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POPA VLAD

KINOVEA AND PYTHON AS ALTERNATIVE AND ACCESSIBLE TOOLS FOR BIOMECHANICAL ANALYSIS

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Introduction

In fields concerned with the locomotor system—physiotherapy, physical education, high-performance sports, fitness, and recreational activities—the need for objective, dynamic, and accessible assessment methods is becoming increasingly evident. The biomechanical analysis of gait occupies a central role in this context, as human walking is a cyclic and complex process that involves the coordinated action of the muscular, skeletal, articular, and nervous systems, while maintaining upright posture and balance under both static and dynamic conditions. The gait cycle includes the sequence of phases between the initial contact of one foot with the ground and the subsequent contact in the next cycle, through the phases of stance, weight transfer, and swing (Taborri et al., 2016).

Laboratory-based biomechanical analysis represents the reference standard, using complex systems consisting of multiple high-speed cameras and specialized equipment. However, these solutions are expensive, difficult to transport, and relatively inflexible, which limits their applicability in real working contexts such as therapy clinics, sports fields, or training facilities (Requena et al., 2012). In this context, identifying alternative methods for extracting and analyzing biomechanical data becomes necessary in order to formulate more precise conclusions and support better-informed practical decisions (Ang & Kong, 2023). Through such methods, variables such as distances, displacements, times, and angles can be quantified, and subsequently relevant parameters such as velocity, acceleration, force, mechanical work, power, or torque can be derived (Liu et al., 2022).

This study proposes the use of Kinovea 0.9.5, a free and intuitive software application, for extracting data from 2D video recordings. The program allows calibration along the axes of interest and facilitates motion analysis under standardized filming conditions, reducing preparation time and the complexity of the evaluation process (Paolino & Zampa, 2023). The obtained data are subsequently centralized and processed numerically.

In parallel, the Ochy application, based on video analysis and artificial intelligence algorithms, offers a modern alternative for evaluating walking and running, usable directly with a smartphone or a camera connected to a computer. By identifying deviations from parameters

considered normative, the application can generate useful information for movement professionals such as physiotherapists, coaches, trainers, podiatrists, or runners.

Regarding data processing, the Python programming language provides a flexible and efficient framework for the numerical analysis of biomechanical datasets. Through customized scripts, calculations, classifications, comparisons, correlations, and graphical representations can be automated. Once the analytical infrastructure is developed, it can be reused for large datasets, contributing to increased objectivity and reproducibility of the evaluation. Consequently, the combined use of accessible tools such as Kinovea and Python responds to the growing need for biomechanical assessment applicable in real-world conditions and at reduced costs (Van Hooren et al., 2019)

Research motivation

The biomechanical analysis of gait is essential for understanding the functioning of the locomotor system and for optimizing therapeutic, educational, and sports interventions. However, the classical infrastructure of biomechanics laboratories requires sophisticated and expensive equipment that is difficult to use outside specialized environments, which limits both access for specialists and the practical applicability of such evaluations (Requena et al., 2012; Wren et al., 2011).

This situation justifies the need for alternative solutions capable of providing objective and reproducible data while remaining economical, flexible, and easy to implement. The integration of the open-source software Kinovea with numerical processing in Python addresses this need through an accessible method with practical relevance and potential for expansion in clinical, educational, and sports contexts (Paolino & Zampa, 2023; Van Hooren et al., 2019).

Thus, the motivation of the research lies in the necessity of democratizing access to biomechanical gait analysis and providing a valid, reproducible method applicable to a wider range of specialists in the fields of movement science, physiotherapy, and sports.

Purpose of the Study

The main purpose of this research is the development, testing, and validation of an alternative, accessible, and efficient method for biomechanical gait analysis, based on the use of

open-source digital tools such as Kinovea and Python, with applicability in the evaluation of locomotor function in educational, sports, and clinical contexts.

The study aims to propose a practical, economical, and reproducible solution for analyzing joint angles and functional parameters of movement, contributing to the expansion of objective assessment in movement sciences. Quantifying the biomechanical characteristics of gait represents an important clinical tool for identifying normal and pathological locomotion patterns (Phinyomark et al., 2016).

Research Objectives

In order to achieve this purpose, the following objectives were formulated:

1. To establish a theoretical foundation regarding gait biomechanics, the joints involved, and current methods of motion analysis.

2. To configure and standardize a video recording and analysis protocol using Kinovea for estimating joint angles during walking.

3. To develop customized Python scripts for numerical data processing, generating tables, graphs, and functional correlations.

4. To apply the protocol to a sample of subjects in order to validate the method in practice and identify variability in functional parameters.

5. To compare the obtained results with data from the scientific literature and established biomechanical methods in order to highlight the advantages and limitations of the proposed method.

6. To formulate practical recommendations for applications in physical education, physiotherapy, and sports training.

Research Hypotheses

The research was based on the following hypotheses:

1. Two-dimensional video analysis performed using Kinovea under standardized recording conditions allows accurate estimation of lower-limb joint angles during gait.

2. Numerical processing of data extracted through Python can provide relevant biomechanical indicators comparable to those obtained using classical biomechanical methods.

3. The combined Kinovea–Python method can highlight significant differences between subjects with distinct functional profiles or different levels of physical activity.

4. This accessible analysis method can represent a viable and scalable alternative for educational, sports, and clinical contexts, complementing or partially replacing expensive laboratory assessments.

5. The obtained biomechanical data allow the formulation of personalized recommendations for optimizing locomotor function, preventing injuries, and supporting the rehabilitation process.

Novelty and Originality of the Research

The study provides an original contribution by integrating and validating an alternative, accessible, and reproducible method of biomechanical analysis based on the combination of the open-source software Kinovea and the Python programming language. This approach proposes a practical solution for evaluating functional movement parameters without requiring specialized laboratories or expensive equipment, thereby contributing to the democratization of biomechanical analysis in educational, clinical, and sports contexts.

The originality of the research consists in:

• developing a biomechanical analysis protocol based on standardized video recordings and numerical processing through custom Python scripts;
• applying the method within a comparative framework to highlight differences between subjects or between different moments of locomotor function assessment;
• proposing a scalable and replicable solution for professionals in movement sciences who do not have access to the resources of a traditional biomechanics laboratory.

The novelty of the study is further supported by addressing functional aspects of gait and joint behavior through tools that are easy to use and adaptable to other population groups such as athletes, postoperative patients, or elderly individuals. The main contribution consists in adapting, testing, and validating a modern motion analysis method with broad potential applications in

physical education, rehabilitation, and high-performance sports. In this regard, the development of motion recording and analysis systems has made it possible to quantify variables such as distances, angles, and time intervals, as well as to define functional benchmarks and deviations from them (Wren et al., 2011). At the same time, technological advances in recent decades have enabled the expansion of posture and movement evaluation beyond laboratory settings and into environments increasingly similar to real practice conditions (Keijsers et al., 2016).

PART I

THE THEORETICAL AND SCIENTIFIC FOUNDATION OF THE DISSERTATION

CHAPTER I. Conceptual and Theoretical Elements of Biomechanical Analysis

The biomechanical analysis of human movement is an interdisciplinary field that examines how anatomical structures and neuromuscular mechanisms contribute to the execution of the body's functional movements. In the case of human gait, biomechanical analysis makes it possible to understand the relationships among body segments, the distribution of forces, and the mechanisms through which the body maintains stability, balance, and energetic efficiency during locomotion.

Gait is a complex locomotor process characterized by the coordinated succession of stance and swing phases, during which multiple joints and body segments act synergistically. The objective evaluation of these mechanisms is an essential component both in biomechanical research and in clinical, rehabilitative, and sports practice.

In the context of digital technological development, human movement analysis can now be performed not only in specialized laboratories, but also through accessible methods such as video analysis and numerical data processing. These approaches enable the extension of biomechanical assessment into real-world settings, facilitating the functional monitoring of movement in physical education, physiotherapy, and sports training.

1.1. Joints Involved in Gait and Their Biomechanical Relevance

The efficient functioning of gait depends on the interaction among several structures of the locomotor system, especially the ankle–foot complex, the knee, the hip, and the vertebral column. These structures form an integrated kinetic chain in which each segment contributes to stability, postural control, and body propulsion.

The ankle–foot complex plays a fundamental role in shock absorption, adaptation to the support surface, and propulsion generation during gait. Movements of dorsiflexion and plantarflexion at the ankle, as well as foot inversion and eversion, occur in a coordinated sequence

throughout the gait cycle. Deviations from these patterns, such as limited range of motion or ligamentous instability, may lead to alterations in locomotor patterns and promote the occurrence of biomechanical dysfunctions.

The knee occupies a central position in the kinetic chain of the lower limb, contributing to body weight support, impact absorption, and force transmission during walking and running. Although its primary movements are flexion and extension, knee function also involves minor rotations controlled through the interaction of the articular, meniscal, and ligamentous structures. Deviation of joint alignment or functional instability may result in gait pattern alterations and overload of other locomotor segments.

The hip is a key joint for body stabilization and for controlling the dynamic movements of the lower limb. Through its wide range of flexion-extension, abduction-adduction, and rotational movements, the hip contributes to balance maintenance, shock absorption, and propulsion generation. Muscular deficits or mobility limitations at this level may produce biomechanical compensations that affect gait efficiency.

The vertebral column completes this functional ensemble through its role as a central structure of support and biomechanical integration. It ensures trunk stability, posture maintenance, and force distribution among body segments. Segmental mobility and muscular control of the trunk directly influence body alignment and gait economy, while imbalances at this level may generate compensations throughout the entire kinetic chain.

In the present research, the analysis of these structures is carried out through video-based assessment methods and numerical data processing. The use of Kinovea software enables the measurement of joint angles in the two-dimensional plane, while Python-based data processing facilitates the comparison of values between subjects and the identification of relevant functional patterns.

1.2. Gait Mechanics

Human gait is a fundamental locomotor activity characterized by a cyclic movement pattern that enables efficient body displacement. From a biomechanical perspective, the gait cycle is defined as the interval between two successive contacts of the same foot with the ground.

The gait cycle is divided into two main phases: the stance phase and the swing phase. The stance phase represents approximately 60% of the total cycle and includes initial contact, full support, and toe-off. The swing phase accounts for approximately 40% of the cycle and includes foot lift, mid-swing, and preparation for the subsequent contact.

During gait, body segments act in a coordinated manner to maintain stability and optimize energy expenditure. Movements of the lower-limb joints are synchronized with trunk and arm movements, which contribute to balance maintenance and body stabilization.

Biomechanical gait analysis is based on the evaluation of spatial, temporal, kinematic, and kinetic parameters. These include step length, gait phase duration, step frequency, joint angles, and ground reaction forces. Such parameters provide relevant information regarding movement efficiency and possible deviations from patterns considered normal.

Traditionally, gait analysis is performed in specialized biomechanics laboratories using three-dimensional motion capture systems and force platforms. However, the development of digital technologies has enabled the use of alternative methods such as two-dimensional video analysis and numerical data processing, which can provide valid estimates of gait parameters under more accessible conditions.

1.3. Biomechanical Models of Gait

In order to explain the mechanisms involved in human gait, the specialized literature has proposed several theoretical models describing how energy is used and transferred during locomotion.

One of the best-known models is the six determinants of gait model, which describes the mechanisms by which the body reduces the vertical displacement of the center of mass during walking. These mechanisms include pelvic rotation and tilt, knee flexion during stance, ankle joint motion, and the functional alignment of the lower limb.

Another important model is the inverted pendulum model, which describes gait as a movement in which the stance limb functions similarly to a rigid pendulum. In this situation, the body's center of mass moves over the supporting foot in a circular arc, and mechanical energy is partially conserved through the alternation between potential and kinetic energy.

The dynamic walking model proposed by McGeer introduces the idea that gait may emerge as a result of the passive mechanical properties of the locomotor system. Experiments performed with bipedal robots demonstrated that stable gait can be generated even without active neuromuscular control, solely through the interaction between gravity and segment inertia.

These models are not mutually exclusive; rather, they provide complementary perspectives on gait mechanics. In the present research, they constitute important theoretical reference points for interpreting the biomechanical parameters extracted from video analysis and numerical data processing.

1.4. Functional Parameters of Movement

Functional parameters are quantitative indicators that describe the efficiency, stability, and coordination of locomotor system movements. In biomechanics, they are used to evaluate motor performance, identify functional deviations, and monitor the progression over time of a therapeutic or training intervention.

Functional parameters can be classified into several categories. Kinematic parameters describe how movement unfolds and include angular amplitudes, segment velocities, and accelerations. Temporal parameters refer to the duration of different movement phases, while spatial parameters describe the distances and trajectories of body segments. In addition, symmetry parameters allow the assessment of functional balance between limbs, while derived parameters provide synthetic indicators of locomotor performance.

In this dissertation, functional parameters are obtained through a methodology based on calibrated video recordings analyzed with Kinovea software and subsequently processed through scripts developed in the Python programming language. This approach enables the automatic extraction of angular and temporal values, statistical data analysis, and comparison of results between subjects or between different assessment moments.

The importance of these parameters lies in the fact that they provide objective information regarding the functional level of the locomotor system, deviations from patterns considered normal, and the effectiveness of therapeutic or sports interventions. Therefore, the analysis of functional parameters represents an essential tool for applied biomechanical assessment

Conclusions of the Theoretical Foundation

The theoretical foundation of the dissertation highlights the complexity of the mechanisms involved in human gait and the need for an integrative approach to the biomechanical analysis of movement. The interaction among lower-limb joints, the stabilizing role of the trunk, gait cycle mechanics, and the existing theoretical models provide the conceptual framework for interpreting biomechanical data.

In this context, the use of accessible tools such as video analysis with Kinovea and numerical data processing with Python represents a modern alternative for evaluating the functional parameters of gait. This approach enables objective and reproducible analyses, with applicability in clinical, educational, and sports settings.

CHAPTER II. Data Extraction and Analysis

The biomechanical analysis of movement has traditionally relied on highly precise laboratory systems consisting of high-speed optical cameras, force platforms, and specialized software. These systems represent the reference standard for evaluating the kinematics and kinetics of walking, running, and other complex motor tasks. However, their high cost, the infrastructure required, and the difficulty of using them outside the laboratory significantly limit their applicability in current educational, clinical, and sports settings. For this reason, contemporary research is increasingly focusing on accessible, portable, and reproducible alternatives capable of providing relevant biomechanical data under field conditions.

2.1. Biomechanical Analysis in the Laboratory

Classical biomechanics laboratories provide the highest level of precision for the evaluation of human movement through the use of multidimensional optoelectronic systems and force platforms. These systems allow detailed analysis of joint angles, segment trajectories, and ground reaction forces. Despite their methodological advantages, such systems require considerable financial resources, specialized personnel, and logistical conditions that are difficult to reproduce outside a controlled environment.

In contrast to this approach, the development of portable and automated systems has created the premises for more accessible biomechanical assessment. Such solutions allow the analysis of posture, gait, and running in natural environments, without depending on the infrastructure of a traditional laboratory. It is within this context that the methodological direction of the present dissertation is situated, focusing on the use of accessible digital tools with broad practical applicability.

2.2. Kinovea – Open-Source Application for 2D Video Motion Analysis

Kinovea is a free and open-source software program designed for motion analysis based on two-dimensional video recordings. Due to its intuitive interface, zero cost, and the possibility of measuring angles, lengths, and time intervals, the application represents a viable alternative for coaches, physiotherapists, teachers, and researchers interested in the functional assessment of movement.

In this dissertation, Kinovea was selected for its accessibility and for the possibility of standardizing filming and analysis procedures. Its use involved a clear protocol: positioning the camera in the plane of interest, fully framing the subject, using an appropriate recording frequency, and spatially calibrating the image by means of a known reference. In addition, the application of visible anatomical markers facilitated the measurement of joint angles and the tracking of body segments.

The functions used in the analysis included the angle measurement tool, timing of movement phases, trajectory tracking, and data export in tabular format. Although Kinovea is limited to 2D analysis and depends on correct camera positioning and accurate identification of anatomical landmarks, the specialized literature supports its usefulness in the analysis of simple locomotor tasks such as walking and straight-line running. In the present research, Kinovea served as the main instrument for the systematic extraction of biomechanical parameters, providing the basis for subsequent processing.

2.3. Ochy – Mobile Application for Automated Gait Analysis

Ochy is a mobile application based on artificial intelligence, designed for the automated analysis of gait and running directly from video recordings made with a smartphone. The application uses computer vision and machine learning algorithms to rapidly extract functional parameters without requiring external sensors, anatomical markers, or spatial calibration.

The integration of Ochy into the research had a comparative purpose. The aim was to evaluate a fully automated method in relation to the semi-automated approach offered by Kinovea. The parameters provided by Ochy include joint angles, step length and symmetry, gait cycle duration, walking speed, and indicators of segmental stability.

The advantages of the application lie in the speed of analysis, ease of use in field conditions, and high accessibility. However, its limitations are important from a scientific standpoint: the user has limited control over the analysis process, and the internal algorithm remains opaque, which reduces methodological transparency. In this sense, Ochy may be considered a useful tool for screening or preliminary monitoring, but less suitable for research requiring strict control over the stages of analysis.

2.4. The Use of Excel in Comparative Analysis

Microsoft Excel was used in this dissertation as a complementary tool for organizing, comparing, and representing biomechanical data extracted from Kinovea and Ochy and subsequently processed in Python. Its selection was justified by accessibility, familiarity in the academic environment, and excellent compatibility with CSV files.

In the present research, Excel was used to centralize raw data, calculate descriptive values, compare parameters between limbs or between methods, and generate meaningful graphical representations. The structure of the working files allowed the separation of raw data from processed data and included comparative tables and functional summaries for each participant.

An important role of Excel was that of an interface between data extraction and interpretation. Through standard formulas and functions, indicators such as means, standard deviations, side-to-side differences, and symmetry indices were calculated. In addition, the program facilitated the visual representation of variations in angles and temporal parameters, contributing to the clarity of the analysis and supporting the conclusions.

2.5. Python and the Numerical Analysis of Biomechanical Data

Python played a central role in the methodology of the dissertation, providing a flexible and reproducible framework for the numerical processing of biomechanical data. Its use was motivated by the ability to rapidly import data extracted from CSV files, automate calculations, generate comparative graphs, and document the entire analysis workflow in a transparent and reusable form.

Within the studies, specific libraries were used for data manipulation, numerical calculation, statistical analysis, graphical representation, and integration of results into Excel files. Through these tools, it was possible to calculate means and standard deviations, compare values between limbs, determine symmetry indices, and automatically identify relevant differences between testing conditions.

The general analysis workflow included data import, cleaning and structuring, descriptive analysis, graphical representation of parameter evolution, and export of results in a form that was easy to interpret. The integration of Python into the methodology reduced the risk of manual errors, increased the rigor of data processing, and provided the research with a higher level of

reproducibility. In addition, the developed code can be adapted and reused in other biomechanical contexts, supporting the practical and extensible nature of the proposed approach.

2.6. SPSS

SPSS was used as a statistical tool for the inferential analysis of the data obtained. The program allows descriptive statistics, hypothesis testing, analysis of variance, correlation analysis, and regression, and is frequently used in biomechanical and clinical research.

In the present dissertation, SPSS was used to organize datasets and to test the significance of the differences observed between variables and evaluation conditions. The data were structured according to the principle that each row represents an observation and each column a biomechanical variable. This organization allowed the coherent application of statistical tests to spatiotemporal and angular parameters.

Among the possible and relevant analyses for this research are t-tests for independent or paired samples, ANOVA for multiple comparisons, Pearson correlations and linear regressions, as well as nonparametric tests for small samples or non-Gaussian distributions. The major advantage of SPSS lies in its accessibility and in the clarity of result interpretation. Its limitations, however, are related to lower flexibility in the analysis of time series and frame-by-frame biomechanical data, which is why its use was complemented by Python and Excel.

Chapter Conclusions

The chapter dedicated to data extraction and analysis highlights the complementarity of the different tools used in the research. Laboratory analysis remains the reference standard; however, accessible methods based on Kinovea, Ochy, Excel, Python, and SPSS offer a functional and sustainable alternative for biomechanical assessment under real-world conditions.

In this dissertation, Kinovea served as the main instrument for extracting biomechanical parameters, Ochy provided a comparative perspective on automated analyses, Excel supported data organization and visualization, Python ensured advanced numerical processing, and SPSS enabled statistical testing of the results. Together, these tools established an accessible, reproducible, and applicable methodology for educational, clinical, and sports settings.

PART II

PRACTICAL APPLICATIONS OF THE DISSERTATION

CHAPTER III. Study 1. Data Extraction Using Kinovea

This study, published by Popa et al. (2023), has an applied, descriptive, and experimental character and aims to test the feasibility of using the open-source software Kinovea for extracting relevant biomechanical data under accessible, non-laboratory conditions. The research design was cross-sectional and observational, with a mixed component combining quantitative analysis of kinematic and temporal parameters with qualitative evaluation of movement. The study aimed to verify the practical usefulness of an accessible biomechanical analysis method applicable in educational, clinical, and sports contexts.

The purpose of the research was to analyze and validate the use of free and easily implementable tools for the biomechanical evaluation of movement, with a focus on the Kinovea application, complemented by Python and Excel for organizing, processing, and comparing the data. Specifically, the study aimed to validate the use of Kinovea for measuring joint angles in the 2D plane, test the possibilities of subsequent numerical analysis, identify functional symmetry, and formulate methodological recommendations for applying the protocol in practice.

The sample consisted of 20 healthy volunteer participants, aged between 20 and 22 years, equally distributed by sex. All subjects were physically active, without recent injuries and without declared locomotor limitations. The selection of a homogeneous group aimed to reduce confounding variables and increase the internal validity of the study. The motor task analyzed was the vertical jump, performed without prior preparation.

Data collection was carried out through video recordings in the relevant planes, followed by importing the files into Kinovea 0.9.5 and calibrating the images based on a known reference dimension. Relevant anatomical points were marked at the ankle, knee, and hip levels, and the analysis focused on three essential moments of the movement: the initial position, the peak of the jump, and landing. The extracted data were exported in CSV format and subsequently processed

in Excel and Python, allowing systematic organization of the information, comparison of values between subjects, and functional interpretation of the results.

The analyzed biomechanical indicators included lower-limb joint angles, estimated vertical displacement of the body, functional symmetry between limbs, total execution time, and segmental alignment. Measuring these indicators allowed the evaluation of preparation for impulse, propulsion efficiency, landing control, and possible alignment deviations. The analysis procedure was standardized and performed by the same operator, and some measurements were repeated to verify consistency.

The results showed that the applied method allows the extraction of relevant biomechanical parameters with a satisfactory level of consistency. The mean knee flexion angle during the impulse phase was approximately 85° (±7°), with no significant differences between limbs, suggesting good functional symmetry. At the hip level, the average extension at the peak of the jump was 20° (±5°), while at the ankle an average plantarflexion of 15° was recorded at take-off. The estimated mean jump height was 38 cm (±4 cm), and the mean total execution time was 0.78 seconds (±0.09). The mean difference between limbs at the knee level was approximately 2°, indicating a good level of biomechanical balance.

An important aspect highlighted by the analysis was the identification of tendencies toward frontal plane deviations at the knee level, particularly dynamic valgus in some participants during the landing phases. Although these deviations did not significantly affect overall performance, they revealed the usefulness of the method as a functional screening and injury prevention tool.

The study was conducted in accordance with ethical principles for research involving human subjects. Participants signed informed consent before inclusion in the study, were informed about the purpose of the research, the procedures used, and their right to withdraw at any time. The collected data were anonymized and stored under secure conditions.

In conclusion, the study demonstrated that the use of Kinovea software, combined with numerical processing in Python and data organization in Excel, represents an accessible, efficient, and reproducible solution for the biomechanical evaluation of functional movements. The method enabled the extraction of relevant indicators regarding joint angles, movement symmetry, temporal parameters, and segmental alignment, providing a solid basis for the use of these tools in physical

education, rehabilitation, and sports. The study's limitations are related to the small sample size and the two-dimensional nature of the analysis, aspects that justify extending the research through future studies on larger samples and under complementary methodological conditions.

CHAPTER IV. Study 2. Data Analysis Using Python

This study has an applied, exploratory–experimental character and aims to develop and test an accessible method of biomechanical analysis through the use of open-source digital tools. The research proposes the integration of the Python programming language into human movement analysis, in combination with video analysis performed using Kinovea, for the processing and interpretation of biomechanical parameters of the vertical jump.

The research design was mixed, combining quantitative analysis of biomechanical parameters with graphical representation and computational interpretation of the data. The study was cross-sectional and observational, with data collected at a single time point for each participant, without experimental manipulation of movement execution conditions. The methodology was designed to allow the reproduction of the analysis using minimal technical resources and free software tools.

The main purpose of the research was to develop and validate an accessible methodology for the biomechanical analysis of vertical jumps by using the Python programming language for processing, organizing, and visualizing data extracted from video analysis. The objectives included developing an algorithm for biomechanical data analysis, automating the extraction of relevant parameters, using Python libraries for graphical representation of results, and evaluating the efficiency of the method in relation to the requirements of accessibility and reproducibility.

The research sample consisted of 56 participants, men and women aged between 20 and 44 years. All subjects were healthy, physically active, and without locomotor injuries during the previous six months. Participants performed a standing vertical jump without a preparatory run-up in order to capture spontaneous motor behavior under conditions as close as possible to real movement situations.

Data collection was performed through video recordings captured using two Canon EOS M50 cameras mounted on tripods at a height of 1.3 m. Recording was carried out simultaneously in the sagittal and frontal planes in order to capture joint movements in the two main planes of analysis. To facilitate the identification of body segments, visual markers were placed at the level of the iliac crest, the greater trochanter, the knees, and the malleoli.

The video recordings were initially analyzed in Kinovea, where two essential biomechanical moments of the jump were identified: the lowest position during the eccentric phase and the maximum point of the aerial phase. For each of these moments, knee joint angles and hip positions were measured. Jump height was estimated as the difference between the hip position in the initial standing position and its position at the peak of the jump.

The extracted data were organized in an Excel file and subsequently imported into Python for numerical processing. The developed scripts enabled the conversion of angular values into deviations from the neutral position (180°), the automatic classification of knee deviations (genu varum, genu valgum, genu recurvatum, or genu flexum), and the correlation of these deviations with functional parameters such as jump height. Data processing was carried out using the Pandas, NumPy, and Matplotlib libraries, which allowed data organization, comparative analyses, and graphical representation of the results.

The analyzed biomechanical indicators included knee joint angles, frontal and sagittal deviations of the lower limb axis, functional symmetry between limbs, and jump height. Knee angles were evaluated both during the preparatory phase of the jump and during the aerial phase, analyzing deviations from neutral alignment. Comparative analysis between the left and right lower limbs allowed the assessment of movement symmetry and the identification of possible functional imbalances.

The obtained results revealed significant individual variations in knee deviations in both the frontal and sagittal planes. Data analysis indicated a general tendency toward genu varum among male participants and genu valgum among female participants, both during the preparation phase and during the aerial phase of the jump. In addition, jump height showed correlations with knee position and the amplitude of initial flexion, suggesting the influence of segmental alignment on biomechanical performance.

The processed data were presented in the form of tables and comparative graphs, facilitating the interpretation of deviations and the identification of relationships between variables. The integration of video analysis with numerical processing in Python enabled systematic data organization and rapid generation of relevant biomechanical indicators.

The study was conducted in accordance with ethical principles for research involving human subjects. Participants signed informed consent prior to participation, and the data were anonymized and used exclusively for scientific purposes in accordance with data protection regulations.

In conclusion, the results of the study demonstrate that the integration of video analysis performed using Kinovea with numerical processing in Python represents an accessible and efficient method for evaluating the biomechanical parameters of the vertical jump. The proposed methodology enables rapid extraction and interpretation of relevant biomechanical indicators and can be used in educational, sports, and clinical contexts. Furthermore, the adopted digital approach facilitates the automation of analysis and provides the premises for developing biomechanical assessment systems based on data-driven methods.

CHAPTER V. Study 3. The Use of Data Extraction and Analysis Tools for Measurements Recorded Before and After a Muscle Decontracture Intervention

This study has an applied and exploratory character and aims to evaluate the immediate effects of a muscle decontracture technique on cervical mobility by measuring the range of motion before and after the intervention. The research design followed a pretest–posttest format without a control group, with two evaluation moments for each participant: before and immediately after the application of the technique. This approach allowed the rapid identification of mobility changes within a practical framework directly relevant to physiotherapy.

The main purpose of the study was to evaluate changes in the range of cervical joint mobility immediately after the application of a muscle decontracture technique, using two-dimensional video analysis with the Kinovea software. The research sought to verify whether this simple, non-invasive, and easily applicable intervention could produce significant modifications in functional mobility within a short time interval.

The sample consisted of 25 healthy participants, including 13 men and 12 women, aged between 19 and 32 years. All subjects were clinically fit, without current cervical pain, significant previous trauma, or known structural pathologies of the cervical spine. Participants were selected based on strict inclusion and exclusion criteria in order to ensure functional homogeneity of the group.

The evaluation was conducted under standardized conditions, with subjects positioned in the supine and prone positions. In both postures, participants were instructed to perform active head rotations to the left and right. The movements were recorded using a video camera positioned perpendicular to the frontal plane, and the analysis of rotation angles was performed in Kinovea. To increase measurement accuracy, visual markers were applied at the level of the chin, the bridge of the nose, and the right acromion, allowing the construction of analysis vectors and the determination of rotation angles relative to the trunk.

The procedure was applied twice for each participant: before the intervention and immediately afterward. In total, eight values were obtained for each subject: left and right rotation

in both supine and prone positions, under pre- and post-intervention conditions. The data were centralized into a single dataset and subsequently analyzed statistically.

The intervention consisted of a muscle decontracture technique involving controlled local manual pressure with a temporary ischemic effect on areas presenting hypertonus. The pressure was applied under relaxed conditions on stabilized segments, with the aim of temporarily reducing muscle tone and increasing segmental mobility. The duration of the intervention was carefully controlled to avoid adverse reactions and to maintain the safe and clinically applicable nature of the technique.

The analyzed biomechanical indicators consisted of active cervical rotation angles to the left and right in the two testing positions. Measurement comparability was ensured by using the same anatomical landmarks, the same analysis method, and identical testing conditions before and after the intervention. Values were expressed in degrees and interpreted both numerically and from a functional perspective.

Statistical analysis was performed using IBM SPSS Statistics 20, applying the paired-samples t-test. The results showed statistically significant increases in cervical mobility across all four evaluated types of movement. The mean differences were +9.5° for left rotation in the prone position, +10.5° for right rotation in the prone position, +7.4° for left rotation in the supine position, and +9.1° for right rotation in the supine position, all with p values < 0.05. These results indicate a clear positive effect of the decontracture technique on the amplitude of active cervical movements.

For a small number of participants, smaller differences between the initial and final values were observed, which can be explained by their proximity to the physiological limits of movement amplitude. In one single case, a very small negative difference was recorded, without affecting the general trend of the group.

The study was conducted in accordance with ethical principles applicable to research involving human subjects. All participants signed informed consent forms, and the collected data were anonymized and used exclusively for scientific purposes in accordance with data protection regulations.

In conclusion, the study demonstrated that the muscle decontracture technique applied through controlled local pressure produces immediate and significant increases in cervical mobility in healthy subjects. At the same time, the use of Kinovea proved effective for the objective and reproducible measurement of movement amplitude, confirming the usefulness of the method both in the evaluation of physiotherapeutic interventions and in monitoring musculoskeletal functional changes.

CHAPTER VI. Study 4. The Use of Open-Source Software as Alternative Tools for Biomechanical Analysis

This study has an applied, descriptive–comparative character and aims to evaluate the feasibility of using open-source software in the biomechanical analysis of gait. The research focused on testing the accuracy and usefulness of accessible tools for evaluating the kinematic parameters of the lower limbs in relation to the methodological requirements of contemporary biomechanical analysis. By using a standardized protocol for video capture and two-dimensional analysis, the study sought to validate practical low-cost methods applicable in clinical, educational, and sports contexts.

The main objective of the research was to evaluate the potential of open-source software to provide valid and reproducible results in gait biomechanical analysis, with particular emphasis on ankle behavior at different walking speeds. Specifically, the study aimed to measure relevant kinematic variables and verify the extent to which these data could be efficiently managed and interpreted through the integration of Kinovea, Excel, and Python. At the same time, the research aimed to develop a replicable methodological framework capable of supporting the broader accessibility of biomechanical assessment through affordable technical tools.

The research sample consisted of 10 healthy adults monitored in a physiotherapy clinic. All participants were clinically functional and had no traumatic history affecting the analyzed segments during the previous year. The subjects were recorded while walking on a treadmill under standardized conditions in order to observe and evaluate distinct phases of the gait cycle.

Data collection was performed through video recording using two cameras set at 50 frames per second (FPS), stabilized on tripods. Recordings were carried out from frontal and posterior-lateral perspectives to capture both plantarflexion and dorsiflexion movements as well as lateral ankle deviations such as talovalgus or talovarus. To improve measurement accuracy, anatomical markers were placed at the level of the Achilles tendon, the malleoli, and other relevant landmarks for ankle analysis.

The Kinovea analysis focused on four key stages of the gait cycle, coded using distinct colors, and for two of these stages the distances between the ankle joints were also measured. The

extracted data were organized into an Excel dataset structured around independent and dependent variables, including subject identification, sex, walking speed, measured joint angles, and gait cycle times for each lower limb. To facilitate numerical processing, the values were converted into degrees relative to a neutral reference of 180°, with deviations expressed from a baseline of 0°.

An important stage of the methodology involved automated data processing in Python. The data were algorithmically recoded into three deviation classes: code 1 for small deviations, code 2 for moderate deviations, and code 3 for large deviations. These codes were subsequently associated with conventional color representations in Excel, allowing rapid and intuitive interpretation of the influence of walking speed on the degree of joint deviation. Automating this stage significantly reduced processing effort and improved the reproducibility of the method.

The analyzed biomechanical indicators included plantarflexion and dorsiflexion angles, lateral ankle deviations, distances between anatomical landmarks, and the duration of stance and swing phases. These indicators were evaluated for each of the four key gait stages and at different walking speeds, providing a detailed perspective on ankle biomechanical variations under controlled conditions.

Statistical analysis revealed a non-normal distribution for most variables, confirmed by the Shapiro–Wilk test. The evaluation of skewness and kurtosis indicated the presence of asymmetric and leptokurtic distributions for a significant proportion of the variables, which justified the use of nonparametric tests and robust interpretation methods. Multivariate analysis using Pillai's Trace indicated the presence of an effect of walking speed on the dependent variables, although this effect did not reach a sufficiently high threshold to confirm a significant influence across all analyzed variables. In addition, the Spearman correlation test revealed only a few moderate relationships between walking speed and biomechanical variables, with the highest coefficient reaching 0.529.

From an interpretative perspective, the results suggested a tendency for the degree of deviation to increase with increasing walking speed; however, this effect was not uniformly observed across all variables. The numerical and color-coded representation of the data facilitated the observation of these trends and demonstrated the usefulness of combining video analysis, algorithmic coding, and visual data representation.

The study was conducted in accordance with ethical principles applicable to research involving human subjects. All participants were informed about the objectives and procedures of the study, signed informed consent forms, and the collected data were anonymized and protected according to applicable regulations.

In conclusion, the study demonstrated that the use of open-source software, particularly Kinovea, complemented by data processing in Python and organization in Excel, represents a viable alternative for biomechanical gait analysis. The proposed method enables the evaluation of relevant ankle and gait cycle parameters using accessible tools, with good reproducibility and practical applicability in physiotherapy, sports, and physical education. The results support the potential of open-source technologies in biomechanical analysis and highlight the need for future studies involving larger samples in order to strengthen the conclusions.

CHAPTER VII. Research on the Use of Kinovea and Python as Alternative and Accessible Tools for Biomechanical Analysis

Human gait represents one of the most important forms of locomotion and, at the same time, a relevant indicator of the functional condition of the musculoskeletal system. Although it appears largely automated, gait is influenced by numerous biomechanical, physiological, neurological, and environmental factors that may alter its functional parameters. In this context, biomechanical gait analysis provides valuable information regarding balance, posture, movement efficiency, and potential segmental deviations.

The premise of the present research was that accessible digital tools such as Kinovea and Python can provide results comparable to those generated by automated artificial intelligence–based applications such as Ochy in the evaluation of ankle deviations during gait. Therefore, the study aimed to validate an alternative, reproducible, and low-cost method applicable in educational, clinical, and sports contexts.

7.1. Purpose, Objectives, and Research Hypothesis

The main purpose of the research was to evaluate the reliability and applicability of alternative biomechanical gait analysis methods by comparing the results provided by the Ochy platform with those obtained through the Kinovea–Python combination. The analysis focused on ankle deviations under different testing conditions, both before and after warm-up and at different walking speeds.

The general objective consisted of determining the degree of concordance and absolute agreement between the two analytical approaches. The specific objectives included evaluating gait at speeds of 3 km/h and 6 km/h before and after warm-up, extracting ankle deviation angles, processing and coding them in Python, calculating Pearson correlations, determining the intraclass correlation coefficient (ICC), applying Bland–Altman analysis, and identifying the influence of walking speed and warm-up on the measured values.

The working hypothesis was that the analysis of ankle deviations performed using Ochy and that obtained using Kinovea with subsequent processing in Python would show strongly

correlated values, a high level of absolute agreement, and minimal bias between the two methods under all testing conditions.

7.2. Research Methodology

The research was conducted on a sample of 30 healthy adults aged between 19 and 35 years, without evident motor dysfunctions or pain symptoms at the time of testing. Participants were selected in order to represent a functionally healthy group suitable for comparative gait analysis.

The tests were performed in a physiotherapy laboratory using a motorized treadmill set at two walking speeds: 3 km/h and 6 km/h. Each participant was tested under the same methodological conditions, both before and after a standardized warm-up sequence designed according to educational principles in physical training and consisting of general activation exercises, joint mobilization, muscular activation, and gradual re-adaptation to effort.

Video recordings were performed using a Canon EOS M50 camera positioned posteriorly in the plane of interest in order to capture the body segment from the pelvis to the distal region of the lower limbs. The analysis focused on two key moments of the gait cycle: the final part of the stance phase and the moment of heel contact. For each foot, the ankle deviation angles were extracted relative to visible anatomical landmarks.

7.3. Instruments and Data Processing

Four main tools were used in the analysis: Kinovea 0.9.5 for manual extraction of joint angles, Ochy for automated artificial intelligence–based analysis, Microsoft Excel for data organization, and Python for recoding and standardizing the values. Statistical analysis was performed using IBM SPSS Statistics 20.

The data were organized according to foot, walking speed, testing moment, and analysis method. In Python, the angular values obtained from Kinovea were recalibrated relative to the neutral reference position of 180°, with deviations expressed from a baseline of 0°. Medial and lateral deviations were coded using positive and negative signs, and the values were subsequently grouped into three severity classes: minimal deviations (0°–9.99°), moderate deviations (10°–24.99°), and pronounced deviations (≥25°). The numerical coding was complemented by a color-coding system in Excel to facilitate visual interpretation of the data.

This processing stage enabled the standardization of the dataset and allowed the same algorithm to be applied rapidly to new sets of values, increasing reproducibility and significantly reducing the time required for analysis.

CHAPTER VIII. Results Obtained and Statistical Processing of the Research Results

To evaluate the relationship and agreement between the analysis methods used, several statistical procedures were applied: the paired-samples t-test, the Pearson correlation coefficient, the intraclass correlation coefficient (ICC), and Bland–Altman analysis.

8.1. Results

The results revealed very strong correlations between the values provided by Ochy and those extracted using Kinovea across all experimental conditions. For walking at 3 km/h before the warm-up protocol, the Pearson correlation coefficients were 0.908 for the left foot and 0.909 for the right foot. After warm-up, at the same speed, the correlations increased to 0.957 for the left foot and 0.987 for the right foot. At the speed of 6 km/h after warm-up, the Pearson coefficients remained extremely high: 0.986 for the left foot and 0.977 for the right foot. All correlations were statistically significant ($p < 0.001$).

The intraclass correlation coefficient analysis confirmed excellent agreement between the two methods. The ICC value for single measurements was 0.956, while the ICC for average measurements reached 0.978, both with narrow confidence intervals and high statistical significance. These results indicate a very high level of reliability and support the comparable use of the two methods in the analysis of ankle deviations during gait.

The Bland–Altman analysis showed a very small bias between the two methods, generally close to 0°, with no systematic tendency toward overestimation or underestimation. The limits of agreement varied approximately between ±1.5° and ±4.5°, depending on the experimental condition. The best agreement values were observed after warm-up, particularly at the walking speed of 3 km/h for the right foot, where the bias was approximately 0.157° and the limits of agreement were narrow. Overall, these results indicate very good agreement between the methods and suggest the possibility of using them interchangeably in functional gait analysis.

8.2. Discussion

The obtained results confirm the main hypothesis of the research and demonstrate that accessible digital tools such as Kinovea and Python can produce results very close to those

generated by an automated artificial intelligence–based commercial platform such as Ochy. The high Pearson and ICC values, together with the minimal bias identified through Bland–Altman analysis, support the reliability and validity of the proposed methodological approach.

Although Ochy offers the advantages of automation and rapid processing, the results do not always justify the difference in cost compared with Kinovea, especially when the analysis is conducted rigorously and under standardized conditions. Kinovea, combined with data processing in Python, provides methodological transparency, control over the analysis process, and the possibility of customizing procedures, which makes it particularly valuable in academic, clinical, and sports environments with limited resources.

On the other hand, the use of Kinovea requires a certain level of operator experience, which may introduce variability between evaluators. However, this limitation can be reduced through appropriate training and the standardization of recording and analysis procedures.

8.3. Final Conclusions of the Research

The research demonstrated that there is a very high level of agreement between the biomechanical analysis of ankle deviations performed using the Ochy platform and that obtained through Kinovea with subsequent processing in Python. Correlations between the methods were very strong across all testing conditions, ICC values indicated excellent reliability, and Bland–Altman analysis revealed minimal mean differences and acceptable limits of agreement for gait analysis.

Therefore, the results confirm that the combined use of Kinovea and Python represents a reliable, accessible, and reproducible alternative for biomechanical gait analysis, comparable to more expensive automated solutions. This conclusion supports the overall objective of the thesis, namely the development and validation of alternative and accessible methods for biomechanical analysis applicable in research, physiotherapy, physical education, and high-performance sports.

8.4. Limitations and Future Perspectives

Among the main limitations of the study are the relatively small sample size, which restricts the generalization of the findings to other population categories, and the use of a video recording frequency of 50 fps, which is sufficient for gait analysis but potentially limiting for faster or more

complex movements. Additionally, the manual extraction of data in Kinovea introduces a possible source of operator-dependent variability.

Future research may extend the study to other categories of subjects—such as elite athletes, elderly individuals, children, or patients with locomotor disorders—and may include comparisons with three-dimensional biomechanical analysis systems. Furthermore, the development of semi-automated procedures for Kinovea and the investigation of inter-rater reliability could further strengthen the practical applicability of the proposed method.

General Conclusions of the Thesis

The present doctoral thesis aimed to develop, test, and validate alternative, accessible, and reproducible methods of biomechanical analysis, primarily using the open-source software Kinovea and the Python programming language, complemented by other digital tools such as Excel and SPSS. The research was motivated by the increasing need to democratize access to biomechanical evaluation, given that traditional biomechanical laboratories remain expensive, difficult to access, and challenging to use in everyday applied contexts.

The theoretical foundation highlighted the complexity of human gait and the need for an integrative approach that considers the functional role of the ankle, knee, hip, and spine, as well as the biomechanical models that explain movement organization and energetic efficiency. In this context, the use of accessible digital tools proved to be both scientifically justified and practically relevant.

The results of the applied studies included in the thesis consistently support the methodological value of the Kinovea–Python combination. The studies dedicated to extracting biomechanical data using Kinovea and processing them in Python demonstrated that relevant parameters regarding joint angles, movement symmetry, segmental deviations, and motor performance can be obtained in a clear, reproducible, and easily interpretable manner. In the case of the vertical jump, the method enabled the identification of functional and postural patterns, including different tendencies in knee alignment depending on sex, as well as relationships between segmental positioning and biomechanical performance.

The study concerning cervical mobility demonstrated that video analysis using Kinovea can objectively capture functional changes produced immediately after a muscle decontracture intervention. The statistically significant increases in cervical rotation amplitude confirmed both the effectiveness of the applied technique and the usefulness of accessible digital tools in evaluating therapeutic interventions.

The study investigating the use of open-source software for gait analysis showed that, although the sample size was limited, the volume and complexity of biomechanical data can be efficiently managed through the integration of Kinovea, Excel, and Python. This approach enabled

the standardization and coding of values and allowed the identification of trends in ankle deviations relative to walking speed.

The central research component of the thesis, which compared the Ochy platform with the Kinovea + Python combination, represents the main original contribution of the work. The results revealed very strong correlations between the two analytical approaches under all testing conditions, both before and after warm-up and at different walking speeds. The high values of the Pearson correlation coefficient and the intraclass correlation coefficient, as well as the minimal bias identified through Bland–Altman analysis, support the conclusion that the proposed alternative methods are reliable and, in many situations, comparable with more expensive automated tools.

Consequently, the research hypotheses formulated at the beginning of the thesis were largely confirmed. Two-dimensional video analysis performed with Kinovea under standardized conditions allows adequate estimation of joint angles and relevant functional parameters. Numerical processing using Python significantly contributes to the objectification, standardization, and interpretation of the data. The combined method can highlight functional differences between subjects and testing conditions and may represent a viable alternative in educational, sports, and clinical contexts.

The main contribution of the thesis lies in validating a biomechanical analysis methodology based on accessible, free, and extensible tools capable of providing useful data for functional movement evaluation. Beyond the specific results, the work proposes a practical methodological model that may reduce dependence on traditional laboratory infrastructure and facilitate the integration of objective assessment into the professional activity of specialists in physiotherapy, physical education, and sports.

At the same time, the thesis highlights the educational dimension of this approach. Integrating competencies in video analysis, data processing, and programming into the training of movement science specialists may contribute to developing a data-driven culture of objective evaluation and increasing professional autonomy in resource-limited contexts.

Overall, the research confirms that the use of Kinovea and Python as alternative and accessible tools for biomechanical analysis represents not only a practical technical solution but

also a solid methodological direction with real potential for development in applied research and professional practice.

Limitations of the Research

Although the results obtained in this research confirm the validity and usefulness of accessible digital tools in biomechanical analysis, several limitations must be acknowledged.

The first limitation concerns the relatively small sample size used in the main research component. Although the group of 30 participants allowed the necessary statistical analyses and the identification of significant results, extending the study to larger samples would allow stronger generalization of the conclusions and a more complex evaluation of individual variability.

Another limitation is related to the technical characteristics of the video capture system. The recordings were performed at approximately 50 frames per second, which is sufficient for normal gait analysis but may limit measurement precision in faster or more complex movements. Future research could benefit from the use of cameras with higher frame rates to improve biomechanical analysis accuracy.

Additionally, the manual extraction of angles in Kinovea introduces a certain dependence on operator experience. Even though analysis procedures were standardized, minor inter-evaluator variations may occur. Compared with fully automated platforms, this characteristic may represent an additional source of variability.

Another limitation lies in the fact that biomechanical analysis was performed in two dimensions (2D). Although this approach is adequate for many practical applications, three-dimensional biomechanical systems provide a more comprehensive description of segmental movements and can capture aspects that are not visible in a two-dimensional plane.

Furthermore, the research focused exclusively on healthy subjects without locomotor disorders. Therefore, the results cannot be directly generalized to clinical populations or individuals with musculoskeletal pathologies without additional targeted studies.

Practical Recommendations

Based on the results obtained in this research, several practical recommendations can be formulated for the use of digital tools in biomechanical analysis.

First, the use of the Kinovea software is recommended in educational settings, applied research environments, sports clubs, and physiotherapy clinics that do not have access to complex biomechanical laboratories. The software provides a free and efficient solution for video-based movement analysis, provided that standardized recording and analysis procedures are followed.

Second, integrating the Python programming language into the data processing stage can significantly contribute to automating analyses, reducing human error, and increasing the reproducibility of results. The use of simple algorithms for coding and classifying biomechanical data facilitates rapid interpretation and enables efficient management of large datasets.

It is also recommended to standardize recording conditions, including camera positioning, lighting conditions, capture frequency, and equipment stabilization, in order to reduce data variability and improve measurement accuracy.

In professional practice, the methods presented can be used to monitor patient progress in physiotherapy, analyze sports techniques, and evaluate functional movements in educational contexts

Future Research Perspectives

The results of this research open several directions for future development.

One important direction would be extending the study to larger and more diverse samples, including different age groups, elite athletes, or individuals with musculoskeletal disorders. Such studies would allow evaluation of the applicability of the method in clinical contexts and could contribute to developing functional assessment protocols adapted to various pathologies.

Another relevant direction involves comparing two-dimensional video-based methods with three-dimensional biomechanical analysis systems in order to more precisely evaluate the level of agreement between accessible methods and laboratory-based technologies.

Additionally, further development may include creating semi-automated analysis procedures within Kinovea or developing Python scripts that reduce the time required for data extraction and minimize operator influence on the results.

Another promising perspective involves integrating artificial intelligence technologies into accessible video analysis so that the process of identifying anatomical landmarks and calculating joint angles becomes more automated and precise.

Overall, the research highlights the considerable potential of accessible digital tools in biomechanical analysis and opens new perspectives for developing modern, efficient, and democratized methods for evaluating human movement.

Original Contributions of the Doctoral Thesis

This doctoral thesis brings several original contributions to the field of biomechanical analysis of human movement by developing and validating accessible biomechanical evaluation methods based on open-source digital tools. These contributions are evident both at the methodological and applied levels through the integration of modern digital technologies into functional gait analysis and other human movements.

A first original contribution consists of developing and validating an integrated biomechanical analysis methodology based on the combined use of the Kinovea software and the Python programming language. This approach enables the extraction of kinematic parameters from video recordings and the subsequent processing of data in a standardized, reproducible, and efficient manner, providing a viable alternative to traditional and significantly more expensive biomechanical systems.

Another important contribution is the development of a biomechanical data processing and coding protocol using Python. By recalibrating angular values relative to the neutral position and classifying them according to severity intervals, the research proposes a simplified method for interpreting segmental deviations. The numerical and color-coded representation of values allows intuitive visualization of results and facilitates rapid identification of biomechanical trends under different experimental conditions.

The thesis also introduces an original comparative analysis between a commercial artificial intelligence–based platform (Ochy) and an open-source alternative method (Kinovea + Python). The results demonstrated very strong correlations and excellent agreement between the two approaches, confirming that free digital tools can produce results comparable to those obtained with automated commercial applications.

Another relevant contribution of the research consists in highlighting the role of warm-up in stabilizing biomechanical gait parameters. The comparative analysis performed before and after warm-up showed that angular values become more consistent following preparation for physical effort, suggesting a positive influence of warm-up on motor control and segmental stability.

An additional innovative aspect of the thesis is the integration of video analysis, data processing, and programming skills into the field of movement science. This interdisciplinary approach proposes a modern model of research and professional training in which biomechanical analysis no longer depends exclusively on specialized laboratories but can also be performed using accessible digital tools.

From an applied perspective, the thesis provides a methodological framework that can be used in physiotherapy, physical education, high-performance sports, and applied biomechanical research. The proposed method enables objective evaluation of movement, monitoring of functional progress, and analysis of sports techniques using relatively simple equipment and free software.

Through these contributions, the research supports the idea of democratizing access to biomechanical analysis and highlights the potential of open-source technologies in developing modern, efficient, and reproducible methods for evaluating human movement.

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