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THE FORWARD STEP IN A BOXER CANDIDATE FOR MASTER OF SPORTS: A BIOMECHANICAL ANALYSIS BY 3D MA TECHNOLOGY

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ABOUT ARTICLE

Key words: boxing biomechanics, forward step, 3D motion analysis, kinematic analysis, kinetic analysis, combat sports performance, foot placement, joint angles, sports biomechanics, motion capture technology.

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Abstract: This study presents a detailed biomechanical analysis of the forward step in a boxer candidate for the title of Master of Sports, utilizing 3D motion analysis technology. The research aims to explore the kinematic and kinetic parameters involved in the execution of the forward step, a critical movement in boxing that directly impacts balance, power generation, and defensive positioning. Through the use of 3D motion capture systems, the study analyzes key variables such as joint angles, foot placement, center of mass displacement, and the force applied during the step. The data gathered provides insights into the technical efficiency and biomechanical advantages that differentiate elite boxers from novice athletes. These findings are essential for optimizing training programs and improving the overall performance of boxers at a highly competitive level. The study emphasizes the potential of 3D technology in enhancing the teaching of sports techniques and the precision of biomechanical feedback in combat sports.

Introduction

The sport of boxing is an intricate blend of power, speed, agility, and precise technique, all of which must be executed under intense physical and mental pressure. Among the many technical elements required to succeed in the ring, footwork plays a fundamental role in maintaining balance, generating force, and creating advantageous positions during both offensive and defensive maneuvers. For a boxer at the level of Candidate for Master of Sports, mastery of these movements, particularly the forward step, is crucial. The forward step is not only a basic maneuver for closing distance with an opponent but also a key factor in enabling a boxer to control the tempo of a fight, enhance the impact of punches, and avoid counters.

A complex combination of biomechanical elements, including precise joint motions, well-timed muscle activation, and optimal synchronization between the upper and lower body, are required for the forward stride. These biomechanical components are precisely calibrated for elite athletes to provide maximum performance with the least amount of energy used. Even though footwork is crucial in boxing, sports biomechanics has not done much study on the forward step, particularly when it comes to elite athletes like Candidates for Master of Sports.

This article aims to provide a comprehensive biomechanical analysis of the forward step in boxing, focusing on the movements and forces that contribute to effective and efficient performance. By examining key aspects such as joint kinetics, muscle activation, ground reaction forces, and balance control, this study seeks to identify the biomechanical principles that underpin the execution of the forward step. Understanding these principles is crucial for developing training protocols that enhance a boxer’s ability to move swiftly and strategically in the ring while minimizing the risk of injury and fatigue.

In addition, this analysis will highlight the significance of the forward step in relation to overall boxing performance, particularly for those aspiring to reach the Master of Sports level. By exploring the biomechanical factors at play, this research provides a foundation for coaches, athletes, and sports scientists to improve the efficiency and effectiveness of footwork training, contributing to the advancement of boxing technique at the elite level.

The forward step typically begins with a weight transfer from the rear foot to the lead foot. The boxer slightly raises their heel off the ground to push forward. This initial push is powered by the gastrocnemius and soleus muscles in the calf, along with the quadriceps in the leading leg for knee extension (Vereecke, E. & Aerts, P., 2020). As the boxer moves forward, the hip joint undergoes flexion, which is primarily controlled by the iliopsoas, while the knee bends through the action of the quadriceps femoris. Proper alignment between hip and knee flexion ensures maximum forward momentum with minimal energy expenditure (Lees, A., 2013). When the lead foot makes contact with the ground, there is a transfer of momentum, and ground reaction forces (GRF) come into play. These forces are critical for balance maintenance and postural control. The magnitude and direction of GRF determine the boxer's ability to stabilize quickly and transition into subsequent movements, like punching or lateral steps (McGill, S.M., 2017). During the forward step, the upper body must remain stable and ready for a punch or defense. The core muscles (abdominals, obliques, and lower back muscles) play a significant role in stabilizing the trunk. Proper core engagement ensures that the boxer maintains a strong position without compromising mobility (Hibbs, A., et al., 2008). Joint kinetics, especially in the ankles, knees, and hips, is critical during the step. The efficiency of movement in these joints is essential for smooth and rapid forward motion. The boxer's ability to control the joints' angular velocity contributes to efficient weight transfer, which in turn affects the speed and power of follow-up actions like punching (Neumann, D.A., 2016). A boxer needs excellent balance and proprioception when performing a forward step. Proprioceptive feedback helps the boxer adjust posture and movement to maintain stability. This is crucial for avoiding overextension or vulnerability to counterattacks (Lephart, S.M. & Fu, F.H., 2010). Speed is a key component in the execution of the forward step. The ability to move quickly while maintaining control directly impacts the boxer's performance. Fast-twitch muscle fibers, particularly in the legs, contribute to rapid acceleration and deceleration, which are essential for avoiding punches and creating openings for attacks (Vescovi, J.D. & McGuigan, M.R., 2010). Boxing is a high-intensity sport that requires sustained energy output. Efficient forward steps help conserve energy, allowing the boxer to maintain performance over time. Understanding the biomechanics of the step helps reduce unnecessary energy expenditure, particularly in elite athletes like Candidates for Master of Sports (Williams, K.R., 2004). The forward step in boxing involves complex, coordinated movements between the lower and upper body. Efficient biomechanical performance requires proper muscle engagement, joint kinetics, ground reaction force management, and balance control. By optimizing these factors, a boxer can improve their speed, power, and overall performance, making the forward step an essential skill for a Candidate for Master of Sports.

Researches aim is biomechanical analysis of the forward step movement of a candidate for sports mastery.

Tasks of the Research:

1. To analyze the kinematic parameters of the forward step in boxing, including joint angles, velocity, and foot placement, using 3D motion analysis technology.

2. To investigate the kinetic variables involved in the forward step, such as force generation, ground reaction forces, and the center of mass displacement during the movement.

3. To compare the biomechanical performance of boxer candidates for Master of Sports with less experienced athletes, identifying key differences in technique and efficiency.

4. To determine the biomechanical factors that contribute to an effective and efficient forward step, which can improve balance, power, and agility in competitive boxing.

5. To provide recommendations for optimizing training programs based on the biomechanical data, helping coaches and athletes enhance their technique and performance.

6. To explore the application of 3D motion analysis technology in the teaching and development of boxing skills, demonstrating its potential in improving feedback mechanisms and technical refinement in combat sports.

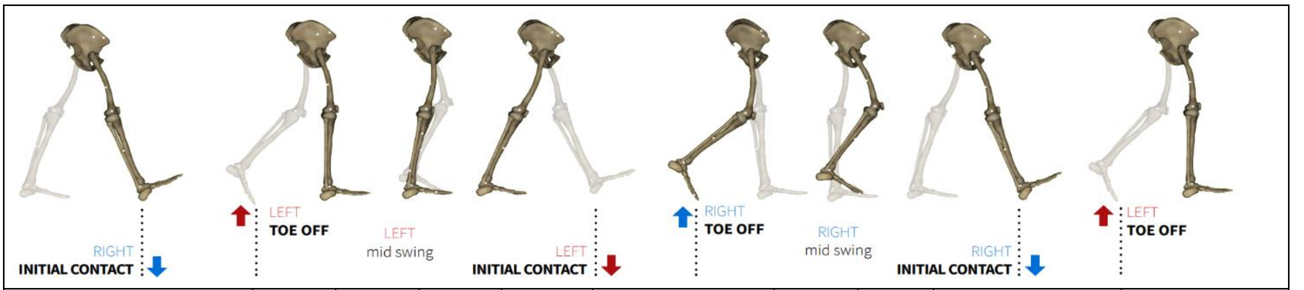
Research Organization: The research was conducted at the Uzbek State University of Physical Education and Sports, specifically within the high-tech laboratory of Sport. The laboratory is equipped with advanced 3D motion analysis technology, allowing for precise biomechanical measurements and data collection. A candidate athlete with a master's degree in boxing participated in the experiment, serving as the subject for the study. The experiment focused on capturing detailed kinematic and kinetic data during the execution of the forward step, a fundamental movement in boxing. The controlled laboratory environment ensured accurate data collection and analysis, providing valuable insights into the biomechanics of elite-level boxing techniques.

Methods: The study employed advanced 3D motion analysis technology to conduct a detailed biomechanical evaluation of the forward step in boxing. The research was carried out in the high-tech laboratory of the Uzbekistan State University of Physical Education and Sports. A candidate athlete for Master of Sports in boxing participated as the subject for the experiment. A high-resolution 3D motion capture system was used to track the athlete’s movements with multiple infrared cameras placed around the laboratory. Reflective markers were strategically placed on key anatomical points, including the pelvis, hips, knees, ankles, and feet, to capture joint angles, foot placements, and body posture.

By employing these methods, the study provided a thorough biomechanical analysis of the forward step, offering valuable insights into the movement patterns and technical efficiency of elite boxers. This section examines the duration and percentage of time spent in the stance and swing phases for both the left and right legs. These parameters are crucial for understanding the mechanics of movement, balance, and efficiency in the context of the gait cycle. The data reflects the temporal aspects of gait, particularly focusing on the duration of the stance, swing, and double support phases.

Table-1

Gait cycle analysis of boxers



0%					100%	
	Right Stance Phase: 0.72 s (74.35 %)			Right Swing Phase: 0.25 s (25.64 %)		
	Double support		Double support		Double support	DS per stride: 0.00 %
		Left Swing Phase: 0.20 s (54.34 %)	Left Stance Phase: 0.17 s (45.65 %)			
	0%				100%	

The right leg spends 74.35% of the total gait cycle in the stance phase. This phase is when the right foot is in contact with the ground, supporting the body's weight. A longer stance phase indicates greater stability, which is critical for boxers who need firm grounding for explosive movements.

The right leg spends 25.64% of the gait cycle in the swing phase, where the foot is off the ground and moving forward. This relatively short duration reflects a quick repositioning of the foot, which is typical in sports requiring rapid footwork, like boxing.

The left leg spends 54.34% of the time in the swing phase. This extended swing duration is slightly unusual and suggests the leg is moving through the air for a longer time relative to the right leg. This could be an adaptation to ensure rapid movement or adjustment in boxing stances.

The left leg spends 45.65% of the gait cycle in the stance phase. The relatively shorter stance phase compared to the right leg could imply that the left leg is used more dynamically, possibly for quicker shifts or adjustments in position during forward stepping movements.

Double support occurs when both feet are in contact with the ground simultaneously, typically seen in walking or slow-paced running. In this analysis, the double support phase is 0.00%, suggesting the boxer does not have a phase where both feet are on the ground at the same time during the forward step. This lack of double support reflects a gait cycle focused on quick transitions, which aligns with the demands of boxing for maintaining agility and speed.

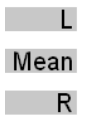
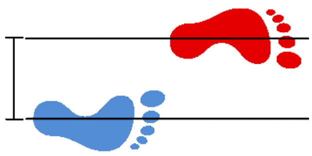
The difference in stance and swing durations between the right and left legs suggests an asymmetric gait. The right leg spends more time in stance, while the left leg is in the air for a longer duration. This could be a deliberate adaptation in the boxer's technique, where the right leg provides more stability and the left leg is quicker for stepping or shifting positions.

The absence of a double support phase highlights the efficiency of this forward stepping movement. For boxers, this allows for faster transitions between stances and ensures continuous movement, which is essential in avoiding attacks or creating offensive opportunities.

This temporal analysis of the boxer's forward step reveals an asymmetric gait with rapid transitions between stance and swing phases, particularly in the left leg. The absence of a double support phase further underscores the focus on quick and dynamic movement, which is crucial for success in boxing. These insights can help refine training to optimize footwork and balance, particularly in maintaining agility while ensuring stability during rapid shifts in stance.

Table-2

Step and Stride Analysis

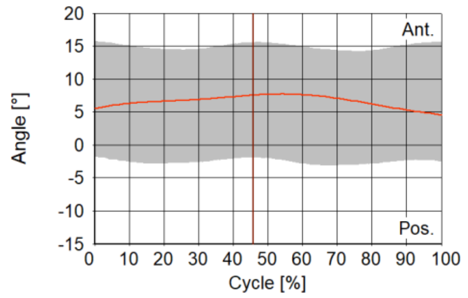
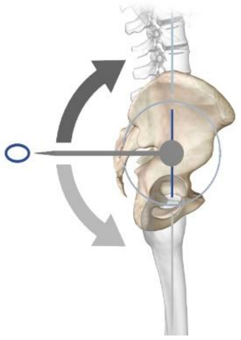
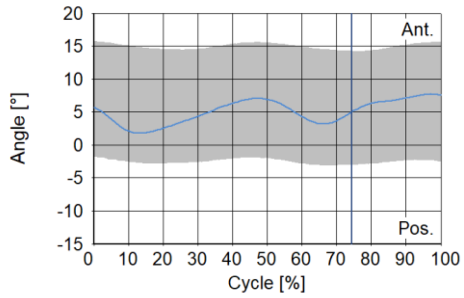
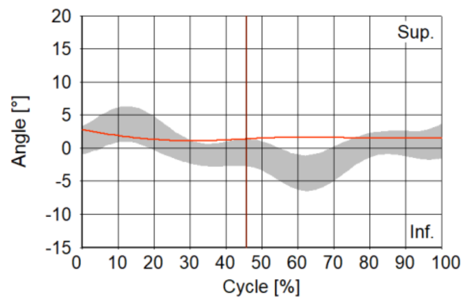
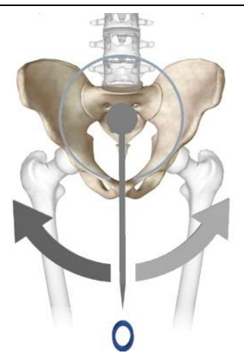
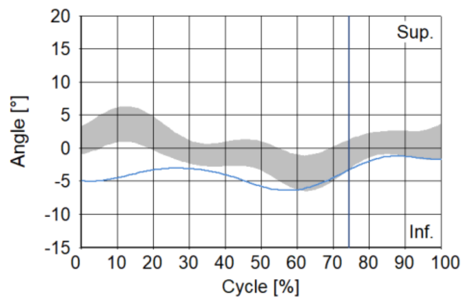
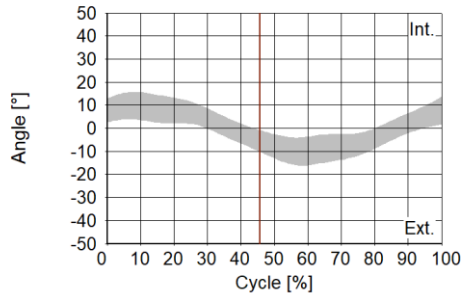
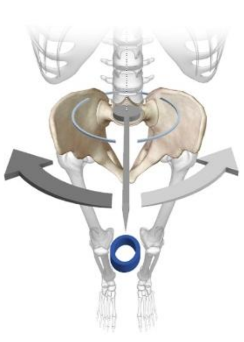
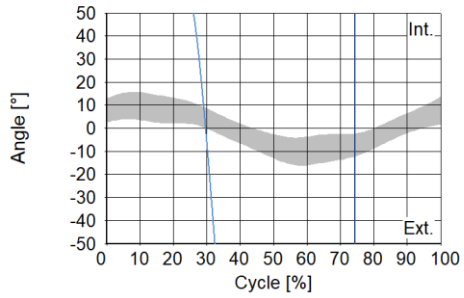
<table>
<tr><th colspan="3">Step over stride lengths (m):</th><th colspan="2">Step over stride durations (s):</th></tr>
<tr><td colspan="3">
</td><td colspan="2">
</td></tr>
<tr><td></td><td>Max. Heel Height</td><td rowspan="3"></td><td>Width of base of support</td><td rowspan="3"></td></tr>
<tr><td>Left</td><td>0.17 m</td><td rowspan="2">0.64 m</td></tr>
<tr><td>Right</td><td>0.15 m</td></tr>
</table>

The maximum heel height during the step phase gives an indication of how much the foot lifts off the ground. In this analysis, the left leg shows a slightly higher heel lift (0.17 m) compared to the right leg (0.15 m). This asymmetry suggests that the left leg may be slightly more engaged in dynamic movements, possibly aiding in quicker recovery during foot transitions (Table-2).

The width of the base of support is the lateral distance between the two feet during stance. A wider base of support (0.64 m in this case) generally provides more stability, which is particularly important in a sport like boxing, where maintaining balance during rapid shifts is essential.

Table-3

Pelvic Motion Analysis: Forward Step in a Boxer Candidate for Master of Sports

LEFT			***1. PELVIS***	RIGHT		
Min:	**Max:**	**Range:**	**Pelvic Tilt** *Anterior[+]/ Posterior[-]*	**Min:**	**Max:**	**Range:**
4 º	7 º	3 º		1 º	7 º	5 º
						
Min:	**Max:**	**Range:**	**Pelvic Obliquity** *Superior[+]/ Inferior[-]*	**Min:**	**Max:**	**Range:**
1 º	3 º	1 º		-7 º	-2 º	5 º
						
Min:	**Max:**	**Range:**	**Pelvic Rotation** *Internal[+]/ External[-]*	**Min:**	**Max:**	**Range:**
108 º	118 º	9 º		-146 º	79 º	224 º
						

The analysis of pelvic motion is critical for understanding the biomechanics of movement, especially in sports like boxing, where stability and flexibility in the pelvis affect balance, agility, and power generation. Below is an analysis of the pelvic tilt, obliquity, and rotation in the forward step movement based on the provided data.

The pelvic tilt measures the rotation of the pelvis in the sagittal plane, indicating whether the pelvis is tilted forward (anterior tilt) or backward (posterior tilt) (Table-3). The left leg shows a slightly higher minimum pelvic tilt (4º) compared to the right leg (1º), but both legs have a similar maximum tilt (7º).

The range of pelvic tilt is wider on the right side (5º) than on the left (3º), suggesting that the right side of the pelvis may have greater flexibility in tilting movements. This asymmetry could result from specific movement patterns in boxing, where one leg may play a more stabilizing role while the other is more active in stepping. Pelvic obliquity refers to the lateral tilt of the pelvis in the coronal plane (side-to-side movement). The left leg has a very narrow range (1º) of pelvic obliquity, with values between 1º and 3º, indicating minimal lateral tilting.

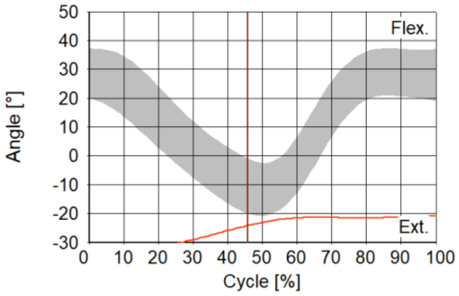
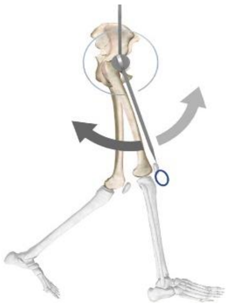
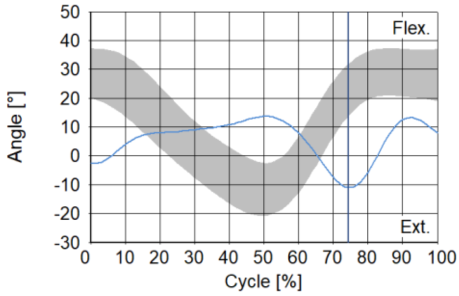
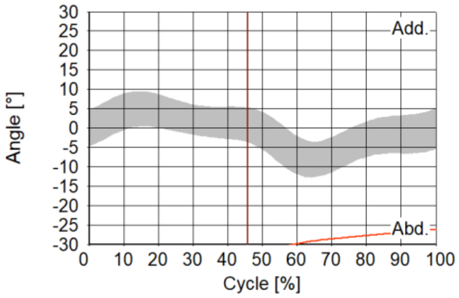
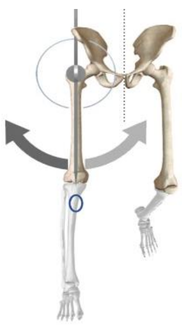
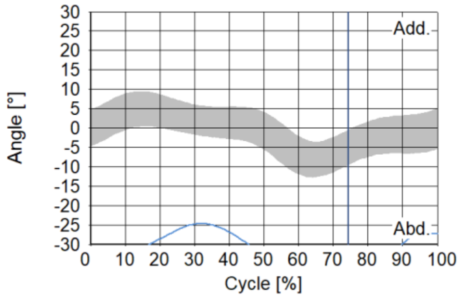
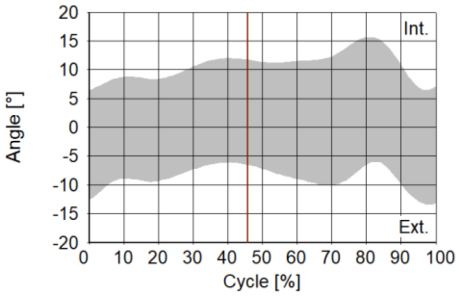
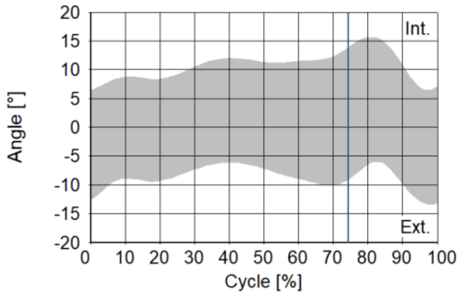
In contrast, the right leg shows a much larger range of movement, from -7º to -2º, suggesting that the right pelvis tilts more noticeably downward during this motion. This could imply that the boxer's weight shifts more to the right leg during the forward step, which might be an adaptation for balancing or for creating offensive opportunities.

Pelvic rotation occurs in the transverse plane and is critical for generating power during stepping or rotational movements, such as punching in boxing. The left leg shows a modest range of pelvic rotation (9º), with values between 108º and 118º, indicating relatively limited rotational movement during the forward step.

However, the right leg demonstrates a significantly larger range of rotation (224º), moving from -146º (internal) to 79º (external rotation). This large range suggests that the boxer generates considerable rotational movement through the pelvis on the right side, which may contribute to generating power, especially during offensive movements like throwing a punch or pivoting.

Table-4

Hips Motion Analysis: Forward Step in a Boxer Candidate for Master of Sports

LEFT			*2. Hips*	RIGHT		
Min:	**Max:**	**Range:**	**Hip Flexion** *Flexion[+]/ Extension[-]*	**Min:**	**Max:**	**Range:**
-41 º	-21 º	19 º		-11 º	13 º	24 º
						
Min:	**Max:**	**Range:**	**Hip Abduction** *Adduction[+]/ Abduction[-]*	**Min:**	**Max:**	**Range:**
-51 º	-27 º	24 º		-47 º	-25 º	22 º
						
Min:	**Max:**	**Range:**	**Hip Rotation** *Internal[+]/ External[-]*	**Min:**	**Max:**	**Range:**
57 º	61 º	3 º		37 º	44 º	7 º
						

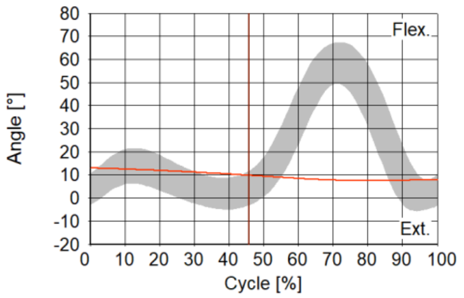
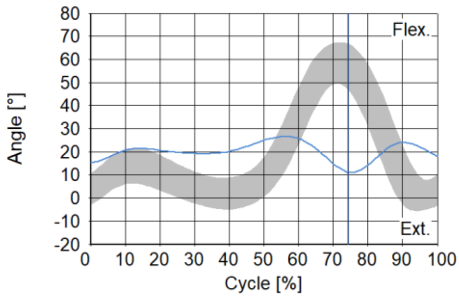
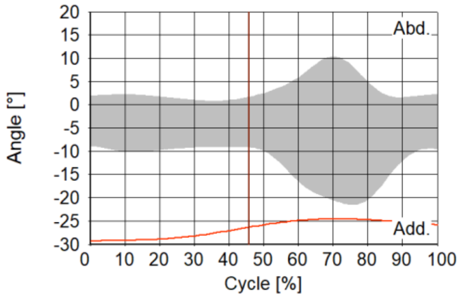
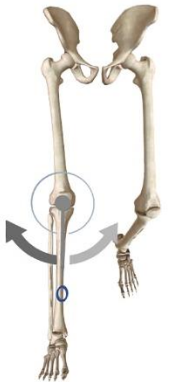
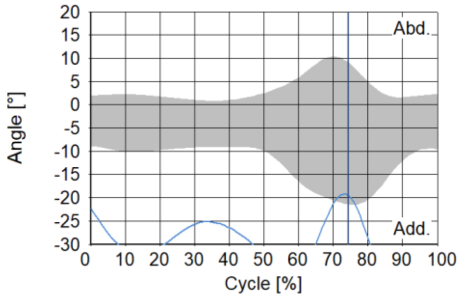
The results show that the right hip has a greater range of motion (24°) in flexion/extension compared to the left hip (19°). Additionally, the right hip demonstrates more forward flexion (13°) than the left hip, which has more extension (-41°). This suggests that the right hip may be more flexible in flexion, while the left hip exhibits a greater capacity for extension. Such asymmetry could result in uneven movement patterns, potentially leading to compensatory mechanisms in other parts of the kinetic chain, such as the lower back or knees (Table-4).

Both hips display a similar range of motion in abduction/adduction, with the left hip showing a slightly greater range (24°) compared to the right (22°). While the difference is minor, it indicates a marginally higher degree of lateral movement in the left hip. This symmetry suggests balanced lateral movement in both hips, though the slight variance may indicate some side-dominance that could influence performance or lead to minor imbalances over time.

Significant differences are observed in hip internal/external rotation. The left hip shows greater internal rotation (57° to 61°) but a smaller range of motion (3°) compared to the right hip, which has a range of 7° (37° to 44°). The disparity in rotational movement suggests that the left hip is more restricted in dynamic movements involving rotation, while the right hip allows for greater flexibility. This imbalance could potentially affect movements requiring hip rotation, such as cutting, pivoting, or rotational power during running or jumping.

Table-5

Knees Motion Analysis: Forward Step in a Boxer Candidate for Master of Sports

<table>
<tr><td colspan="3">LEFT</td><td>3. Knees</td><td colspan="3">RIGHT</td></tr>
<tr><td>Min:</td><td>Max:</td><td>Range:</td><td rowspan="2">Knee Flexion
Flexion[+]/ Extension[-]</td><td>Min:</td><td>Max:</td><td>Range:</td></tr>
<tr><td>7 º</td><td>13 º</td><td>5 º</td><td>11 º</td><td>26 º</td><td>15 º</td></tr>
<tr><td colspan="3">
</td><td></td><td colspan="3">
</td></tr>
<tr><td>Min:</td><td>Max:</td><td>Range:</td><td rowspan="2">Knee Abduction
Abduction[+]/ Adduction[-]</td><td>Min:</td><td>Max:</td><td>Range:</td></tr>
<tr><td>-30 º</td><td>-25 º</td><td>4 º</td><td>-45 º</td><td>-20 º</td><td>25 º</td></tr>
<tr><td colspan="3">
</td><td></td><td colspan="3">
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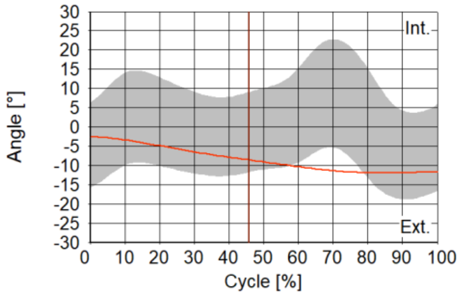
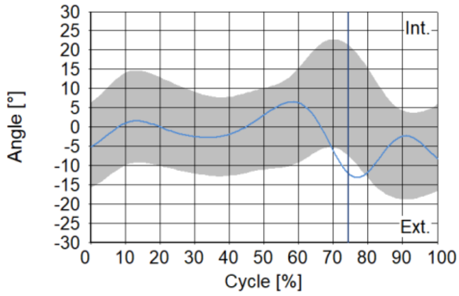
<tr><td>Min:</td><td>Max:</td><td>Range:</td><td rowspan="2">Knee Rotation
Internal[+]/ External[-]</td><td>Min:</td><td>Max:</td><td>Range:</td></tr>
<tr><td>-12 º</td><td>-3 º</td><td>9 º</td><td>-14 º</td><td>6 º</td><td>19 º</td></tr>
<tr><td colspan="3">
</td><td></td><td colspan="3">
</td></tr>
</table>

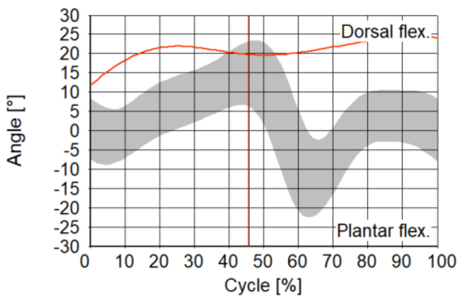
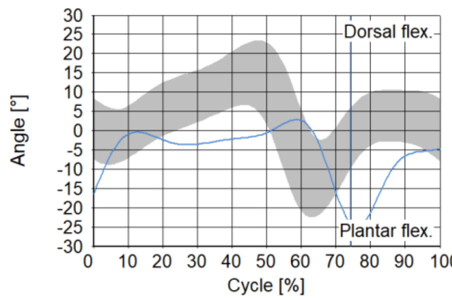
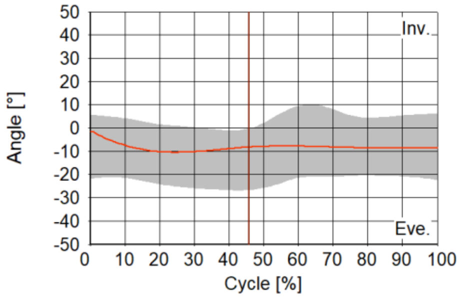
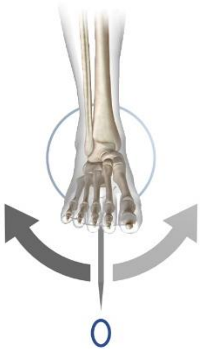
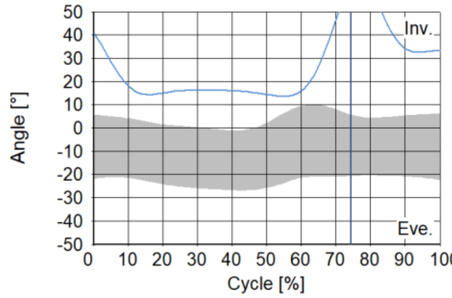
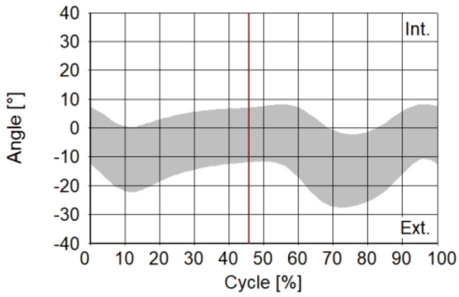
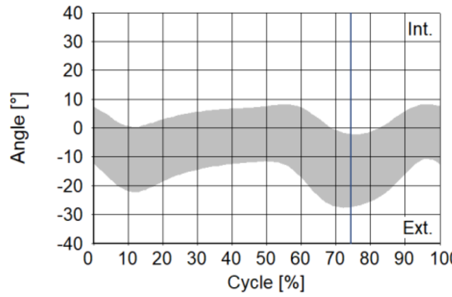
The analysis of knee flexion and extension reveals a significant asymmetry between the left and right knees. The left knee has a more restricted range of motion (5°) compared to the right knee (15°). The right knee demonstrates greater flexion (26° vs. 13°), which could suggest greater flexibility or dynamic capacity in the right leg. This asymmetry might result in compensatory movement strategies, with the left knee experiencing higher loads during activities like running or jumping, potentially increasing the risk of overuse injuries (Table-5).

Significant differences are also observed in knee abduction/adduction between the left and right knees. The right knee exhibits a much larger range of motion (25°) compared to the left knee (4°). The right knee's greater adduction movement could indicate increased lateral mobility, which may be beneficial for dynamic lateral movements but could also expose the knee to greater instability during high-impact activities. The limited lateral movement in the left knee suggests that it may be more stable, but potentially more prone to rigidity in lateral movements.

In terms of knee rotation, the right knee again shows a greater range of motion (19°) compared to the left knee (9°). The right knee's enhanced capacity for rotation suggests more dynamic movement potential, which could be beneficial for sports requiring quick changes in direction, such as soccer or basketball. However, excessive rotational range without adequate stability may elevate the risk of ligament injuries, particularly in sports that involve pivoting or twisting actions.

Table-6

Ankles Motion Analysis: Forward Step in a Boxer Candidate for Master of Sports

LEFT			*4. Ankles*	RIGHT		
Min:	**Max:**	**Range:**	**Ankle Flexion** *Dorsal[+]/Plantar[-]*	**Min:**	**Max:**	**Range:**
10 º	24 º	13 º		-25 º	3 º	27 º
						
Min:	**Max:**	**Range:**	**Ankle Abduction** *Inversion[+]/Eversion[-]*	**Min:**	**Max:**	**Range:**
-11 º	0 º	10 º		13 º	62 º	49 º
						
Min:	**Max:**	**Range:**	**Ankle Rotation** *Internal[+]/External[-]*	**Min:**	**Max:**	**Range:**
-58 º	-50 º	7 º		-59 º	-44 º	15 º
						

Ankle biomechanics play a critical role in a boxer's stability, mobility, and power generation during various movements such as stepping, pivoting, and delivering punches. Below is an analysis of the three primary ankle movements—dorsiflexion/plantarflexion, inversion/eversion, and internal/external rotation—based on the data provided for both the left and right ankles (Table-5).

Dorsiflexion refers to the movement of raising the toes towards the shin, while plantarflexion is the movement of pointing the toes downward.

The left ankle shows a moderate range of dorsiflexion, indicating that the boxer uses this movement to stabilize their stance, particularly when moving backward or during evasive footwork. The dorsiflexion angle (up to 24º) is typical for defensive movements where the foot needs to be more grounded and stable.

The right ankle exhibits a greater range of motion (27º) and reaches more extreme plantarflexion (-25º), indicating that the right foot is used for generating forward movement and propulsion. The larger range in the right ankle also suggests a greater ability to push off the ground, which is essential when moving forward or delivering a punch.

The right ankle has a larger range of motion, which likely corresponds to its role in pushing off the ground during offensive movements like advancing toward the opponent. In contrast, the left ankle, with its moderate dorsiflexion, serves as a stabilizer during defensive or lateral movements.

Inversion refers to turning the sole of the foot inward, and eversion refers to turning it outward. These movements are critical for maintaining balance and changing direction during dynamic actions like dodging or pivoting.

The left ankle demonstrates a small range of inversion/eversion, indicating that it remains relatively stable during movements. The slight eversion (-11º) suggests that the left foot plays a supporting role, providing balance during quick pivots or defensive steps.

The right ankle shows a much larger range of inversion, with values reaching up to 62º, indicating a high degree of lateral foot movement. This wide range of motion suggests that the right foot is frequently used for lateral shifts and quick directional changes during offensive movements, such as pivoting to position the body for punches.

The right ankle's significant range of inversion/eversion allows for more dynamic lateral movement, which is essential in boxing for changing direction and quickly shifting the body weight. In contrast, the left ankle, with its minimal inversion/eversion, provides a more stable base.

Internal rotation refers to the inward rotation of the foot, while external rotation is the outward rotation. These rotations are important for foot positioning, especially when pivoting or changing stance.

The left ankle shows a relatively small range of external rotation, remaining between -58º and -50º. This limited movement suggests that the left foot is more fixed in position, providing stability and reducing the need for large rotational movements during the boxer's stance or defensive maneuvers.

The right ankle shows a greater range of external rotation, with movement reaching from -59º to -44º. This larger range indicates that the right ankle is used for rotational movements, which are key when pivoting to reposition the body during punching or evasive maneuvers.

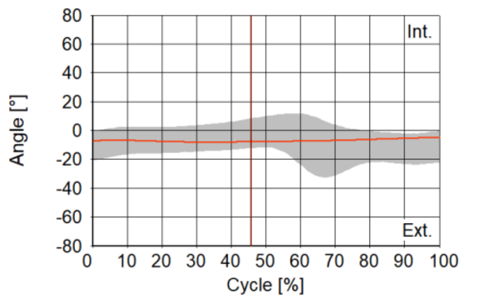
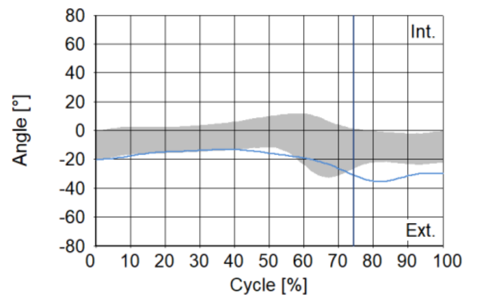
The right ankle's greater range of external rotation supports its role in dynamic footwork, especially during pivots and rapid directional changes. The left ankle's smaller range ensures stability, especially when the boxer is shifting weight between feet or maintaining balance during defensive actions.

Foot direction, specifically internal and external rotation, is crucial in boxing for maintaining balance, facilitating movement, and optimizing power during strikes. This analysis focuses on the internal and external rotation of the left and right feet, examining the range of motion and its implications for footwork, balance, and overall boxing performance (Table-7).

Foot rotation (internal/external) refers to the angle at which the foot turns inward (internal) or outward (external). In boxing, proper foot rotation is essential for movement efficiency and generating power, particularly during pivots, stepping, and weight transfer.

Table-7

Foot Biomechanics Analysis in a Boxer Candidate for Master of Sports

LEFT			**Foot Direction** *Internal[+] /External[-]*	**RIGHT**		
Min:	**Max:**	**Range:**		**Min:**	**Max:**	**Range:**
-8 º	-5 º	3 º		-36 º	-14 º	22 º
						

The left foot exhibits minimal external rotation, with a range of only 3º. This limited rotation indicates that the left foot is likely used to maintain stability during movements, acting as a support for the boxer's stance. With a small range of motion, the left foot is not highly involved in dynamic pivots or large directional changes, but rather serves to anchor the body during defensive actions or weight transfers.

The right foot shows a much larger range of external rotation, from -36º to -14º, with a total range of 22º. This significant range indicates that the right foot plays a pivotal role in boxing movements, particularly in stepping forward or pivoting to change direction. The larger external rotation allows the boxer to adjust their stance rapidly, shift weight effectively, and generate force during punches. The right foot's increased rotation range is typical of the rear foot, which is responsible for initiating and supporting rotational movements during punching or evasive footwork.

The difference in rotational range between the left and right feet is notable. The right foot, with its significantly larger range, is more active in movements that involve lateral or rotational changes, such as pivots, sidesteps, and advancing toward an opponent. The left foot’s limited rotation reflects its role as a stabilizer, helping the boxer maintain balance during more dynamic actions initiated by the right leg.

The 22º range of external rotation allows the boxer to execute rapid directional changes, essential for maintaining mobility and positioning in the ring. The larger rotation in the right foot supports more aggressive movements, such as pivots and strikes, where shifting body weight is necessary.

The left foot’s smaller range of motion suggests its function is primarily to provide a stable foundation. This reduced rotational capability ensures that the boxer can remain balanced, particularly during defensive movements or when shifting weight from one leg to the other.

Power in boxing often comes from the lower body, particularly through rotational movements. The right foot's ability to externally rotate by a larger margin allows the boxer to generate force more effectively by transferring weight and rotating the hips and shoulders. The left foot helps anchor the boxer’s stance, allowing the right side of the body to engage in more powerful, rotational movements while remaining balanced.

The difference in foot rotation is indicative of the asymmetry in a boxer’s footwork. The right foot is responsible for more dynamic, explosive movements, while the left foot provides a foundation for maintaining posture and balance during rapid shifts or defensive movements.

In this analysis of foot biomechanics, it is evident that the right foot, with its larger range of external rotation, is more involved in dynamic movements such as pivots and weight shifts, which are essential for delivering powerful punches or quickly changing direction. The left foot, with its smaller range of rotation, plays a crucial role in providing stability, ensuring that the boxer remains balanced during defensive movements or weight transfers.

CONCLUSION

This study offers a comprehensive biomechanical analysis of the forward step in a boxer candidate for Master of Sports, focusing on kinematic and kinetic parameters such as joint angles, foot placement, muscle activation, and ground reaction forces. Utilizing advanced 3D motion analysis technology, the research highlights key differences in the biomechanics of elite-level athletes, emphasizing the importance of footwork in maintaining balance, generating power, and controlling the tempo of a boxing match.

The findings demonstrate that efficient forward stepping involves a complex coordination of lower and upper body movements, with the right leg playing a more dynamic role in propulsion and the left leg providing stability. The asymmetry between the two legs in terms of stance, swing phases, and joint mobility suggests an adaptation unique to high-level boxing. Furthermore, the absence of double support during the gait cycle reflects the boxer's focus on quick transitions, essential for maintaining agility and avoiding counterattacks in the ring.

The research also underscores the significance of pelvic, hip, knee, and ankle motion in the execution of the forward step, highlighting the roles of balance, proprioception, and energy efficiency. By optimizing these biomechanical factors, boxers can enhance their movement efficiency, reduce the risk of injury, and improve overall performance in both offensive and defensive situations.

In conclusion, the use of 3D motion analysis technology provides valuable insights into the biomechanics of boxing footwork, particularly the forward step, which is critical for success at the Master of Sports level. The study's findings can inform training protocols, allowing coaches and athletes to refine their techniques, improve agility and stability, and ultimately enhance their competitive performance. This research contributes to the growing understanding of sports biomechanics in combat sports, demonstrating the potential for 3D technology to revolutionize the way boxing techniques are taught and perfected.

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