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Biomechanical disparities in pankration: A comparative computational analysis of ancient and contemporary techniques

Andreas G. Bourantanis[1]; Nikitas N. Nomikos[2]; Pantelis T. Nikolaidis[3]; Chris K. Yiannakopoulos[2]; Nikolaos G. Aggelousis[4]; Weijie W. Wang[1],

[1] Department of Orthopaedic and Trauma Surgery, Institute of Motion Analysis and Research, The Ninewells Hospital and Medical School, The University of Dundee, Dundee, UK; [2] School of Physical Education & Sport Science, Kapodistrian University of Athens (NKUA), Athens, Greece; [3] School of Health and Caring Sciences, University of West Attica, Athens, Greece; [4] Democritus University of Thrace, Department of Physical Education and Sport Science, Komotini, Greece

Abstract

Study aim: The study analyzed biomechanical similarities and differences between ancient and modern sports techniques, focusing on pankration. It examined historical artifacts and modern pankration scenes to elucidate biomechanical developments over time.

Material and methods: OpenPose was employed for this analysis, focusing on both ancient depictions of pankration and contemporary pankration footage. The methodology involved collecting and analyzing depictions of archaeological artifacts, examining video performances frame by frame, and applying computational analysis to determine the Cartesian two-dimensional coordinates of joints. Comparative vector mapping and kinematic analyses were used for assessment.

Results: The analysis revealed distinct biomechanical patterns between ancient and modern pankration techniques. It was found that ancient techniques primarily leverage gravity for movement execution, while modern techniques emphasize the utilization of muscular capacity. This distinction indicates a transformation in biomechanical strategy, shifting from a gravity-focused approach in ancient practices to a muscle-focused approach in modern practices.

Conclusions: The research highlights the differences between ancient and modern pankration, emphasizing punching and kicking techniques. These changes reflect broader shifts in athletic practices over time, influenced by cultural and historical factors, and similar disciplines. The study not only enhances our understanding of ancient sports biomechanics but also opens avenues for future exploration of other ancient athletic disciplines using current computational methods.

Keywords: Pankration, Sports Science, Biomechanics, Combat Sports, MMA

Introduction

Modern sports, whose genesis can be traced to antiquity, exhibit partial biomechanical concordance with practices from ancient epochs (Longman et al., 2020). This inference is derived from an analysis of archaeological artifacts, encompassing iconographic depictions and historical narratives, which indicate a biomechanical parallelism with current methodologies in these sports disciplines (Bourantanis, 2021). However, a comprehensive and precise biomechanical reconstruction of the techniques employed in these ancient athletic events remains a challenge, primarily due to the constraints posed by the finite and fragmentary nature of historical and archaeological sources (Bourantanis, 2021). Through the biomechanical analysis of ancient athletic techniques, we can extract significant insights into these disciplines (Medved, 2022). A detailed understanding of the biomechanical properties inherent in the practices of ancient athletes could pave the way for novel revelations about these sports. Such an understanding may also facilitate a closer approximation to their initial biomechanical configurations.

A notable example is the ancient long jump, which presents interpretative challenges due to limited and conflicting ancient sources (Friedman & Miller, 2017; Renson, 2019; Swaddling,1999). Although literary references, such as in Homer's Odyssey, exist, the technical

Author's address Pantelis T. Nikolaidis, School of Health and Caring Sciences, University of West Attica, Athens, Greece
pademil@hotmail.com

details remain unclear, with debates over whether the event was a long jump or triple jump (Šiljak, 2016). It is, however, known that athletes used halters—weights designed to enhance jump distance and improve landing technique (Šiljak, 2016). Attempts to replicate the technique, including experiments with modern athletes and computer simulations, have seen limited success (Friedman & Miller, 2017).

Similarly, the discus throw has garnered significant scholarly attention (Šiljak, 2016). Researchers have proposed various hypotheses regarding ancient techniques, with some suggesting experimental recreations under conditions resembling those of ancient Greece (Šiljak, 2016). Athletes reportedly applied soil to the discus and their hands for better grip. Using collected data and images, scholars have attempted to reconstruct the discus-throwing process (Swaddling, 1999).

Pankration presents a unique biomechanical case, blending techniques from boxing and wrestling, as noted by Philostratus (Plutarch, no date [n.d.]). Plato describes pankratiasts as experts in combat (Plato, n.d.), yet its complexity and historical significance remain underexplored due to limited comprehensive sources and its exclusion from the Olympic program. Modern reconstructions often rely on subjective data, incorporating elements from contemporary boxing, wrestling, and other sports such as karate, raising concerns about their authenticity (Bourantanis, 2024; Morello, 2012).

This project advocates for a paradigm shift in studying pankration, emphasizing a biomechanical approach supported by advanced computational methods (Bourantanis, 2024). By employing computer vision technologies such as OpenPose (Cao et al., 2021), we could possibly overcome the limitations of fragmented ancient depictions and achieve a more precise understanding of pankration's biomechanical features.

The main tool of the present research, i.e. OpenPose, has proven effective and accurate in analyzing other sports, such as basketball free throws and ski jumping (Ludwig et al., 2020; Nakai et al., 2019). This research hypothesizes that modern technological methods can be used to approach the biomechanics of ancient pankration, focusing on striking movements due to their extensive representation in ancient artifacts. Therefore, the purpose of this study was to quantify and compare ancient and modern pankration techniques, providing a more accurate representation of the limbs' displacement and identify differences between historical and modern pankration.

Methods

To conduct this analysis, a sample of five ancient artifacts depicting scenes either directly associated with pankration or its constituent sports—namely, boxing and wrestling—was collated.

Alongside photographs, we acquired audiovisual resources capturing both the technical aspects and competitive dimensions of the sport. Specifically, this footage encompasses demonstrative sequences delineating the sport's technical curriculum, as well as key moments in competitive engagements from which still frames corresponding to techniques employed in ancient pankration were extracted. This invaluable audiovisual material was generously furnished by the Hellenic Federation of Pankration (H.PA.F.), the governing body representing the contemporary incarnation of the sport.

Moreover, an extensive review was conducted on 2.5 hours of video footage derived from matches governed by United World Wrestling (UWW) Pankration division (Zoughari, 2008). The methodological schema for the experimental investigation was conceptualized as an array of tasks. These tasks comprised the following components:

1. Procurement of archaeological artifacts and assimilation of audio-visual resources, courtesy of the Hellenic Federation of Pankration Athlema.
2. Frame-by-frame dissection of the video performances, with a focus on establishing congruencies with ancient pankration techniques based on visual resemblances, utilizing computer vision (OpenPose) (Bourantanis, 2021; Cao et al., 2021).
3. Post-production enhancements to the optical fidelity of the extracted images to ensure analytical precision.
4. Computational analyses employing the OpenPose framework to obtain biomechanical coordinates.
5. Manual rectification of these coordinates executed via Python programming to ensure accuracy.
6. Vector mapping methods were employed to delineate the athlete's posture, using the original images as spatial referents, also implemented through Python.
7. Synthesis of the vectors indicating the kinematic displacements of the movements under study.
8. Reiteration of the archaeological artifact procurement and audio-visual material assimilation from the Hellenic Federation of Pankration Athlema, as necessitated by the analytical outcomes.

Visual representations encapsulating scenes from ancient pankration were sourced from museums. Audiovisual material for analysis was provided by the sport's contemporary institutional authority.

Separation of the frames of the executions in the video and their alignment with the ancient depictions, based on the visual similarity of the technique used

The video corpus used in the present research serves a dual purpose: it is illustrative, but it also has a didactic function, delineating the comprehensive curriculum under which athletes are trained in modern pankration. Thus, the video serves as a pedagogical schema, detailing the kinetic protocol that athletes are instructed to assimilate.

The experimental methodology commenced with the collection of depictions pertinent to both ancient and contemporary forms of pankration. Visual artifacts encapsulating scenes from the ancient sport were secured from reputable archaeological repositories. Contemporaneous photographic representations were furnished by the governing federation currently serving as the sport's institutional authority.

Turning to historical accounts, Plutarch reports the interplay between boxing and wrestling within the pankration framework (Plutarch, n.d.). He suggests that, although boxers may seek to engage in more intimate bodily contact akin to wrestling maneuvers, such actions are generally curtailed by match officials. Plutarch's writings reveal the strategic importance of maintaining a certain distance prior to initiating direct combat, thereby influencing the choice of techniques employed (Remijsen, 2010). This is corroborated by ancient narratives, such as the encounter between Amycus and Polydeuces, where it is noted that fighters maintained a discernible spatial separation prior to their boxing engagement (Frazer, 1997).

Moreover, what characterizes wrestling as the more technically intricate discipline and alludes to its amalgamation with boxing is a response to practical necessities, which often prioritize simpler and more forceful actions (Plutarch, n.d.). In this context, the coalescence of historical descriptions and visual representations allows for the inference of a tactical sequence that appears to be mediated, in part, by the spatial proximity between combatants (Plutarch, n.d.). Further substantiating this point, specific holds depicted in ancient artifacts, such as the one illustrated in the respective images (**Appendix**), reveal tactical maneuvers targeting the opponent's abdominal region. This is in alignment with Lucian's references to abdominal strikes (**Appendix**). In light of these multifaceted considerations, the visual materials have been curated and sequentially arranged as presented in this inquiry (Lucian, n.d.).

Improvement of the quality and analysis of the ancient depictions with OpenPose

Initially, the assemblage of visual materials was subjected to a quality enhancement protocol utilizing rudimentary utilities integrated within the Windows operating system (Figure 1). This preliminary step was essential for rendering the images amenable to subsequent analysis by the OpenPose computational framework. Additionally, video materials, inclusive of pedagogical content, were processed using the same Windows-integrated utilities (Figure 1).

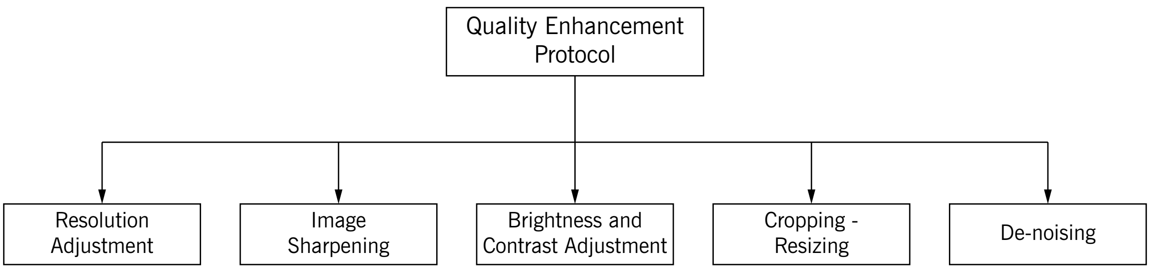

Figure 1. Quality Enhancement Protocol. Microsoft Photos was used for adjusting resolution, modifying brightness and contrast, sharpening, and cropping. The enhancements were performed to improve the clarity and quality of the visual material for further analysis.

This facilitated the isolation of distinct frames capturing the specific techniques under investigation, namely pugilistic maneuvers and a kick. To elaborate, alterations were made in the realms of image resolution and lighting conditions to ensure that OpenPose could adequately detect and interpret the requisite data points (Figure 1). Furthermore, standardization procedures were implemented to harmonize the scale and resolution across all images, which are described subsequently

After these preparatory steps, the ancient visual artifacts were subjected to in-depth analysis through the OpenPose computational platform. Leveraging this technology on the pictorial representations sourced from archaeological repositories, we observed successful identification of the coordinates corresponding to the bodily configurations of the athletes depicted (Figure 2). This validates the utility of OpenPose in discerning complex biomechanical data even from historical illustrations, thus contributing significantly to the study's methodological robustness. To ensure the accuracy of OpenPose in the present research, we generated a vector-based plot superimposed on the original image. This allowed us to assess whether the numerical data corresponded accurately to the actual visual representation, as seen in Figure 2.

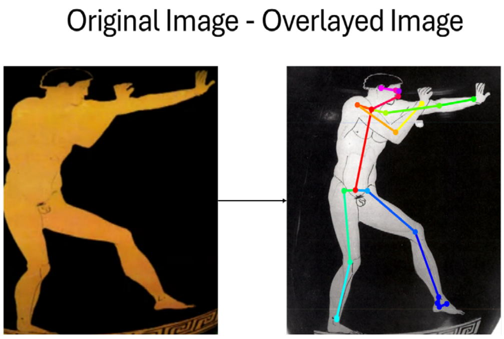

Figure 2. OpenPose successfully extracted coordinates from the original image (left). It detected more keypoints than required, including the ear. Even though it failed to detect the toes, this did not affect the results of our analysis, as they were not used in the present research.

Analysis of the audiovisual material provided by the federation

Optical observation alone lacks the requisite objectivity and precision to evaluate the articulations and angular configurations of the athletes' joints. To surmount this limitation and attain a higher level of analytical exactitude, we employed computer vision techniques. Again, for this purpose a Python script was crafted to facilitate this computational approach (Bourantanis, 2024).

The script served as a computational tool, which specifically focused on the quantification of joint angles based on skeletal data. These skeletal data are presumed to be derived through OpenPose, which can capture and digitize human movement into a structured format (JSON in this case). The script employed mathematical and computational techniques to calculate angles formed at various joints in the human body. The script was able to analyze a sequence of skeletal data captured from video frames, typically of athletes, to compute joint angles. The objective was to identify frames where the athletes' posture aligns with predefined criteria based on these joint angles. This means that the joint angles need to be approximately equal to the ancient angles so that $\theta_{\text{joint}_i} \approx \theta_{\text{ancient}_i}$. This criterion was set so that the body posture the athlete assumed throughout the movement was almost identical to the ancient depictions. Since complete equality was practically impossible, we set a target of 4% convergence in the angles for this research.

The mathematical formula used to calculate the angle θ between three points p_1, p_2, and p_3 (with p_2 as the vertex) is given by:

$$\cos(\theta) = \frac{|p_1| \cdot |p_2|}{p_1 \cdot p_2}$$

Here, a and b are vectors defined as:

$$a = p_1 - p_2 \quad \text{and} \quad b = p_3 - p_2$$

The angle θ was then computed using the arccosine function:

$$\theta = \arccos\left(\frac{a \cdot b}{\|a\| \cdot \|b\|}\right)$$

This formula was employed in the function within the script to calculate the angle for a specific joint based on its coordinates in the frame.

Additionally, the script was designed to loop through multiple JSON files, each corresponding to a different video frame, and to perform this calculation for each frame. The list of computed joint angles was then returned, and these data were used to identify frames where the athletes' posture matched the aforementioned criteria. From an anatomical perspective, the script acknowledged a wide range of joints, including the elbows, wrists, shoulders, and knees, among others. In terms of programming these were defined in a dictionary within our script, which served as a translation layer between numerical indices and anatomical nomenclature.

The script also incorporated error-handling measures to deal with issues such as missing data ('people' key not found), inconsistent data (NaN [not a number] values), and mathematical impossibilities (zero vector norms). By identifying frames that meet specific angle criteria, we were able to pinpoint moments where an athlete's posture matched a desired form. Our objective was to find frames where a modern athlete achieved a posture visually similar to the depiction of the ancient athletes.

Vectorial analysis and rescaling for examining the configurations

The next step was to examine the anatomical configurations represented in ancient depictions of athletes. In particular, we employed a vectorial representation to dissect the human anatomical structure into constituent skeletal segments (Figure 2). For instance, the arm was delineated by two sequential vectors: the first originating at the shoulder and terminating at the elbow joint, followed by a subsequent vector extending from the elbow to the wrist.

These vector coordinates were captured and archived in files for subsequent analysis. An additional Python script was employed to map these stored vectors onto a new graphical representation, utilizing the coordinates of the depicted athlete's pelvic region as a referential pivot (Figure 3). This script enabled the translocation of the primary vectorial constructs, which define the anatomical structure, from the initial image to the anatomical configuration represented in a secondary image. The point of reference for this transformation was anchored to the coordinates of the base of the spinal column (Cao et al., 2021).

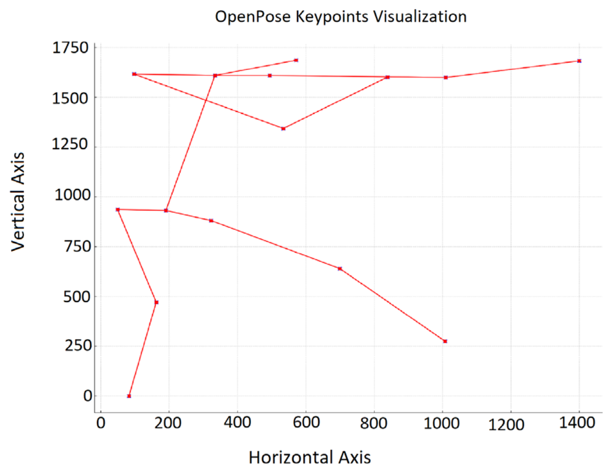

Figure 3. Graphical representation of OpenPose keypoints projected onto the sagittal plane, reconstructed from the artifact in Figure 1. The visualization, created using Python's Matplotlib library, connects keypoint coordinates along vertical and horizontal axes, with distances measured in pixels relative to the image resolution.

Following data ingestion, the script undertakes a preprocessing phase to clean and structure the raw keypoint data into a format conducive to subsequent analysis. The next computational module focuses on the calculation of spinal metrics, specifically the Euclidean distance and angular orientation between designated keypoints, which serve as vital metrics for the ensuing normalization process.

The normalization is temporal in nature, aiming to rescale the keypoint data based on the calculated spinal metrics, thereby enabling a standardized comparison across different time frames. The specific approach culminates in a data visualization step, outputting graphical representations that illustrate the temporal evolution of specific keypoints.

Mathematical formalism

The Euclidean distance D between the 'neck' and 'midhip' keypoints was mathematically formalized as:

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Here, the formula expresses the Euclidean distance between two points in a two-dimensional space, where the coordinates of the points are (x_1, y_1) and (x_2, y_2) The distance D is calculated by taking the square root of the sum of the squared differences between their respective x and y coordinates. Specifically, the horizontal difference $(x_2 - x_1)$ and the vertical difference $(y_2 - y_1)$ are each squared, added together, and then the square root of this sum gives the straight-line distance between the two points.

Analytical approach to temporal normalization

The script employed a temporal normalization technique that leverages the calculated spinal metrics. For each ensuing frame, a scaling ratio r was computed by dividing the current spinal length by this referential length. This scaling ratio r was then applied to every x and y coordinate of the keypoints in the subsequent frames, thereby achieving a form of temporal standardization. The scaled coordinates were computed as follows:

$$x' = r \cdot x$$
$$y' = r \cdot y$$

We need to clarify that the vector measurement referred to pixels and was not examined in this research, as the rescaling we performed to match the size of one image to the other affects the vector measurement. However, it does not impact the absolute value of the angles, which remain constant regardless of the rescaling. The origin of the reference system was located at the lower-left corner of the image. Finally, according to the international standard, angles were measured counterclockwise, with 0° set along the positive x-axis (to the right), and angles increased in a counterclockwise direction.

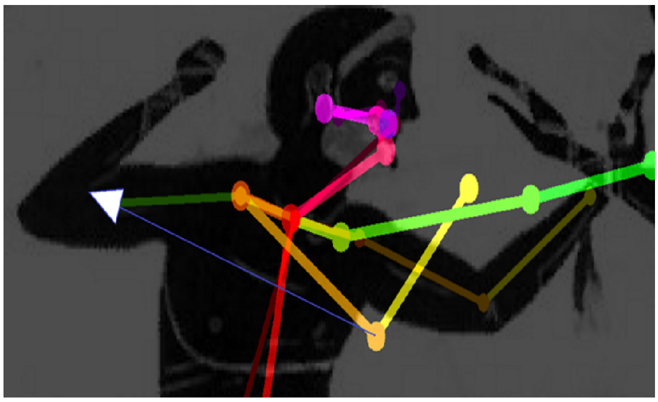

Figure 4. Transition of the elbow from an initial intermediate position. The figure was drawn by OpenPose and shows the athlete's initial stance, while the image displays the position taken by the limb that is about to strike, and the arrow represents the displacement of the elbow's position. The image was made using overlay as a means to make clear the rationale of this part of the study.

Descriptive analysis

For this sample we used a descriptive statistics approach. In the analytical approach we employed for the descriptive statistics, the frequency, proportion, and range were calculated to provide a simple overview of the dataset concerning kicks. To visually represent the distribution of kicks that were similar and dissimilar to ancient forms, a pie chart was generated using Python (Figure 5).

This chart visually separates the kicks into two categories, providing a graphical representation of the proportion of kicks that were similar to ancient depictions relative to those that were not.

The punch statistics were not applicable in this case as there was no clear representation of the preparatory phase or a clear resemblance of the punch to the aforementioned preparatory posture. For this reason, we used the fundamental punch taught in modern pankration disciplines.

Results

The results of the descriptive statistical analysis demonstrate the program's ability to identify kicks similar to those found in ancient artworks. The analysis revealed that a mere 4 kicks, constituting approximately 3.9% of the total, exhibited any resemblance to ancient depictions. The range of similarity for these few kicks varied between 35% and 78%, indicating inconsistency even among the kicks classified as similar.

The pie chart in Figure 5 visually represents these proportions. As depicted, the overwhelming majority of kicks (96.1%) did not resemble ancient forms, while a minuscule portion (3.9%) did.

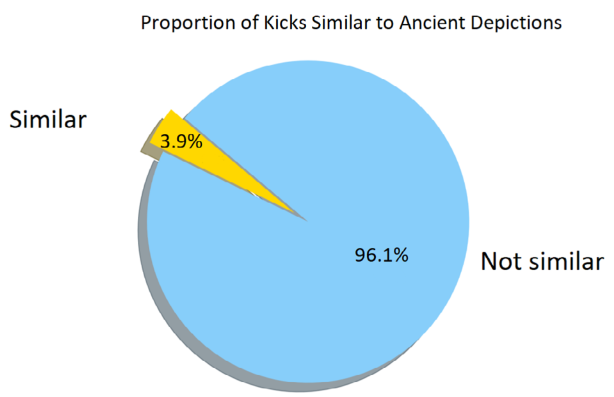

Figure 5. Percentage similarity of modern pankration kicks compared to ancient depictions. The majority of kicks (96.1%) show no resemblance to ancient techniques, while only a small fraction (3.9%) displays partial similarity, which reflects significant divergence between the two eras. The present plot indicates the clear technical difference based on the body's angles during the movement.

Applying the experimental protocol, we obtained some preliminary results on specific biomechanical characteristics related to pugilistic movements in the context of ancient sporting activities. It is important to note that our analytical framework divides the execution of a punch into two distinct kinematic phases, notwithstanding the fact that the 'laktisma', which is a direct strike, does not adhere to this dual-phase construct.

Displacement vectors and kinematic presentation of the strikes

The inaugural phase, as visually represented in the following diagrams, encapsulated the preparatory or "displacement" phase, in which the limb transitioned toward a state of readiness, denoted herein as the 'paraskevi' position. This phase essentially served as a biomechanical preamble for the ensuing strike. The rationale for scrutinizing the limb's displacement trajectory derived from textual descriptions indicating that the athletes adopted a readiness posture as an initial stance. As the inter-athlete distance diminished, manual strikes commenced, corroborated by depictions capturing athletes in specific postures indicative of hand-based strikes at that juncture.

Kick vectors

The initial exploration focused on the 'laktisma,' primarily targeting the abdominal region of the opponent. This anatomical target was chosen in the absence of extant references suggesting cranial strikes. Conversely, arm strikes, as substantiated by the archaeological corpus, were primarily aimed at making facial contact with the opponent.

To quantify the vectorial displacement of the striking limb, coordinates from two temporally distinct frames were utilized: the initial frame depicted the limb's starting posture, and the terminal frame captured the moment of kinematic impact. From these data points, both the magnitude and directionality of the displacement vectors were computed, and the slope of these vectors was subsequently ascertained. The culmination of these data manipulations is reflected in the diagrams that encapsulate the empirically derived results of this study (Figure 3). We observed the angle difference between the two sports. The magnitude of the vectors was calculated as approximately 1147.66 pixels in the ancient case and approximately 1073.55 pixels in the new case, with angles of 161° and 152.24°, respectively.

In Figure 6, the magnitude of the "New" vector (blue) was calculated as approximately 791.01 pixels, with an angle of 2.90 degrees. The "Punch in Ancient" vector (green) has a magnitude of approximately 1079.36 pixels and an angle of 347.81 degrees. Lastly, the "Preparation Phase" vector (orange) has a magnitude of approximately 911.62 pixels with an angle of 147.63 degrees.

In Figure 7 ("Forearm Displacement of Pair 2"), it is evident that the strike in the new case, represented by the blue line, is direct with a slightly downward slope at an angle of 176.20 degrees and a magnitude of approximately 1057.32 pixels. The green line represents the "Punch in Ancient," characterized by an angle of 183.99 degrees and a magnitude of approximately 1306.17 pixels. Lastly, the "Preparation Phase," depicted by the orange line, shows a displacement at an angle of 38.49 degrees with a magnitude of approximately 835.53 pixels.

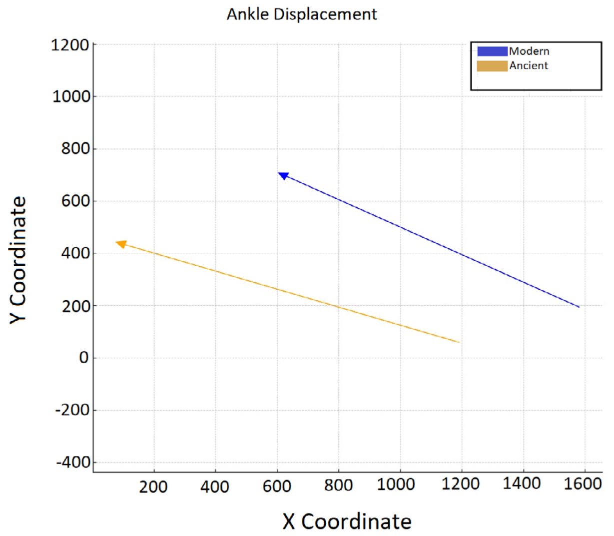

Figure 6. Ankle displacement trajectories for a kick in modern (blue) and ancient (yellow) pankration. The modern trajectory shows a higher vertical displacement, indicating kicks aimed at elevated targets such as the head. In contrast, the ancient trajectory reflects a lower displacement, consistent with strikes targeting the abdomen. The units are measured in pixels.

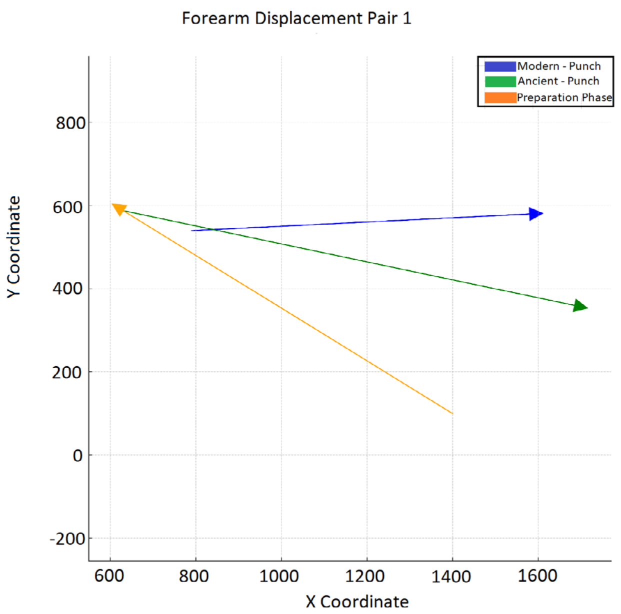

Figure 7. Forearm displacement trajectories for a kick in modern (blue), ancient punch (green), and ancient preparatory phase (orange) techniques. The modern trajectory is linear and upward, in contrast to the ancient downward motion and preparatory movement. The units are measured in pixels.

In Figure 8, the forearm displacement of Pair 3 is presented through the corresponding vectors. Their slope is consistent with those observed in previous diagrams. In the new depiction, represented by the blue vector, the strike is slightly upward at an angle of 3.37 degrees and has a magnitude of approximately 832.44 pixels.

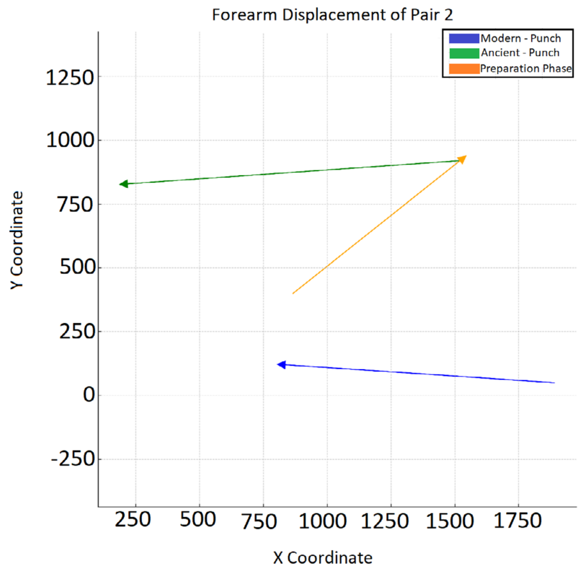

Figure 8. The forearm displacement trajectories are presented for the second punch in modern (blue), ancient punch (green), and ancient preparatory phase (orange) techniques. The modern trajectory is linear and downward, while the ancient punch exhibits an upward motion and the preparatory phase shows a steep ascent, a similar pattern to the previous one. The units are measured in pixels.

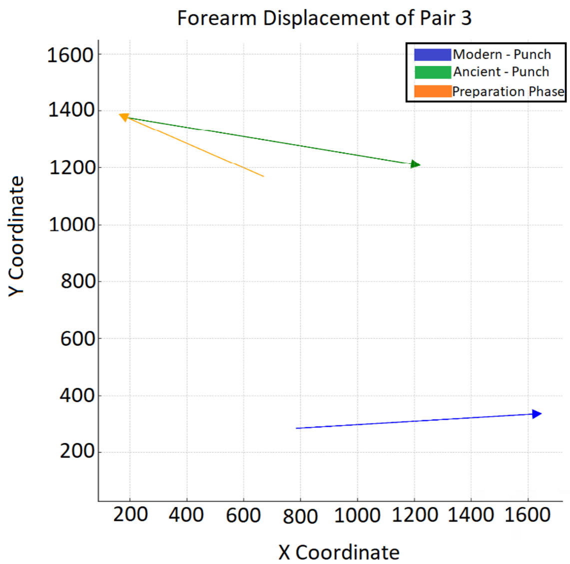

Figure 9. Trajectories for a punch in modern (blue), ancient punch (green), and ancient preparatory phase (orange) techniques. The modern punch follows a linear horizontal motion, contrasting with the ascending preparatory phase and downward trajectory of the ancient punch. The units are measured in pixels.

In the ancient depiction, represented by the green and orange vectors, a similar pattern is observed. The green vector shows the wrist displaced higher than the level of the head at an angle of 350.74 degrees with a magnitude of approximately 1013.20 pixels. This is followed by a strike in the Preparation Phase, represented by the orange vector, which has a descending direction at an angle of 156.67 degrees and a magnitude of approximately 522.73 pixels.

Discussion

The objective in this project was to scrutinize variances in specific techniques between ancient and contemporary forms of pankration. This investigative hypothesis was formulated upon the observation of shared technical attributes in both ancient and modern iterations of the sport. Despite the inherent limitations owing to the scarcity of primary sources, empirical data gleaned from ancient artifacts and extant textual records exhibit discernible correlations between ancient and modern athletic practices.

Within the ambit of this study, particular emphasis was placed on the examination of joint coordinates discerned in both archaic iconographic representations and contemporary video material provided by the federation. The study scrutinized the kinematic displacements of the forearm, specifically the wrist joint during hand strikes and the ankle joint during leg strikes. It was presupposed that the leg strikes were initiated directly from the athlete's initial stance without transitioning through any intermediary postures. The data thus gleaned uncovered potential kinetic patterns employed by ancient athletes in executing hand and leg strikes. Simultaneously, comparable movement paradigms in modern pankration were ascertained based on identical data sets, serving the broader comparative analysis (Bourantanis et al., 2022).

Each diagrammatic representation in the study delineates the pertinent displacement vectors associated with the terminal elements of the kinematic chain: the wrist or ankle joint for hand and leg strikes, respectively. Since the comprehensive characterization of such a vector was rendered through its directional and magnitude components, we included the magnitude (pixels), as reported previously (Miklavcic, 2020). However, within the context of this investigation, the magnitude of the vector was deemed inconsequential. This is principally because a multitude of extraneous variables such as the athlete's physical attributes and the equipment deployed could influence it. Therefore, the analytical focus was predominantly oriented toward the angular component of the vector, denoting the inclination or directional proclivity of the corresponding strike.

Also, for the sake of analytical economy, the extracted kinematic patterns for both ancient and modern pankration punches and leg strikes are presented in a comparative framework. Initial qualitative assessments of primary source materials revealed several disparities between ancient depictions and modern photographic evidence. These divergences were most apparent in the pre-execution stances assumed by athletes. Subsequent quantitative analyses of these images presented different technical attributes, thereby corroborating the existence of distinct kinetic patterns both in antiquity and in contemporary practice.

One notable pattern discerned was the elevated arm position maintained by athletes at the moment of executing a strike—a ubiquitous feature across all examined ancient representations. This elevated limb position possibly afforded athletes the strategic movement to either transition into another strike or revert to their initial stance, contingent upon multiple variables. Furthermore, in contrast to modern visual materials where mainly circular and fewer linear strikes were identified, ancient depictions predominantly showcased downward strikes. These were invariably preceded by what has been termed the "preparation position" in this study. The modern strikes, in contrast, largely target the opponent's head and are executed linearly at a consistent elevation relative to the initial hand position, typically with a marginally upward trajectory. The analysis amplifies our understanding of both the ancient and modern forms of pankration, shedding light on the complex interplay of biomechanics and strategy in this enduring combat sport.

Execution of the kick

Here, the first represents the vectorial displacement of the tibiofemoral joint from its initial position at the onset of a kick. The angular analysis suggests that in modern practice, the objective is often a high strike, aimed at the opponent's head. This is corroborated by the ancillary video material and may be rationalized within the framework of the sport's semi-contact scoring system, which typically awards higher points for such strikes.

In contrast, ancient iconography, typified by the relevant plot, seems to depict an abdominal strike. The slope of the tibiofemoral joint's displacement furnishes vital kinematic data, indicative of an ancient technique termed 'laktisma' (Nomikos, 2009). The bodily posture—characterized by a fully extended supporting leg and significant foot displacement—suggests a targeted impact on the abdominal region, potentially causing visceral injuries such as liver or spleen rupture (Nomikos, 2009; Nomikos, 2015). This diverges markedly from the high-target strategy observed in modern pankration.

Execution of punches

Figure 7 delineates the wrist joint's displacement as the athlete executes a hand strike in the modern variant of the sport. The trajectory is slight and almost linear, with a small angular inclination, indicative of a face-directed strike. The diagram also elucidates the preparatory or 'readiness' position, a critical precursor to the strike itself. In ancient depictions, this position frequently manifests with the hand elevated above the head, potentially suggesting an increase in dynamic energy, which is subsequently converted to kinetic energy upon strike execution.

Figure 8 introduces another strike variant, executed in a lateral (right-to-left) way. This choice necessitated a different set of modern pankration images to maintain directional congruence. The strike's trajectory retains a slight upward inclination, contrasting with the descending vectors frequently observed in ancient representations. The wrist joint's displacement vector angle underscores this distinction.

Finally, Figure 9 illustrates another basic strike in modern pankration, juxtaposed against its ancient counterpart. The modern strike, initiated at neck height, terminates approximately at the opponent's lower jaw level, with a distinct displacement almost twice that of preceding examples. Conversely, the ancient strike manifested divergent kinematic characteristics, with a descending trajectory and substantial angular deviation, thereby accentuating the temporal disparities in technique.

An additional observation regarding the identified discrepancy in the aforementioned kinematic pattern was the motion execution in three dimensions (Hall, 1998). The lateral movement of the fist, evident from the requirement of shoulder abduction and adduction for the forearm to achieve its final position (Hall, 1998), as depicted on vases (Figure 12), is more pronounced in ancient iterations compared to modern ones. The perception of motion towards an individual, such as an approaching fist, possibly involved the coordination of multiple brain regions.

It is known that the primary visual cortex, located in the occipital lobes, plays a crucial role in motion perception (Gutinsky & Dragoi, 2008). This cortex receives visual input from the eyes and processes it to construct a representation of the visual scene. The parietal lobes, previously mentioned, also contribute to motion perception, processing spatial information to provide a sense of the position and movement of objects relative to the individual (Gutinsky & Dragoi, 2008).

The superior temporal sulcus (STS) in the temporal lobes is another area involved in motion perception, specifically in processing dynamic visual information and perceiving biological movements (Nath & Beuchamp, 2011).

It is noteworthy that multiple brain regions collaborate to perceive motion, and different types of motion may activate various brain areas to varying degrees (Mulla et al. 2023; Zemková & Zapletalová, 2022). It is understood that motion generates an increased amount of information for the brain to process. As described, lateral motion is minimal in modern pankration, implying that the inclusion of associated regions necessary for an appropriate motor response significantly increases the amount of information to be processed. So, through the present, simple kinematic analysis, notable variances in strike execution between ancient and contemporary pankration are observed. Both the directionality and angular components of the displacement vectors offer an understanding of these differences.

Previous studies have predominantly focused on the biomechanics of combat sports, such as boxing and karate, where the emphasis has been on linear and circular strikes aimed at high targets, such as the head and torso (Bourantanis, 2024; Hall, 1998). The present research, however, revealed the existence of downward strikes and preparatory positions in ancient pankration, which contrasts sharply with modern approaches. The discovery of elevated arm positions before strike execution, frequently observed in ancient depictions, is closer to findings in traditional martial arts, where there is a focus on energy conversion from dynamic to kinetic (Zoughari, 2008). This was less evident in modern pankration, where strikes tended to be more direct, consistent with previous findings in modern combat sports. Further, the leg strike analysis, where ancient athletes targeted the abdominal region, offered new insights that contrast with existing research on sports, where high kicks are generally aimed at the opponent's head, a technique favored for its scoring potential in semi-contact sports (Miklavcic, 2020).

In summary, the comparative analysis of striking techniques in both ancient and modern forms of pankration has identified distinctive kinematic patterns within the constraints of the methodological framework applied to historical and contemporary visual representations. The observed variances predominantly pertain to the directionality of the strikes and blows. For instance, the tibial joint's trajectory in modern pankration is markedly influenced by the elevated target level—typically the head—compared to the abdominal targeting observed in ancient practice. Conversely, the hand strikes demonstrate antipodal directional characteristics, primarily engendered by the divergent initial hand positions during the preparatory phase. The ancient technique appeared to potentially exploit a conversion mechanism from dynamic to kinetic energy, whereas the contemporary variant leverages the elastic energy stored in the shoulder's soft-tissue components during the arm's pre-strike loading phase.

Conclusion

Modern and ancient pankration exhibit different kinematic structures, possibly reflecting changes that have occurred over time. One key difference is that ancient pankration featured a pre-strike elevated hand position, which is absent in contemporary practice. Furthermore, the body posture and the anatomical areas targeted during strikes vary considerably between the two periods. The findings highlight a technical differentiation of the sport. Future studies, especially those utilizing advanced technologies, could yield more precise insights into ancient techniques. We conclude that more research is required to approach the technical features of ancient pankration.

Limitations and implications for future studies

The main limitations of this study derive from its reliance on selected ancient artifacts and the use of two-dimensional analysis tools. Also, the fragmented historical sources may have caused potential misinterpretation. Future studies should focus on developing biomechanical models to simulate ancient pankration techniques, taking into account factors such as muscle strength and joint flexibility. This would help in approaching how ancient athletes used to execute movements. A combination of modeling with historical and cultural insights would help to ensure that the synthesized movements reflect not only the physical dynamics but also the historical authenticity of ancient pankration techniques.

Strengths of the research

The strength of this research lies in its innovative application of computational techniques, i.e., the methodological approach, employed to compare ancient and modern pankration techniques. The unprecedented approach of studying the displacement of strikes in antiquity provided a novel biomechanical perspective on movement in the ancients. The use of machine learning tools such as OpenPose for extracting joint coordinates from both historical depictions and modern footage enhanced the scientific credibility of the research. As a whole, this methodological framework allowed for a biomechanical comparison, which has never been conducted before, and thereby offered valuable insights into the distinction of pankration techniques between antiquity and the modern era.

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Appendix

Figure 10. The image depicts an athlete engaged in the ancient Greek sport of pankration, as illustrated on a red-figure amphora housed in the Staatliche Antikensammlungen Museum in Munich, Germany.

The athlete is presented in a stance of readiness, with one arm extended forward and the other bent at the elbow, as if he is preparing to strike or grapple. His weight is shifted onto the back leg, suggesting dynamic movement and anticipation of action.

Figure 11. Scene of a pankration match depicted on a black-figure amphora from the classical period (5th century BCE), currently held at the Metropolitan Museum of Art in New York City.

Two athletes are depicted in a combat scene where one is performing a kick, likely aiming at the opponent's abdomen, while the defender appears to be executing a counter-technique. The aggressor's body, with one leg raised, is indicative of the action of striking, while the other athlete leans forward, possibly in an attempt to prepare a subsequent move.

Figure 12. Detailed scene of a boxing match from a black-figure amphora dating to the 6th century BCE, part of the Antikensammlung Berlin collection. Both figures are depicted with a dynamic sense of movement: one boxer is caught in the midst of throwing a punch, while the other boxer appears to be on the defensive, leaning back to evade the blow.

Figure 13. This image represents an ancient Greek red-figure amphora from the 5th century BCE, currently preserved in the National Archaeological Museum of Florence.

The scene portrays a moment in a combat sport, possibly pankration, illustrating a punch being delivered to a fallen opponent, known as a Lapith. The athlete delivering the blow is depicted in mid-motion, with one arm fully extended in the punch and the other held back, likely for balance and to prepare for further engagement.

Figure 14. A fragment from an ancient Greek amphora dating to the 6th century BCE, which is preserved in the British Museum.

It features a dynamic depiction of two boxers exchanging blows with their fists—a scene from an athletic contest that showcases a form of ancient boxing. The athletes are shown in profile, engaged in a vigorous exchange, with one figure's arm drawn back ready to strike and the other's fist seemingly making contact with his opponent.