurai, P., Nimishaanth, S. S., & Thiagarajan, K. A. (2023). Lumbar spine injury in Indian fast bowlers: 3D biomechanical analysis and prevention strategies. *Indian Journal of Orthopaedics, 57*(10), 1600–1604

Ashraf, N., Ullah, I., Shah, M., Hussain, S. A., & Batool, U. B., (2019). Effects of plyometric training program on speed and agility in young cricketers. *T Rehabilitation Journal, 3*(1), 85–89.

Bailey, D., Saw, A. E., Crowther, R. H., & Sims, K. (2023). Run Faster, Bowl Faster: In-Match Analysis of Elite Female Cricket Pace Bowlers. *J. Sport Exerc. Sci, 7*, 21-26.

Bala, B. (2014). *A study on physical fitness anthropometric and psychological profile of national level junior male cricketers* (Doctoral dissertation). University of Kalyani, WB, India.

Bali, S. L., & Thomas, R. (2010). The relation of ball release speed to the biomechanics of the ankle in the cricket fast bowler. *Orthopaedic Proceedings*, *92-B*(SUPP_I), 244-244. https://doi.org/10.1302/0301-620X.92BSUPP_I.0920244

Bandarupalli, S. (2022, September 24). Stats: Jhulan Goswami, the most prolific bowler of women's cricket. *ESPN Cricinfo*. Retrieved from https://www.espncricinfo.com/story/stats-jhulan-goswami-the-most-prolific-bowler-of-women-s-cricket-1336407

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*(5), 403–424. https://doi.org/10.1080/02640419608727727

Bhattacharjee, P. (2024, April 20). *Women's Cricket is on the Rise in India*. https://missingperspectives.com/posts/puja-womens-cricket-is-on-the-rise-in-india/?utm_source=chatgpt.com

Biswas, A., & Ghosh, A. K. (2020). Anthropometric profile of district-level cricketers of West Bengal. *International Journal of Physical Education, Sports and Health*, *7*(5), 240-244.

Boyat, A. K., & Rathod, P. V. (2021). A Study to Identify the Most Common Exercises Used in Cricket for Improving Speed in Medium Fast Bowlers in India-A Mail Survey. *Journal of Research in Medical and Dental Science*, *9*(1), 1-7.

Bull, Hamish G.; Alway, Peter; and King, Mark A. (2024). Relationship Between Pre-Delivery Stride and Fast Bowling Performance in Cricket, *ISBS Proceedings Archive*, *42*(1), Article 148.

Butts, C., Barber, B., Moore, M., Collins, M., & Ansari, Z. (2023). Holding up a Mirror to Cricket: A Report by the Independent Commission for Equity in Cricket. Retrieved from https://discovery.ucl.ac.uk/id/eprint/10191312/

Callaghan, S. J., Lockie, R. G., Andrews, W. A., Yu, W., Chipchase, R. F., & Nimphius, S. (2019). The effects of an eight over cricket bowling spell upon pace bowling biomechanics and performance within different delivery lengths. *Sports, 7*(9), 200. https://doi.org/10.3390/sports7090200

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, 100(2), 126–131.

Clerke, A. M. et al. (2005). Effects of hand shape on maximal isometric grip strength in teenagers. *Journal of Hand Therapy, 18* (1), 19-29.

Cochrane, J., Lloyd, D., Buttifant, D., & Seward, H. (2013). Kinematic and kinetic energy analysis of segmental sequencing in cricket fast bowling. *Sports Technology*, *6*(1), 25–33. https://doi.org/10.1080/19346182.2012.737800

Coutis, P. (1998). Modelling the Projectile Motion of a Cricket Ball. *International Journal of Mathematical Education in Science and Technology, 29*(6), 789–798.

Crewe, H., Campbell, A., Elliott, B., & Alderson, J. (2013). Lumbo-pelvic loading during fast bowling in adolescent cricketers: The influence of bowling speed and technique. *Journal of Sports Sciences, 31*(10), 1082–1090. https://doi.org/10.1080/02640414.2012.762601

Cullen, S., Fleming, J., Logue, D. M., O'Connor, J., Connor, B., Cleary, J., Watson, J. A., & Madigan, S. M. (2022). Anthropometric profiles of elite athletes. *Journal of Human Sport and Exercise*, *17*(1), 145–155

Daniel, P. V. K., & Senthil, P. (2024). Association of core stability and hand-eye coordination among cricket fast bowlers. *International Journal of Scientific Research, 13*(2), 28–31.

Davis, B. et al. (2000) Physical Education and the study of sport. *4th ed. Spain: Harcourt* p. 123

Davis, B., Bull, R., Roscoe, J., & Roscoe, D. (2000). Physical fitness and fitness testing. Davis, B et al. Physical Education and the study of sport. *4th ed. Spain: Harcourt*, 123.

Desai, P., Yeole, U., Waghmare, A., & Andhare, N. (2019). Assessment of shoulder girdle muscles strength and functional performance in fast cricket bowlers. *JMSCR 07*(03), 1358-1361.

Dhapola, M. S. (2017). Effect of SAQ training on agility and endurance between cricket players. *International Journal of Physiology, Nutrition and Physical Education, 2*(2), 434–436.

Duncan, I. (2013). *Skirting the Boundary: A History of Women's Cricket*. Biteback Publishing.

Eler, N., & Eler, S. (2018). The Effect of Agility Exercises on the COD Speed and Speed in Terms of the Frequency of the Training. *Universal Journal of Educational Research*, *6*(9).

Elliott, B., Wallis, R., Sakurai, S., Lloyd, D., & Besier, T. (2002). The measurement of shoulder alignment in cricket fast bowling. *Journal of Sports Sciences, 20*(6), 507–510. https://doi.org/10.1080/02640410252925170

Epifano, D. J., Ryan, S., Clarke, A. C., & Middleton, K. J. (2021). Objective assessment of fast bowling delivery intensity in amateur male cricketers. *Journal of Sports Sciences, 40*(4), 442–449. https://doi.org/10.1080/02640414.2021.1996987

Felton, P. J. & King M. A. (2017, July). *Gender differences in cricket fast bowling*. Paper presented at XXVI Congress of the International Society of Biomechanics, Brisbane, Australia.

Felton, P. J. (2015). *Factors limiting fast bowling performance in cricket* (Doctoral dissertation). Loughborough University, UK.

Felton, P. J., & King, M. A. (2016). The effect of elbow hyperextension on ball speed in cricket fast bowling. *Journal of Sports Sciences, 34*(18), 1752–1758. https://doi.org/10.1080/02640414.2015.1137340

Felton, P. J., McCaig, S., & King, M. A. (2023). Cricket fast bowling: The relationship between range of motion and key performance and injury technique characteristics. *Journal of Sports Sciences*, *41*(5), 567–575. https://doi.org/10.1080/02640414.2023.2200520

Ferdinands, R. E. (2011). Analysis of segmental kinetic energy in cricket bowling. *Procedia Engineering*, *13*, 246-251.

Ferdinands, R. E. D., Sinclair, P. J., Stuelcken, M. C., & Greene, A. (2014). Rear leg kinematics and kinetics in cricket fast bowling. *Sports Technology*, *7*(1–2), 52–61. https://doi.org/10.1080/19346182.2014.893352

Feros, S. A. (2015). *The Determinants and development of fast bowling performance in cricket* (Doctoral dissertation). Federation University, Australia.

Feros, S. A., Gerhardy, M. H., Fyfe, J. J., & Dwyer, D. B. (2024). The kinematic relationships of ball release speed in elite female cricket pace bowlers. *International Journal of Sports Science & Coaching*, *19*(5), 2144-2151. https://doi.org/10.1177/17479541241242910

Feros, S. A., Young, W. B., & O'Brien, B. J. (2019). Relationship between selected physical qualities, bowling kinematics, and pace bowling skill in club-standard cricketers. *The Journal of Strength & Conditioning Research, 33*(10), 2812-2825.

Fletcher, T., Velija, P., & Nicholson, R. (2024). The Hundred: A sociological analysis of gender relations and the (semi-) professionalisation of women’s cricket in England. *International Review for the Sociology of Sport*, *59*(7), 1012-1031. https://doi.org/10.1177/10126902241246581

Ghosh, J., & Chatterjee, S. (2014). Relationship of selected anthropometric variables to pace bowling in cricket. *Unmesh: A journal of Physical Education*, *10*(1-2). 29-33.

Ghosh, N., & Mondal, P. (2024). Influence of segmental joint angle and flexion at delivery stride on pace bowling in cricket. *International Journal of Physical Education, Sports and Health*, *11*(1), 50–55.

Glazier, P. S., Paradisis, G. P., & Cooper, S. M. (2000). Anthropometric and kinematic influences on release speed in men’s fast-medium bowling. *Journal of Sports Sciences, 18*(12), 1013–1021. https://doi.org/10.1080/026404100446810

Goswami, S., Srivastava, V. K., & Rajpoot, Y. S. (2016). Association Between Ball Velocity and Hand Grip Strength of Male Cricket Players. *Indian Journal of Physical Education, Sports Medicine & Exercise Science, 16*(1and2), 60-63.

Govindasamy, K., Thangamuthu, P., Anitha, J., Lakshmanan, C., & Marithangam, M. (2018). Analysis of anthropometric peculiarities among fast and spin bowlers in the cricket academy of Tamil Nadu cricket association. *International Journal of Physiology, Nutrition and Physical Education, 3*(2), 1017-1019.

Hamill, J., & Knutzen, K. M. (2015). *Biomechanical Basis of Human Movement* (4th ed.). Lippincott Williams & Wilkins.

Hanley, Brian & Lloyd, Ray & Bissas, Athanassios. (2005). Relationships between ball release velocity and kinematic variables in fast bowling in cricket. *Journal of Sports Sciences*, *23*, 112-113.

Herridge, R., Turner, A. N., & Bishop, C. J. (2020). Monitoring changes in power, speed, agility, and endurance in elite cricketers during the off-season period. *Journal of Strength and Conditioning Research, 34*(8), 2285–2293.

Hussain, I., Bari, M. A., & Imran, M. (2011). Biomechanical Analysis of Flex Elbow on Bowling Speed in Cricket. *Innovative Systems Design and Engineering, 2*(3), 165-171.

International Cricket Council. (2023). *What is Cricket? – The three formats*. Retrieved from https://www.icc-cricket.com/about/cricket/game-formats/the-three-formats

ISAK: International Society for the Advancement of Kinanthropometry. (2001). *International Standards for Anthropometric Assessment*. Australia: National Library of Australia.

Jessop, D. M., & Pain, M. T. (2016). Maximum Velocities in Flexion and Extension Actions for Sport. *Journal of human kinetics*, *50*, 37–44. https://doi.org/10.1515/hukin-2015-0139

Johnson, B. L., & Nelson, J. K. (1986). *Practical Measurements for Evaluation in Physical Education.* New York: Macmillan Publishing Co.

Johnstone, J. A., Mitchell, A. C., Hughes, G., Watson, T., Ford, P. A., & Garrett, A. T. (2014). The athletic profile of fast bowling in cricket: A review. *The Journal of Strength & Conditioning Research, 28*(5), 1465-1473.

Joshi, G., Singh, A., & Sathe, A. (2021). Effect of different bowling surfaces on bowling speed of pace bowlers: A cross-sectional study. *Journal of Education: Rabindra Bharati University*. *22*(1), 134-140.

Kansal, D. K. (1996). *Test and Measurement in Sports and Physical Education.* New Delhi: DVS Publications.

Kiely, N., Pickering Rodriguez, L., Watsford, M., Reddin, T., Hardy, S., & Duffield, R. (2021). The influence of technique and physical capacity on ball release speed in cricket fast-bowling. *Journal of Sports Sciences, 39*(20), 2361–2369. https://doi.org/10.1080/02640414.2021.1933349

Kulkarni, S. (2000, September 8). The history of Indian women's cricket. *ESPN Cricinfo*. Retrieved from https://www.espncricinfo.com.

Logeswaran, A. S., Raj, D. S., Giridharaprasath, R. G., & Nirendan, J. (2022). Impact of endurance training on aerobic fitness and speed endurance of inter-collegiate cricket players. *Journal of Sports Science and Nutrition, 3*(1), 23–26.

Longmore, A., Alston, R., Williams, M.K. (2024, August 17). *cricket*. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/sports/cricket-sport

Loram, L. C., McKinon, W., Wormgoor, S., Rogers, G. G., Nowak, I., & Harden, L. M. (2005). Determinants of ball release speed in schoolboy fast-medium bowlers in cricket. *Journal of sports medicine and physical fitness, 45*(4), 483-490.

Lyons, C., Felton, P., & McCabe, C. (2023). Female cricket pace bowling: kinematic and anthropometric relationships with ball release speed. *South African Journal of Sports Medicine, 35*(1).

Manawadu, K., Felton, P., Hiley, M., & King, M. (2022). A Comparison of Pitch Length Variations and The Ability to Control Length in Cricket Fast Bowling. *ISBS Proceedings Archive*, *40*(1), 411.

Manna, C., & Thander, A. (2021). A comparative study of suryanamaskar and dynamic stretching on fast bowling performance in cricket. *International Journal of Applied Research, 7*(5), 20-23.

Marshall, R. N., & Ferdinands, R. (2005). The biomechanics of the elbow in cricket bowling. *International SportMed Journal, 6*(1), 1-6.

Marylebone Cricket Club. (2017a). *The Laws of Cricket: Law 13 – Innings*. Retrieved from https://www.lords.org/mcc/the-laws-of-cricket/innings

Marylebone Cricket Club. (2017b). *The Laws of Cricket*. *Law 32 to 42*. Retrieved from https://www.lords.org/mcc/the-laws-of-cricket

Mayengbam, S. S., & Rajashekaran, M. (2024). Analysis of game-specific skill practices on hand-eye coordination and balance of cricket players. *International Journal for Multidisciplinary Research*, *6*(1), 1–10.

Middleton, K. J., Alderson, J. A., Elliott, B. C., & Mills, P. M. (2015). The influence of elbow joint kinematics on wrist speed in cricket fast bowling. *Journal of Sports Sciences*, *33*(15), 1622–1631. https://doi.org/10.1080/02640414.2014.1003586

Mohanty, S. P., Babu, S. S., & Nair, N. S. (2001). The use of arm span as a predictor of height: A study of South Indian women. *Journal of orthopaedic surgery (Hong Kong)*, *9*(1), 19–23. https://doi.org/10.1177/230949900100900105

Munro, C. E., & Christie, C. J. (2018). Research directions for the enhancement of women's cricket. *International Journal of Sports Science & Coaching*, *13*(5), 708-712. https://doi.org/10.1177/1747954118764102

Nelson, J. K., & Johnson, B. L. (1986). *Measurement and evaluation in physical education* (4th ed.). Macmillan Publishing Company.

Norton, K., & Olds, T. (1996). *Anthropometrica: A Textbook of Body Measurement for Sports and Health Courses*. UNSW Press.

November, R. V., & Leach, L. L. (2016). Physical and performance measures of university cricket players. *African Journal for Physical Activity and Health Sciences, 22*(4:2), 1140–1156.

Paswan, C. K. (2020). Biomechanical analysis of selected kinematic variables in release phase of medium pace bowling in cricket with accuracy: A detailed structural equational model. *International Journal of Physiology, Nutrition and Physical Education*. *5*(1). 203-209.

Petersen, C. J. (2010). *Elite cricket match and training demands and performance enhancement in hot/humid environments* (Doctoral dissertation, University of Western Australia).

Petersen, C., Wilson, B., & Hopkins, W. (2004). Effects of modified-implement training on fast bowling in cricket. *Journal of Sports Sciences, 22*(11–12), 1035–1039. https://doi.org/10.1080/02640410410001729973

Pote, L., & Christie, C. J. (2018). Injury prevention strategies in cricket. *Strength and Conditioning Journal, 40*(5), 34–43.

Pyne, D. B., Duthie, G. M., Saunders, P. U., Petersen, C. A., & Portus, M. R. (2006). Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *The Journal of Strength & Conditioning Research, 20*(3), 620-626.

R. Portus, M., Sinclair, P. J., Burke, S. T., Moore, D. J. A., & Farhart, P. J. (2000). Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *Journal of Sports Sciences, 18*(12), 999–1011. https://doi.org/10.1080/026404100446801

Raikar, S.P. (2024, January 31). *Marylebone Cricket Club*. *Encyclopedia Britannica*. Retrieved from https://www.britannica.com/topic/Marylebone-Cricket-Club

Rehman, S. U., & Sivakumar, K. (2021). Effect of circuit and interval trainings on speed and agility among male inter-collegiate cricket players. *Turkish Online Journal of Qualitative Inquiry, 12*(7), 6823–6829.

Salonia, M. A., Chu, D. A., Cheifetz, P. M., & Freidhoff, G. C. (2004). Upper-body power as measured by medicine-ball throw distance and its relationship to class level among 10- and 11-year-old female participants in club gymnastics. *Journal of Strength and Conditioning Research*, *18*(4), 695–702.

Sankar, C. K. (2011). The relationship between anthropometric and kinematic variables and ball release speed in men's slow-medium bowling. In *Proceedings of the XXIII International Symposium on Biomechanics in Sports* (pp. 849–852).

Sarkar, D. (2022). A Comparative Study on Anthropometric Variables and Physical Fitness variables between rural and university level male medium fast bowlers in

Cricket. *International Research Journal of Humanities and Interdisciplinary Studies, 3*(3), 110-117.

Sarmah, B., Bordoloi, N., Narvariya, P., & Thapa, R. K. (2025). Considering the effects of upper body, lower body, and their combination on post-activation performance enhancement of bowling velocity among amateur cricket players. *Physical Education Theory and Methodology, 25*(1), 53–57.

Sharma, H. B., & Kailashiya, J. (2017). The anthropometric correlates for the physiological demand of strength and flexibility: A study in young Indian field hockey players. *Journal of Clinical and Diagnostic Research, 11*(6), CC01–CC05

Singh, K., & Singh, R. (2015). Relationship of selected anthropometric variables with the velocity of ball in pace bowling in cricket. *International Journal of Applied Research, 1*(10), 613-616.

Sisodia, A. & Bagchi, (2017). Relationship of flexibility with velocity of ball in fast bowling in cricket. *International Journal of Physical Education, Sports and Health, 4*(2), 286-288.

Spratford, W., Portus, M., Wixted, A., Leadbetter, R., & James, D. A. (2015). Peak outward acceleration and ball release in cricket. *Journal of Sports Sciences, 33*(7), 754-760.

Stuelcken, M., Pyne, D., & Sinclair, P. (2007). Anthropometric characteristics of elite cricket fast bowlers. *Journal of Sports Sciences, 25*(14), 1587–1597. https://doi.org/10.1080/02640410701275185

Thandar, A., & Khan, M. (2017). A study on front foot placement and its effect on bowling action in cricket. *International Journal of Applied Research*, 3(6), 578-580.

Thander, A., & Prasad, S. S. (2019). Fastest bowling delivery is associated with selected kinematic factors in junior pace bowlers. *European Journal of Physical Education and Sport Science*, *5*(8), 89-95.

Thomas, R. H. (2022). *Cricketing Lives: A Characterful History from Pitch to Page*. Reaktion Books.

Threlfall-Sykes, J. (2015). *A History of English Women's Cricket, 1880-1939*. De Montfort University.

Wagh, Y., Wagh, S., & Nikam, K. D., (2022). Assessment of role of physical fitness of cricket players in response to various tests. *Asian Journal of Medical Sciences, 13*(7), 224–229.

Weldon, A., Duncan, M. J., Turner, A. N., Christie, C. J., & Pang, C. M. C. (2021). Contemporary practices of strength and conditioning coaches in professional cricket. *International Journal of Sports Science & Coaching*, *16*(3), 585–600. https://doi.org/10.1177/1747954120977472

Wormgoor, S., Harden, L., & McKinon, W. (2008, July). The determinants of ball release speed in cricket fast bowlers. *In ISBS-Conference Proceedings Archive-26th International Conference on Biomechanics in Sports*.

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. https://doi.org/10.1080/02640411003774537

Worthington, P. J., King, M. A., & Ranson, C. A. (2012). The influence of cricket fast bowlers' front leg technique on peak ground reaction forces. *Journal of Sports Sciences, 31*(4), 434–441. https://doi.org/10.1080/02640414.2012.736628

Worthington, P. J., King, M. A., & Ranson, C. A. (2013). Relationships between fast bowling technique and ball release speed in cricket. *Journal of Applied Biomechanics, 29*(1), 78-84. Retrieved Oct 13, 2024, from https://doi.org/10.1123/jab.29.1.78

Zhang, Y. Unka, J. and Liu, G. (2011). The influence of cricket bowler's joint rotations on ball release speed. *Proceedings 2011 International Conference on Human Health and Biomedical Engineering*. 1022-1025. https://doi.org/10.1109/HHBE.2011.6028997

APPENDICES

APPENDIX-1

Anti-Plagiarism Certificate

FACTORS DETERMINING BALL RELEASE VELOCITY OF WOMEN PACE BOWLERS IN CRICKET

ORIGINALITY REPORT

3%
SIMILARITY INDEX

PRIMARY SOURCES

1	www.researchgate.net Internet	140 words — < 1%
2	www.science.gov Internet	129 words — < 1%
3	www.scribd.com Internet	76 words — < 1%
4	Leigh, St. "The influence of technique on throwing performance and injury risk in javelin throwers", Proquest, 2014. ProQuest	72 words — < 1%
5	brage.bibsys.no Internet	51 words — < 1%
6	jses.net Internet	49 words — < 1%
7	irep.ntu.ac.uk Internet	45 words — < 1%
8	www.ijiemr.org Internet	44 words — < 1%
9	www.kheljournal.com Internet	41 words — < 1%

APPENDIX-2

Ground Permission for Data Collection

To

Date: 21/03/2024

The Director of Physical Instructor

Sports Board

Jadavpur University

Through, The HOD, Department of Physical Education, Jadavpur University

Sub- Application for Permission for Using University Playground and Cricket Mat

Sir,

With due respect I, Neptune Ghosh, Research Scholar, Department of Physical Education, Jadavpur University, beg to state that on 28/03/2024 (F/N), I have planned for data collection for my Ph.D. work, which consists few physical tests along with videography of cricket bowling technique. For this purpose, I need to use the university playground (main ground) and the cricket practice mat of the sports board on 28/03/2024 from 7:00 AM to 10:00 AM.

Hence, you are kindly requested to give the permission to use the above mention things for the research purpose.

Thanking You.

Yours faithfully,

Neptune Ghosh

(Neptune Ghosh)

Research Scholar

Department of Physical Education

Jadavpur University

To,
The DPI,
Forwarded for consideration and necessary action
21/03/2024

HEAD
DEPT. OF PHYSICAL EDUCATION
JADAVPUR UNIVERSITY
KOLKATA-32

APPENDIX-3

Sample Score Sheet for Data Collection of Demographic Details

Sl. No.	Name	DoB (dd/mm/yyyy)	Age (As on 28/03/2024)	Height (cm)	Weight (kg)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

APPENDIX-4

Sample Score Sheet for Data Collection of Anthropometric Parameters

Sl. No.	Name	Upper arm length (cm.)	Forearm length (cm.)	Hand length (cm.)	Arm Span (cm.)	Upper leg length (cm.)	Lower leg length (cm.)	Foot length (cm.)	Standing reach height (cm.)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

APPENDIX-5

Sample Score Sheet for Data Collection of Physical Fitness Parameters

Sl. No.	Name	Arm Strength Test (Kg.)	Back Strength Test (Kg.)	Leg Strength Test (Kg.)	Prone Hold Test (Sec.)	Medicine Ball Throw Test (Mt.)	Vertical Jump Test (cm.)		20 mt. Speed Test (sec.)	Flexibility (cm.)
							Reach Height	Jump Height		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										

APPENDIX-6

Player's Bio Data Format for Data Collection

Player's Bio Data

Name:……

Date of Birth:…………/…………/…………………

Address:………

Mobile No.:……………………………………………

Cricketing Career:

Played Tournaments for	**Total number of Tournaments Played**	**Total number of Matches Played**	**Playing tournaments since (Year)**
Club: 1. 2. 3.			
District (……………………….)			
State (Bengal)			
Other CAB (……………………..)			

Date:

Signature of the Player

APPENDIX-7

Consent/ Self-declaration Format for Data Collection

Self-Declaration

I,……………………………………………………….. (Name), daughter of ………………………………………………. (Father's Name), hereby declare that I have agreed to be the subject of Ph.D. research work of Mr. Neptune Ghosh by self and I am not forced by anyone. I am going to perform all the required tests for this research work only for the sake of the development of women cricket. I also declare that I don't have any kind of previous injury before giving the test and no one will be the responsible for any kind of injury during the tests.

Date: Signature of the Player

APPENDIX-8

First Page of Publication 1

International Journal of Applied Research 2024; 10(3): 221-224

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor (RJIF): 8.4
IJAR 2024; 10(3): 221-224
www.allresearchjournal.com
Received: 07-02-2024
Accepted: 10-03-2024

Neptune Ghosh
Research Scholar,
Department of Physical Education, Jadavpur University, West Bengal, India

Dr. Papan Mondal
Assistant Professor,
Department of Physical Education, Jadavpur University, West Bengal, India

Corresponding Author:
Neptune Ghosh
Research Scholar,
Department of Physical Education, Jadavpur University, West Bengal, India

Influence of segmental joint angle and flexion at delivery stride on pace bowling in cricket

Neptune Ghosh and Dr. Papan Mondal

DOI: https://doi.org/10.22271/allresearch.2024.v10.i3c.12076

Abstract
Introduction: Body segments are considered to be rigid bodies for the purposes of describing the motion of the body. Joint angle (also called inter-segmental angle) is simply the angle between the two segments on either side of the joint, usually measured in degrees. Bowling, in cricket, is the action of propelling the ball towards the wicket with the help of this segmental force.
Methodology: For the purpose of conducting the study, eight male pace bowlers, medium to medium-fast, were purposively selected from various first division club of Kolkata league under C.A.B., age ranging from 20 to 30 years. Ball release velocity, selected segmental angles i.e. Ankle joint angle, Knee joint angle and Hip joint angle at front foot contact, same segmental angles at the time of ball release and the flexions of those joints from front foot contact (FFC) to ball release (BR) were considered as the variables for the study. The bowling delivery actions of the selected bowlers were recorded using two video camera which were stabilised on the tripods. The video was analysed by using the Kinovea-0.8.24 motion analysis software. Mean, standard deviation and Pearson Product Moment Correlation tests were employed to analyse the data statistically.
Results and Discussion: The statistical analysis revealed that the selected segmental joint angles (Ankle joint angle, Knee joint angle and Hip joint angle) at front foot contact were positively correlated with Ball Release Velocity whereas the same segmental angles at ball Release were found to be negatively correlated with Ball Release Velocity. At the same way, flexions of all three joints from FFC to BR are also positively correlated with ball release velocity. Among the all parameters, only Hip joint angle at Ball Release (r= -0.753) and hip flexion from FFC to BR (r= 0.746) were found to be significantly correlated with the Ball Release Velocity.
Conclusions: From the result and discussion, it may be concluded easily that lesser hip joint angle at the time of ball release and greater hip flexion from front foot contact to ball release, can help the pace bowlers to maximise their ball release velocity.

Keywords: Medium pace, bowling, segmental joint, angle, ball release velocity, cricket

Introduction

One of the primary weapons in a pace bowler's arsenal is pace of the ball or Ball Release Velocity. At higher speeds, the reaction time for the batter is significantly reduced. A fast bowler delivering at 140+ km per hour leaves the batter with only fractions of a second to decide whether to play or leave the ball, which increases pressure and often results in poor shot selection. Faster deliveries are also harder to judge when it comes to footwork, and even slight misjudgements can lead to dismissals like bowled, caught behind, or leg before wicket (LBW).

Additionally, speed enhances the effectiveness of other variations that pace bowlers use. For instance, bouncers, when delivered at high speed, rise sharply off the pitch, challenging batters to defend or evade them quickly. Similarly, Yorkers, when bowled at extreme pace, become much harder for the batter to dig out because they reach the toes almost instantly. Even a slower ball becomes more deceptive if the bowler has consistently maintained high speeds beforehand, making the drop in pace harder for the batter to detect.

The segmental joints in the body act like a series of interconnected levers that work together to generate and transfer force. Proper synchronization and coordination of these joints allow a bowler to deliver the ball with maximum speed. If any part of this chain is inefficient or misaligned, it can result in a loss of speed, power, and even control. Therefore, the

APPENDIX-9

First Page of Publication 2

International Journal of Physical Education, Sports and Health 2024; 11(5): 322-326

P-ISSN: 2394-1685
E-ISSN: 2394-1693
Impact Factor (RJIF): 5.38
IJPESH 2024; 11(5): 322-326

https://www.kheljournal.com
Received: 11-08-2024
Accepted: 21-09-2024

Neptune Ghosh
Research Scholar, Department of Physical Education, Jadavpur University, West Bengal, India

Dr. Papan Mondal
Assistant Professor, Department of Physical Education, Jadavpur University, West Bengal, India

Corresponding Author:
Neptune Ghosh
Research Scholar, Department of Physical Education, Jadavpur University, West Bengal, India

Influence of run-up velocity on cricket bowling

Neptune Ghosh and Dr. Papan Mondal

DOI: https://doi.org/10.22271/kheljournal.2024.v11.i5e.3537

Abstract
Introduction: In cricket, a fast bowler needs to take a longer run-up or approach toward the wicket than a spinner, due to the need to generate momentum and rhythm. Fast bowlers measure their preferred run up in strides, and mark the distance from the wicket.
Methodology: For the purpose of the study, eight medium pace bowlers were selected from various First Division Clubs of Kolkata league under CAB (Cricket Association of Bengal), age ranging from 20 to 30 years. Ball release velocity and different run-up velocities (Initial, Final and Average) have been considered as the factors in this study. The bowling actions of medium bowling technique of the selected cricketers (24.25±4.68 year, 172.31±5.70 cm, 64.25±8.00 kg) were recorded by two fixed video cameras [Camera-1(Canon 1200D): 50fps and Camera-2(Nikon 5100D): 30fps]. The video was analyzed by using the Kinovea-0.8.25 motion analysis software to measure the selected kinematic parameters. Mean, standard deviation and Pearson Product Moment Correlation tests were employed using SPSS-20 software.
Results and Discussions: The results of the statistical analysis of the data revealed that the final run-up velocity (20.79±2.35 km./h) had positive relation (r=0.722) with the ball release velocity (110.18±6.39 km./h) at 0.05 significance level. The initial run-up velocity (12.03±2.09 km./h) and average run-up velocity (16.41±1.77 km./h) also had insignificant positive relation with ball release velocity. Bowlers with a quicker run-up may have a greater amount of linear momentum that can be helpful in generating higher ball release speed.
Conclusions: From the study it may be concluded easily that for medium pace bowling in cricket, the faster final run-up velocity facilitates the bowler to bowl faster.

Keywords: Cricket, bowling, run-up velocity, medium pace, ball release velocity

Introduction
Pace bowling in cricket involves delivering the ball at high speeds, typically above 85 km/h (53 mph), with variations in swing, seam, and bounce to deceive the batsman. Fast bowlers use their strength and technique to generate speed and movement through the air or off the pitch (e.g., Wasim Akram for swing, Brett Lee for sheer pace). The primary objective is to outpace or outmaneuver the batsman, forcing mistakes or dismissals.
Ball velocity plays a pivotal role in pace bowling, significantly influencing both the bowler's effectiveness and the batsman's ability to respond. High velocity reduces the time a batsman has to judge and react, increasing the chances of misjudgments and leading to dismissals. Faster deliveries also enhance swing through the air and seam movement off the pitch, adding an element of unpredictability that makes it difficult for the batsman to anticipate the ball's trajectory. Additionally, higher speed generates more bounce off the pitch, making bouncers more intimidating and harder to control. Key deliveries like Yorkers become more potent at high speeds, as they allow little time for the batsman to defend or adjust. Maintaining high velocity over time also exerts mental and physical pressure on the batsman, often leading to mistakes and creating opportunities for wickets. Overall, ball velocity is a fundamental tool in a fast bowler's arsenal, enabling them to dominate the game by limiting the batsman's reactions and controlling the pace of play.
The velocity of a bowler's run-up is crucial in determining the ball's final velocity at release. A faster run-up helps generate greater momentum, which is transferred through the bowler's body and into the bowling action, directly influencing ball speed. By creating kinetic energy with their legs and transferring it efficiently through their hips, shoulders, and arm, bowlers can deliver faster balls. However, the run-up must be smooth and well-coordinated; if it's rushed or

APPENDIX-10

Certificate of Seminar Presentation

EAST ASIA RESEARCH

Certificate of Participation

This is to certify that

Neptune Ghosh

has attended

Asia-Singapore Conference on Sport Science (ACSS 2019)

held at the Grand Copthorne Waterfront on the 18th and 19th July 2019

Anthony Tan Lee Ming
Managing Director
East Asia Research

APPENDIX-11

Marksheet of Course Work

JADAVPUR UNIVERSITY
KOLKATA-700 032
MARK SHEET

NO.: PHCW/16052/ 000694

(For Ph. D Course Work)

Results of the PH.D. COURSE WORK EXAMINATION. 2020

In ARTS held in DECEMBER. 2019

Name NEPTUNE GHOSH

Examination Roll No. PHDPED20102

Course Name / Subject	Credit Hr.(c_i)	Marks	Grade
Phy.Ed/Ph.D./1.1 :: RESEARCH METHODOLOGY	4	30	A
Phy.Ed/Ph.D./1.2 :: MODERN TRENDS IN PHYSICAL EDUCATION	4	29	B+

Total Marks : 59 (out of 100) **SGPA:** 8.50 **Remarks:** P

Prepared by : [signature] Checked by : [signature]

Date of issue : 18-02-2020

Controller of Examinations

APPENDIX-12

Certificate of UGC-NET

Electronic Certificate No.: 161017173

University Grants Commission

NATIONAL EDUCATIONAL TESTING BUREAU

ज्ञान-विज्ञानं विमुक्तये

NATIONAL ELIGIBILITY TEST FOR ASSISTANT PROFESSOR

UGC Ref. No.: 17173/(NET-JULY 2016) Roll No.: 89022177

Certified that NEPTUNE GHOSH

Son/Daughter of RAJKUMAR GHOSH

and PURNIMA GHOSH had applied for the UGC-NET for eligibility for Assistant Professor held on 10-07-2016 in the GENERAL category and qualified by securing marks at par with the qualifying cut-off for GENERAL category in the Subject PHYSICAL EDUCATION

As per the information provided by the candidate, he/she had not completed his/her Master's degree or equivalent examination at the time of applying for NET.

The date of eligibility for Assistant Professor is the date of declaration of NET result, i.e., 21st November 2016, OR the date of completion of Master's degree or equivalent examination with required percentage of Marks within two years from the date of declaration of NET result, i.e., by 20th November 2018, whichever is later.

This is an electronic certificate only and its authenticity should be verified from the UGC by the employer. This electronic certificate can also be verified by scanning QR Bar Code printed on the electronic certificate.

Validity of this electronic certificate is forever.

Date of Issue: 27-02-2017

Head
NET Bureau

Note: a) UGC has issued the electronic certificate on the basis of information provided by the candidate in his/her Application Form. The appointing authority should verify the original records/certificates of the candidate while considering him/her for appointment, as the Commission is not responsible for the same. The candidate must fulfil the minimum eligibility conditions for NET as laid down in the notification for UGC-NET.

b) Wherever SC/ST/OBC/PWD is shown in the UGC Ref. No., the institution/recruitment body should check the relevant documents of that category.

APPENDIX-13

Certificate of WBSET

Certificate No. WBCSC20172316

THE WEST BENGAL COLLEGE SERVICE COMMISSION

TWENTIETH STATE ELIGIBILITY TEST FOR THE POST OF ASSISTANT PROFESSOR OF COLLEGES & UNIVERSITIES

(Accredited by the UNIVERSITY GRANTS COMMISSION, New Delhi)

(Valid in the State of West Bengal only)

Certified that NEPTUNE GHOSH

Son/Daughter of RAJKUMAR GHOSH

and PURNIMA GHOSH

Roll No. 0515712 *Category* GENERAL *PWD* NO

has qualified at the Twentieth West Bengal SET -2017 *held on* 03.12.2017 *in*

the Subject PHYSICAL EDUCATION

The date of qualifying for SET is 06.06.2018

This Certificate is valid forever.

Prof. (Dr.) Subha Sankar Sarkar
Chairman
Steering Committee, W.B.SET

Dr. Dipak Kumar Kar
Chairperson
The West Bengal College Service Commission &
Member Secretary, W.B. SET

Date of Issue : 21.06.2018

Note :

a) The West Bengal College Service Commission is issuing the Certificate on the strength of the information provided by the candidate. The appointing authority should verify the original record/certificate(s) of the candidate while considering him/her for appointment, as the SET agency cannot take the responsibility of authenticating the genuineness of his/her claims.

b) If the candidate is a PG student, he/she must complete the same with the requisite marks within two years of the date of declaration of result of the SET examination.

c) If the candidate belongs to SC/ST/OBC/PWD category, the appointing authority should check the document(s) while considering him/her for appointment, as per the stipulations laid down by the concerned Dept. (s) of the State Govt.

d) This is an electronic certificate and its authenticity should be verified by the employer from the WBCSC. The electronic Certificate can also be verified by **scanning QR Bar Code printed on the certificate.**

APPENDIX-14

Permission Letter of 1st Extension of Ph.D. Registration

যাদবপুর বিশ্ববিদ্যালয়

INDRAJIT BANERJEE
Secretary
FACULTY OF ARTS

*JADAVPUR UNIVERSITY
KOLKATA-700 032, INDIA

F.I. No. 117/17/Arts

Ref.No. Ø-7/A/785/23

Dated: 15.12.2023
T9

To
Sri Neptune Ghosh
Vill: Bhandara, P.O: Bahara,
P.S:Kandi, Dist: Murshidabad,
Pin-723146, W.B

Sir/Madam,

In reply to your application dated: 23.11.2023, this is to inform you that the validity of your Ph.D. (Arts) registration has been extended for a period of one year with effect from 29.11.2023 as recommended by the Research Advisory Committee and duly approved by the Dean, Faculty of Arts dated: 07.12.2023.

Thanking you,

Yours faithfully,

Secretary,
Faculty Council of Arts.

* Established on and from 24th December, 1955 vide Notification No.10986-Edn/IU-42/55 dated 6th December, 1955 under Jadavpur University Act, 1955 (West Bengal Act XXIII of 1955) followed by Jadavpur University Act, 1981 (West Bengal Act XXIV of 1981)

দূরভাষ: ৯১-৩৩-২৪৫৭-২২১২
দূরবার্তা: ৯১-৩৩-২৪১৪-৬০০৮
Website :https//jadavpuruniversity.in
E-mail : banindrajit@gmail.com/secretaryfa@jadavpuruniversity.in
Phone : +91-33-2457-2212
Fax : +91-33-2414-6008

APPENDIX-15

Permission Letter of 2nd Extension of Ph.D. Registration

যাদবপুর বিশ্ববিদ্যালয়

DR. INDRAJIT BANERJEE
Secretary
FACULTY OF ARTS

*JADAVPUR UNIVERSITY
KOLKATA-700 032, INDIA

F.I. No. 117/17/Arts

Ref. No. ᵹ-7/A/986/24

Dated: 04.12.2024

To
Neptune Ghosh
KV Stafff Quarter – C9,
KV No. 2 AFS Kalaikunda,
West Medinipur - 721303,
West Bengal.

Sir/Madam,

In reply to your application dated 13.11.2024, this is to inform you that the validity of your Ph.D. (Arts) registration has been extended for a further period of **Six (6) months** with effect from 29.11.2024 vide D.C. Res. No. 3 dated 18.06.2024 as a very special case and also be noted that the registration shall be cancelled automatically thereafter.

Thanking you,

Yours faithfully,

Secretary
Faculty Council of Arts

* Established on and from 24th December, 1955 vide Notification No.10986-Edn/IU-42/55 dated 6th December, 1955 under Jadavpur University Act, 1955 (West Bengal Act XXIII of 1955) followed by Jadavpur University Act, 1981 (West Bengal Act XXIV of 1981)

দূরভাষ: ৯১-৩৩-২৪৫৭-২২১২
দূরবার্তা: ৯১-৩৩-২৪১৪-৬০০৮
Website :https//jadavpuruniversity.in
E-mail : banindrajit@gmail.com/secretaryfa@jadavpuruniversity.in
Phone : +91-33-2457-2212
Fax : +91-33-2414-6008

APPENDIX-16

Photographs of Data Collection

APPENDIX-17

Group Photo of Experts and Team Involved in Data Collection