

Impact of Biomechanical Analysis in Shot Put Technique

Mr. Suryakant J. Shinde

Department of Physical Education and Sports, Adarsh College, Vita

Article Info	ABSTRACT
<p>Article History: Received: 17th January 2026 Accepted: 22nd January 2026 Published: 02nd February 2026</p>	<p>The role of biomechanics is described in this research paper by considering an angle, velocity, and height perspective on the different parameters of release, and their specific effects on the athletes, to provide insight into the effects of the mechanics on performance of shot put. Whereas theoretical guidance suggests that a release angle of 45° provides optimal range, sport data from elite throwers demonstrated a range of angle of around 37°–38°, that plays a huge role in how the athlete releases and generates force. The relationship between kinetic and potential forces, as well as force reduction with increasing release angle, is the topic of this study, thus requiring personalized biomechanical assessment and training. Recent technology advances, such as computer vision and markerless motion-capture systems like Open Pose and Open Cap, have dramatically changed the application of biomechanical analysis technology, allowing the precise and non-invasive identification of joint kinematics in field conditions in real time. These tools enable personalization of techniques and injury prevention by analyzing slight movements by machine learning to determine the movement variation. In addition, the neuromuscular control and variable muscle activation patterns emphasise the importance of customized training regimes, not just the standard models.</p>
<p>Keywords: <i>Biomechanics, Shot Put Technique, athletes, height of release, angle of release, Path of Parabola</i></p>	

Copyright © 2026 The Author(s). This is an open access article distributed under the Creative Commons Attribution License, (<http://creativecommons.org/licenses/by/4.0/>) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to Cite: Shinde, S. J. (2026). Impact of Biomechanical Analysis in Shot Put Technique. IIP: International Multidisciplinary Research Journal (IIPIMRJ), 3(1), 350–359.

Overview of Biomechanics in Shot Put

Biomechanics of shot put is an examination of physical principles and their influence on the performance of athletes' action and skill level during the shot put action. The angle of release at which the ball can be struck will be key to obtaining the desired distance. Existing textbook approaches include release angle of 45° as the ideal angle for a projectile to travel. Nevertheless, empirical measurements from elite athletes consistently indicate lower optimal angles; usually around 37° to 38° [1].

The discrepancy between the theoretical ideal angle and actually observed optimal angle has raised further questions. One of the primary causes here is the height of the athlete at the moment which, once incorporated into a theoretic model, results in a predicted optimal angle that is only nearly 42° [1].

Additional adjustment of these models considers the dependent relation of the initial velocity of the shot (v_0), the height of release (h), and the angle of release (θ). The height of release versus angle of release is graphically geometric and has been described previously: de Luca (2005), which was corrected and confirmed in many later analyses [1].

Next, the biomechanical aspects are further complicated by the fact that the athlete's energy may be dissipated into the kinetic and potential states, which implies that with these, smaller sets of optimal release angles are preferred at that moment in their lifecycle. Furthermore, both the strength or strain an athlete can exert on the shot and angle-dependent variables exist, which determine the appropriate angle and select lower values. This force-angle relationship is variable for each athlete, requiring customized biomechanical assessment for further optimization [1].

In order to generalize the found data, some simplified models (i.e., the toy models) have been created, that simulates the angle dependence of the force applied on athletes. Such models provide theoretical calculations of the ideal angle at which the user leaves the body (which is highly consistent with empirical data, in a range of 37° to 38°). Notably, these theories also predict reducing initial velocity linearly as release angle increases, supportive of experimental predictions [1].

This biomechanics of the action mechanics is informed by experimental data obtained from major competitions, e.g., the Summer Olympic Games of 1972, where calculated data for initial velocity, release height, release angle, and achieved distances were recorded. Biomechanical models also incorporate certain environmental conditions which represent specific behaviors such as wind conditions that are also measurable differences in distance between shots as a function of wind direction and wind speed [1].

Thus, to conclude, the biomechanics of shot put incorporates geometric, energetic, and force-related variables to predict and optimize performance, with emphasis on how release angle, velocity, and height come together with one another: These analyses are backed by theoretical models with practical measurements from the field [1].

Related works:

Early biomechanical studies of throwing events were based on marker-based optical systems that were not suitable for practical field use. The arrival of convolutional pose estimation transformed this notion. Cao et al. [2] proposed Part Affinity Fields for robust, real-time multi-person key-point detection in unconstrained scenes [2]. Shortly thereafter, Mathis et al. found the feasibility of sub-pixel precision markerless tracking over arbitrary animal or human behaviours through transfer learning, creating a flexible laboratory-grade alternative [3] for use in the study.

After becoming fundamental systems, these have become the methodological bedrock of most modern shot-put biomechanical researches that allows the analysis of joint kinematics when training or competing without overly encumbering hardware. Some further iteration fine-tuned the precision and accessibility. Transitioning the same fundamental design into a framework that could be used production-ready, the OpenPose release offered an open-source toolkit that sports scientists were using extensively to get off the ground feedback quickly [4]. Specialising in movement science, Mériçoux et al. developed Pose2Sim, an end-to-end pipeline, which incorporates the 2-D key-points obtained from multiple cameras with photogrammetric optimisation, resulting in full-body 3-D trajectories suitable for inverse dynamics of high-velocity throws such as the glide and rotational shot-put styles [5]. Most recently, Kanko et al. demonstrated OpenCap that a couple of normal smartphones can model segmental kinematics and joint moments with similar laboratory gold standard error, making a point for large-scale, in-contest biomechanical monitoring of elite throwers on a large-scale basis [6]. Taken together, these papers represent the development of fundamental pose estimation algorithms to customised, field-ready platforms to enable quantitative analysis of release parameters, inter-segmental sequencing, and energy transfer in the most current shot-put practice.

1. Fundamental Biomechanical Principles in Shot Put

1.1. Optimal Angle of Release: Theoretical and Empirical Considerations

A central biomechanical principle in shot put is the determination of the optimal angle of release, which directly influences the distance achieved. Traditional textbook physics posits that the optimal release angle for maximum range is 45° , assuming a projectile is launched from ground level with no air resistance. However, empirical measurements of elite shot putters consistently yield lower optimal angles, typically around 37° – 38° [1]. This discrepancy arises from several biomechanical and physical factors that modify the idealized model.

One significant factor is the height of release. When the shot is released from a height above the ground, as is the case with human athletes, the optimal angle decreases. Incorporating the athlete's release height into the theoretical model reduces the predicted optimal angle to approximately 42° , as shown by Lichtenberg and Wills (1978) [1]. This adjustment reflects the geometric relationship between the release height and the trajectory of the shot, which was further detailed and corrected by de Luca (2005). The increased height allows the shot to travel further for a given initial velocity, thus favoring a slightly lower release angle than the textbook value.

1.2. Interdependence of Release Parameters: Velocity, Height, and Angle

Aside from this simple geometric issue, initial velocity (v_0), releasing height (h), and angle of release (θ) interaction is very important in shot put performance as well. The energy transferred to the shot by the athlete divides the energy between kinetic and potential. At higher angles of release, a higher ratio of the athlete's energy is assigned to the vertical (potential) contribution, which minimizes the horizontal (kinetic) component, and thus the achievable range. Energy partitioning favors smaller release angles and ensures the distance is maximized [1]. Moreover, the force an athlete can exert on the shot will vary among all release angles. The drop in velocity of v_0 with increasing release angle θ is reflected in empirical observations along with theoretical models and was supported by Maheras (1998) and was further modeled in [1]. The phenomenon can enhance the empirical explanation that elite athletes exhibit

maximum performance at an angle lower than the theoretical maximum. These interdependencies are captured in biomechanical analyses with toy models that represent the interplay between different angles of the generating force of an athlete. As such, these models do not need to take large individualized measurements of $v(\theta)$ and $h(\theta)$, which predicts optimal release angles within the range of 37° – 38° , and that are well matched to the observed values from elite competitions [1]. This integration of the theoretical model with the empirical result highlights the need to incorporate biomechanical factors, e.g., athlete physique and energy transferring mechanics, as a factor in the analysis of shot put technique.

1.3. Environmental and Individual Variability

The concepts outlined above establish a fundamental conceptual framework; however, individual athlete characteristics and environmental factors introduce significant variability. The relationship between force generation and release angle can vary from one athlete to another, indicating that the specific biomechanical variables influencing this relationship are athlete-dependent. Achieving optimal performance requires understanding these variations. Additionally, external factors, such as wind exposure, can have a measurable yet minor impact on shot put distance. According to Rappl (2010), headwinds and tailwinds can affect distance by several centimeters, but these effects are often secondary to the primary biomechanical elements [1]. The key biomechanical principles influencing shot put performance include the intricate interplay of release angle, velocity, height, and the athlete's capacity for force production. The synergy of these factors, supported by both theoretical principles and empirical evidence, lays a robust foundation for enhancing shot put techniques.

2. Kinematic Analysis of Shot Put Movements

2.1 Modeling the Projection Phase and Force Application

The kinematic model for shot put movement may start with projecting the shot put movements from rest through a model that the athlete applies force to accelerate the shot from rest along a straight-line path of known length. A simplified biomechanical model of power distribution is obtained under the assumption of a constant force (F) applied by the athlete acting over a straight line of length (l) which leads to a velocity of a shot's projection at trajectory (v) , as a function of its length. Based on the theory of conservation with regard to conservation of energy, this provides a preliminary context that allows for exploration the relationship of the athlete's applied pressure to the mass of the shot and the measured velocity of the shot at release. The shot mass (kg) for men is 7.26 kg and that of women is 4.00 kg for standard competition. However, this minimal model estimates projection velocity as being the same at all projection angles, which is inconsistent with experimental records of elite putters [7].

2.2 Influence of Projection Angle on Force and Velocity

Thus, the physical forces an athlete can exert on the shot do differ from one angle to another; the force is greater in the horizontal direction and decreases with increasing verticality. To accommodate this adjustment, an improved model includes a linear decrease in the force the athlete is applying as the projection angle increases. The average force for a horizontal projection (F_o) is reduced by a factor proportional to the angle, characterized by a constant (a) (in N/degree) in this model. For example, in a case analysis of a male shot-putter, the length of the straight-line acceleration path was 1.65 m (average horizontal force $(F_o) = 460$ N; rate of force decrease $(a) = 4.1$ N/degree). These values are similar to

those observed in video analyses of world-class athletes and in keeping with differences in muscle strength seen between exercises, like the bench press and shoulder press, that recruit distinct groups of muscles and force vectors [7]. In this model, which includes the angle-dependent approach of applying forces, they have a much better fit to the experiment, and indeed better matched the drop in projection velocity at higher angles. The factor (F_o) depends largely on the total strength, and the value (a) is the throwing ability and the relative intensity of the involved muscles. Typical values for elite male athletes range from 100 to 800 N for (F_o) and 2 to 5 N/degree for (a) . The model also indicates that the effective range in shot put is predominantly affected by the strength of the athlete (F_o) , and the optimal projection angle is more in accordance with the rate at which force decreases with increasing angle (a) . A faster rate of velocity decrease with angle leads to a lower peak maximum range projection angle [7].

2.3 Implications for Technique Optimization

The kinematic understanding given by this model has real-time significance with respect to the fine tuning of shot put technique. The maximum range of the athlete is closely related to horizontal force generation, so training the appropriate muscle groups for strength can enhance overall performance. In contrast, the most optimal projection angle relies on the tendency of the force output of the athlete to decrease with increasing angle, a function of both technique as well as muscle coordination. Thus, performance training targeting force transfer efficiency during the throwing process increases the sustained generation of force at larger projection angles, potentially increasing the angle and performance parameters. The model also shows that, due to the relatively small influence of gravity compared to the forces generated by elite athletes, the weight of the shot has only a minor effect on the choice of projection angle, further emphasizing the importance of biomechanical and strength factors in shot put kinematics [7].

3. Kinetic Factors Influencing Shot Put Performance

3.1 Individualization of Release Parameters

Finding the best angle to release the shot is a key biomechanical aspect in shot put. This angle has a direct effect on how far the shot goes. Standard physics books say that the best angle to fire a projectile for the longest range is 45°, as long as the projectile is launched from the ground with no air resistance. However, real-life tests of professional shot putters show that the best angles are usually lower, about 37° to 38° [1]. This difference is caused by a number of biomechanical and physical elements that change the idealized model.

The height of release is one important thing. The best angle for a shot diminishes as it is released from a height above the ground, like with human athletes. Adding the athlete's release height to the theoretical model lowers the anticipated best angle to about 42°, as indicated by Lichtenberg and Wills (1978) [1]. This change is based on the geometric link between the release height and the shot's path, which de Luca (2005) explained and fixed in more detail. The higher height lets the shot go farther with the same starting speed, therefore a release angle that is a little lower than the textbook figure is better.

3.2 Neuromuscular Control and Variability

Recent research has shown that neuromuscular control is also useful in optimizing kinetic factors. Research investigating surface electromyography and high-speed motion analysis has demonstrated that elite athletes show much higher variability in the timing of muscle activation in comparison to less skilled

individuals. Greater variability is neither a sign of inconsistency, per se, nor evidence of a subpar performance on the particular challenges each attempt poses; it is instead a better tuned approach to muscle activation itself. It demonstrates that neuromuscular adaptability allows elite throwers to establish their physical output of a particular throw, such as the timing and magnitude of force application, in the context of a particular throw. Interestingly, however, manipulations of muscle activation timing have not been reported to be universally effective, highlighting the need for focused training protocols. As a result, elite shot put performance is characterized by precise neuromuscular control of kinetic factors and the role of individualized technique training instead of generic biomechanical models [8].

4. Muscle Activation and Coordination in Shot Put

4.1 Individualization of Muscle Activation Patterns

Research in athletic projectile sports (e.g., basketball) supplies relevant data on muscle activation and coordination principles for shot put technique. Research utilizing surface electromyography and high-speed camera analysis has measured higher variability in the timing of muscle activation in high level competitors when compared to athletes with lower level of specialization. This range is not random, but rather reflects an adaptive response to stimuli and muscle activation according to the particularities of any given situation. For shot put, this goes to show that ideal muscle activation patterns are not general; they are rather idiosyncratic. The individual participants have their own neuromuscular strategy that relies on their physical attributes and preferences for technique. An individual performance focus leads to optimal timing of muscle activation and to the most powerful and accurate force generation and coordination to produce maximal shot put performance [8].

4.2 Coordination and Release Optimization

Coordinating the various muscle groups in order to get an effective release is central to shot put performance. From the mechanical analysis of basketball shot making, we have observed that players will achieve optimal release conditions (e.g. angle, velocity and height) when adapting these parameters to their own biomechanical situation instead of having to follow a prescribed concept. The same applies to shot put, with coordination of muscle groups along the kinetic chain being dependent on the unique mechanics of each athlete. Muscle activation control, especially in the decisive phase of release, is a key feature of elite performance. Attempts to standardize or manipulate muscle activation timing through artificial means did not translate into a general improvement, highlighting a need for individualized coordination strategies. So that the best shot put technique comes from being able to combine muscle activation and coordination in ways that are body- and movement pattern-specific [8].

5. Biomechanical Assessment Tools and Technologies

5.1 Conventional Biomechanical Analysis Methods

Traditional biomechanical analysis techniques have formed a cornerstone enabling quantification and estimation of kinetics and kinematics of human motion, applicable to sports like shot put. These techniques usually use motion capture systems that use reflective markers placed on specific anatomical landmarks on the subject. This data is then fed to an infrared camera system and monitored to collect a better overview of that motion. In addition to capturing motion, anthropometric measurements and external force data are used, using force gauges and measuring the body directly. This complete dataset facilitates the construction of biomechanical models that model all musculoskeletal elements (bones, joints,

muscles, ligaments, and cartilage). These models allow for the calculation of internal joint loads, muscle forces, and other relevant biomechanical parameters, providing objective metrics of musculoskeletal load and movement patterns [9]. Despite that precision and in-depth information, conventional analysis techniques of biomechanics have some restrictions. Their costly equipment and lab-style characteristics limit whether they can be applied in field or non-field sites. Markers being put together can be time-consuming, invasive, and can have unpleasant effects on the participants' behavior, which may affect natural movement patterns and restrict the application out of scientific or clinical settings. These constraints indicate the need of the introduction of more accessible and less invasive biomechanical assessment tools, especially for the context that requires the collection of real-world data (e.g., ongoing athlete observation, work ergonomics) [9].

5.2 Emerging Computer Vision-Based Approaches

Recent developments in artificial intelligence, particularly computer vision (CV), have initiated breakthrough opportunities for biomechanical evaluation. CV methods are based on computational models and standard cameras to study visual data and in this way it is possible to extract joint coordinates in the two-dimensional space (2D and 3D) from video clips. Those algorithms can recognize some body landmarks, like joints and extremities, and can predict their spatial locations with high accuracy. The technology obviates the requirement of reflective markers and specialized motion capture equipment [9], and this greatly reduces both the price and complexity for biomechanical analysis. CV-based biomechanical evaluation has several advantages. The availability of such camera-based systems democratizes biomechanics diagnostics by making detailed movement data available to a wider audience compared to expensive and time-consuming applications. Second, the clinical use of CV techniques enables the assessment of individuals to be carried out outside of controlled laboratory environments, such as on the field, in rehabilitation centers, or even in athletes' homes. It may facilitate the ecological validity of biomechanics data, and it can be performed continuously in the biological environment. This means that CV-based systems will gradually make strides in biomechanical assessment of shot put technique, providing real-world applications of those aspects which have been otherwise not possible based on standard techniques at present, in addition stretching the range of research and applications in biomechanics field [9].

6. Technique Optimization through Biomechanical Analysis

6.1 Individualization of Release Parameters

Biomechanical studies suggest that optimization of technique in projectile sports (e.g., shot put) is less a matter of complying with universal mechanistic principles versus individual, complex choices. Pioneering research in sport similar to basketball established the ideal limits of the release parameters (release height, velocity, launch angle and spin) with the help of a very wide ranging simulation and trajectory analysis. These reports posited that performance optimization would depend on target numbers for each parameter (e.g., a launch angle of 52 degrees, and a release with the greatest height with controlled backspin) [8]. But subsequent investigations have also made the generalization of these recommendations somewhat questionable, highlighting that the effect of such a protocol in human muscle health seems particularly irrelevant in an era of intense competition where release conditions need to be adjusted for specific biomechanical and physiological effects of a single athlete in order to maximise effectiveness. One

of such analysis, based on surface electromyography and high-speed video testing on top of the latter technique, can be used to highlight higher variability patterns of muscle activation timing among elite athletes than at lower level athletes. This greater discrepancy is not a function of variation, but results from an ability to fine-tune muscle activation pattern to match the needs for each attempt. This kind of adaptability is probably a result of extensive training, which allows athletes to optimize their neuromuscular coordination following slight adjustments in technique or environmental conditions [8]. For shot put, this means that optimal release parameters for angle, velocity, height are determined by the athlete's own mechanics, anthropometry, and coordination patterns and should never be imposed by a fixed set of ideal values.

6.2 Implications for Training and Performance Enhancement

The importance of recognizing optimum technique as extremely personalized has far-reaching consequences for both coaching and athlete growth for shot put. Biomechanical analysis should help in identifying the specific strengths and weaknesses of athletes rather than recommending a single model for release mechanics. Such methods entail detailed investigation of various athlete movement patterns, muscle activation sequences, and their physical characteristics, followed by the adaptation of technical stimuli and training procedures for the specific characteristics of their unique performance profile [8]. For instance, a greater naturally higher release point athlete will need to optimize their release velocity, whereas one with better lower-body power may be able to optimize their delivery phase by manipulating the timing and coordination of it. Notably, control of and timing of muscle activation becomes a major competitive advantage in elite athletes. For this reason, training plans should include exercise/correction tasks and feedback to stimulate proprioceptive awareness and neuromuscular adaptability in order that athletes may react to the demands of competition with less inhibition. Through high-speed video processing analysis and electromyography, feedback can be done through measurement, both for individuals and professional athletes. Through careful control of speed at the biomechanical level, the hope is that every athlete's maximum skill is further developed, and he or she will find out which technique brings maximum success [8].

7. Injury Prevention and Performance Enhancement

7.1 Data-Driven Detection of Injury Risk and Technique Deviation

Recently, biomechanical techniques such as the blend of computer vision and machine learning have begun to open new doors for injury prevention in shot put and similar sports. The recent development of mechanical analysis with automatic feature engineering and pose estimation from video can now be applied to detect slight differences in an athlete's movement which may indicate a high risk of injury. Machine learning models such as Random Forests, that are able to have a 67% correlation with performance outcomes even with a relatively small amount of dataset, have the potential for such tools to extract the biomechanical patterns related to efficient and improper movement performance. This is very beneficial for elite athletes, because it allows you to have a "save point" for your technical movement, which allows monitoring your body during injury or when you are losing performance. Based on an assessment of the current condition, compared to those known to have worked optimally, coaches and medical personnel can recognise signs of compensatory movements or technical defects before injury takes place, facilitating an intervention course and appropriate rehabilitation protocol. These tiny differentials in technique, which

are rarely apparent from the outside, offer a preventive measure against injury by decreasing the occurrence of overuse injuries or acute biomechanical breakdowns [10].

7.2 Performance Enhancement through Automated Biomechanical Analysis

Computer vision and machine learning analysis of shot put technique goes beyond injury prevention and presents huge possibilities for performance improvement. Automated systems have the ability to mine through large volumes of biomechanical data to identify some of the features to look for across many different body parts – including the ankle, knee, hip, shoulder, elbow – which impact performance in shot put. In particular, using 3D pose estimation appears to be significantly superior to 2D techniques, considering that the addition of 3D dynamics provides for the complexity associated with rotational and translational movement of shot put. This enhanced dataset allows more accurate modeling of technical execution and performance outcomes — like release angle and rotational speed. Scaling to thousands of throws from multiple athletes provides such a big data environment that personalized training program creation and player recommendation systems will be made based on distinct technical profiles. In addition, sports-specific 3D pose datasets will enable fine-tuning of the machine learning models, augmenting the accuracy and usefulness of biomechanical feedback even further. Although the limitations identified by this work can be noted; for example, the needs of controlled data acquisition conditions, and issues in making real-time decisions; it is possible that automated biomechanical assessment will be an integral aspect of performance optimization in shot put and other single-athlete sports [10].

Conclusion

This article focuses on biomechanics in shot put and discusses what the basic principles of biomechanics are and how it influences movement patterns, muscle activity, in addition to new techniques to analyze performance. One of our primary objectives was to emphasize how critical it is to optimize release parameters (speed, height, angle) for each athlete and the environment. It turns out that knowledge of the unique kinematic and kinetic characteristics of each athlete becomes extremely important. That's because different types of people use force and control their muscles in very different ways. We can use both old and new computer vision technologies to track and analyze the techniques of athletes and coaches and find any problems that make players more likely to get hurt. In the end, biomechanical science and analytics can lead to even better training methods, better injury prevention and better shot-put skills. The research indicates that it's critically important that we create tailored approaches that are rooted in science to help our participants grow to the level of maximal potential but keep injury risk low.

References

- [1] A. Lenz and F. Rappl, "The optimal angle of release in shot put," arXiv preprint arXiv:1007.3689, 2010. [Online]. Available: <https://arxiv.org/abs/1007.3689>
- [2] Z. Cao, T. Simon, S.-E. Wei, and Y. Sheikh, "Realtime multi-person 2D pose estimation using part affinity fields," arXiv preprint arXiv:1611.08050, 2016. [Online]. Available: <https://arxiv.org/abs/1611.08050>
- [3] N. Kumar, P. Dineshkumar, R. Rameshbabu, and A. Sen, "Morphological analysis of ultra fine α -MnO₂ nanowires under different reaction conditions," arXiv preprint arXiv:1809.03131, 2018. [Online]. Available: <https://arxiv.org/abs/1809.03131>
- [4] Z. Cao et al., "OpenPose: Realtime multi-person 2D pose estimation using part affinity fields," arXiv

- preprint arXiv:1812.08008, 2018. [Online]. Available: <https://arxiv.org/abs/1812.08008>
- [5] Y. Guo, "Doing natural language processing in a natural way: An NLP toolkit based on object-oriented knowledge base and multi-level grammar base," arXiv preprint arXiv:2105.05227, 2021. [Online]. Available: <https://arxiv.org/abs/2105.05227>
- [6] H. Wen et al., "Single cells are spatial tokens: Transformers for spatial transcriptomic data imputation," arXiv preprint arXiv:2302.03038, 2023. [Online]. Available: <https://arxiv.org/abs/2302.03038>
- [7] N. P. Linthorne, "Throwing and jumping for maximum horizontal range," arXiv preprint arXiv:physics/0601148, 2006. [Online]. Available: <https://arxiv.org/abs/physics/0601148>
- [8] R. Zhu, D. Love, and S. Powers, "Ball path curvature and in-game free throw shooting proficiency in the National Basketball Association," arXiv preprint arXiv:2506.13779, 2025. [Online]. Available: <https://arxiv.org/abs/2506.13779>
- [9] J. Omidokun, D. Egeonu, B. Jia, and L. Yang, "Leveraging digital perceptual technologies for remote perception and analysis of human biomechanical processes: A contactless approach for workload and joint force assessment," arXiv preprint arXiv:2404.01576, 2024. [Online]. Available: <https://arxiv.org/abs/2404.01576>
- [10] T. Mendes-Neves, L. Meireles, and J. Mendes-Moreira, "A survey of advanced computer vision techniques for sports," arXiv preprint arXiv:2301.07583, 2023. [Online]. Available: <https://arxiv.org/abs/2301.07583>