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Survey on Video-Based Biomechanics and Biometry Tools for Fracture and Injury Assessment in Sports

Vanessa E. Ortiz-Padilla †, Mauricio A. Ramírez-Moreno †, Gerardo Presbítero-Espinosa †, Ricardo A. Ramírez-Mendoza and Jorge de J. Lozoya-Santos *

Mechatronics Department, School of Engineering and Sciences, Tecnologico de Monterrey, Av. Eugenio Garza Sada 2501 Sur, Tecnológico, Monterrey 64849, Mexico; a00822903@itesm.mx (V.E.O.-P.); mauricio.ramirezm@tec.mx (M.A.R.-M.); presbitg@tec.mx (G.P.-E.); ricardo.ramirez@tec.mx (R.A.R.-M.)

* Correspondence: jorge.lozoya@tec.mx

† These authors contributed equally to this work.

Abstract: This work presents a survey literature review on biomechanics, specifically aimed at the study of existent biomechanical tools through video analysis, in order to identify opportunities for researchers in the field, and discuss future proposals and perspectives. Scientific literature (journal papers and conference proceedings) in the field of video-based biomechanics published after 2010 were selected and discussed. The most common application of the study of biomechanics using this technique is sports, where the most reported applications are american football, soccer, basketball, baseball, jumping, among others. These techniques have also been studied in a less proportion, in ergonomy, and injury prevention. From the revised literature, it is clear that biomechanics studies mainly focus on the analysis of angles, speed or acceleration, however, not many studies explore the dynamical forces in the joints. The development of video-based biomechanic tools for force analysis could provide methods for assessment and prediction of biomechanical force associated risks such as injuries and fractures. Therefore, it is convenient to start exploring this field. A few case studies are reported, where force estimation is performed via manual tracking in different scenarios. This demonstration is carried out using conventional manual tracking, however, the inclusion of similar methods in an automated manner could help in the development of intelligent healthcare, force prediction tools for athletes and/or elderly population. Future trends and challenges in this field are also discussed, where data availability and artificial intelligence models will be key to proposing new and more reliable methods for biomechanical analysis.

Keywords: biomechanics; biometry; video analysis; force estimation; digital tracking

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Citation: Ortiz-Padilla, V.E.; Ramírez-Moreno, M.A.; Presbítero-Espinosa, G.; Ramírez-Mendoza, R.A.; Lozoya-Santos, J.d.J. Survey on Video-Based Biomechanics and Biometry Tools for Fracture and Injury Assessment in Sports. *Appl. Sci.* **2022**, *12*, 3981. https://doi.org/10.3390/app12083981

Academic Editors: Antonio Parziale, Rosa Senatore, Nicole Dalia Cilia and Ana Paula Betencourt Martins Amaro

Received: 18 February 2022
Accepted: 4 April 2022
Published: 14 April 2022

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1. Introduction

1.1. Biomechanics and Biometry

Biomechanics is the field where the movements of a living body are studied from a mathematical and physics perspective for different purposes, such as ergonomy, healthcare, sports, among others [1]. Research in biomechanics in the sports science field has allowed the development of important applications for improvement in healthcare and human performance [2]. Meanwhile, Biometry refers to the development and implementation of statistical and mathematical methods for data analysis solutions to problems in the biological sciences field [3]. Biomechanics and biometry are similar in the sense that they analyze biological information with mathematical methods to generate a solution. The aforementioned areas have allowed to develop biomechanical tools for digital joint tracking [4], joint-range associated injury prevention and rehabilitation [5], athlete's technique assessment and correction [6], among others.

For several years, biomechanical studies have assessed the existing risk of developing fractures and injuries generated from high-performance sports activities. Among the types

of fractures formed in sports activities, the formation of stress fractures stands out. A stress fracture is defined as a "partial or complete fracture of bone due to its inability to withstand non-visible stress applied in a rhythmic, repeated, sub-threshold manner" [7]. There is not a precisely defined mechanism for the initiation of stress fractures, although it is known that when surrounding muscles become fatigued, they concentrate excessive forces over the zones surrounding the bone, generating microcracks.

1.2. Risk of Fractures and Injuries in Sports

When microcrack formation exceeds bone remodeling, these accumulate and grow towards threshold lengths, which cause the formation of macro fractures consisting of measures approximating 1 mm, to provoke the final rupture through the bone cortex. In high-intensity sports, fatigue injuries compose 20% of the total injuries [8], while in the military, they can be as high as 31% [9]. These fractures locate mainly in the tibia and fibula in long-distance runners [10].

Tibia is the most frequently fractured bone during sports activities, after sustaining five to six times the body weight [11]. The sports where this type of fracture occurs more commonly are classical ballet, aerobics, tennis, basketball, football, volleyball. After tibial shaft (40.3%), the cases of fractures in athletes due to stress include rib (15.8%), metatarsal bone (9.7%), ulnar olecranon (8.2%), pubic bone (5.6%), fibular shaft (4.6%), tibial medial malleolus (4.1%), and other types of bones (11.8%) [12]. In general, ref. [13] reported metatarsal fatigue fractures to consist of 38% of all the bone stress injuries and even 58% in the military.

Furthermore, studies have reported measurement and prevention of the development of stress fractures due to sports activities. Some of these include the analysis of using shock-absorbing insoles, basketball shoes, training modifications, and calcium supplements [14].

In soccer, the metatarsal bone has to be studied, and its risk for developing fatigue injuries. In this regard, refs. [15,16] affirmed these types of fractures included almost 78% of all stress fractures that occurred in a European League from 2000 to 2009, involving refracturing in 27% of the cases, and even not full recovery in 14% of them. Hence, this type of injury can lead to high risks of a career-ending decision [17].

Moreover, several studies exist regarding the involvement of stresses in the fifth metatarsal region towards developing fatigue fractures. Among these, one of the first studies in football involving repetitive loading is presented in [18]. In this work, athletes developed fractures in the fifth metatarsal while performing kicking and cutting movements. Other studies include: plantar pressure influences the risk of injuries [19]; specific action against static motions for detecting discrepancies in lateral foot loadings [20]; plantar forces at the lateral forefoot between healthy and fractured players [21]; more tendency to fracture for the case of a non-preferred foot [22]; explanations regarding static plantar pressure measurements to be not efficient in assessing fatigue injury risks [23]; specific regions within the foot showing higher pressures in the non-preferred feet of football players [24]; longer fifth metatarsal and higher medial longitudinal arch in the case of fractured against healthy players [25], among other studies.

In [26], authors reported analysis regarding the use of deterministic models to study biomechanics to improve movement performance and injury risk reduction. This type of models help to determine the relationship between a movement outcome measurement and the biomechanical parameters involved in such measure. Typically, block diagrams and equations are used to understand the relationship of variables, and provide its numerical representation respectively [26]. Another work makes use of video processing software, with a front and lateral view analysis in stroke to highlight errors towards proper instruction and minimize injury risk [27].

A study focused on the shoulder biomechanics in swimming [28] concluded supraspinatus tendinopathy was the most common cause of shoulder pain, suggesting that a proper evaluation involves the entire kinetic chain. Another relevant study regarding the inclusion of strategies for the prevention and treatment focusing on swimmers´ shoulders is

presented in [29]. Other research studies involving swimming biomechanics analysis are included in Table 1.

Table 1. Video-based biomechanics tools reported in the literature. For each specific study, the Sport, Method/Software and Analysis implemented is presented.

Reference	Sport	Method/Software	Analysis
[30]	High-jump	Pixel segmentation	Biomechanical analysis on risks and cases of Achilles tendon injury in high-jump attempts.
[31]	Australian football	Head of an instrumented Hybrid III anthropomorphic test device (ATD),	Head impact exposure and concussion risk under video analysis
[32]	Australian football	X-Patch	Head acceleration measurements and impacts by video analysis
[6]	Baseball	High-speed motion analysis	Two-dimensional biomechanical analysis use in assessing proper pitching techniques
[33]	Basketball	Video analysis software	Risk factors and causes of Achilles tendon (AT) ruptures in NBA players.
[34]	Equestrian Sports	Kinovea 0.8.20; Head Impact Telemetry (HIT) System	Helmet impact mechanics; concussion thresholds.
[35]	American football	Optical motion capture system (Vicon, Los Angeles, CA)	Helmet head protection. Kinematics among head and helmet.
[36]	American football	Head impact sensors	Review on the concussion biomechanics and use of head impact sensors.
[37]	Gaelic field sports	Scoring Gray Cook	Normative reference values from the study of functional movement
[38]	Ice Hockey	Head Impact Telemetry (HIT) System	Identification of per-game frequencies of head impacts and concussions
[39]	Rugby	Manual digitizing Vicon Motus V9, Vicon Motion Systems, USA	Prevention for chronic injuries, towards safer engagement conditions
[40]	Alpine Skiing	Consensus decision by experts	Injury mechanisms descriptions of anterior cruciate ligament (ACL) injury during competition
[41]	Snowboard	Consensus decision by experts	Snowboard cross (SBX) descriptions of injury mechanisms
[42]	Football	Consensus decision by experts	Kinematics and frequency cases of ACL injuries in professional Italian football
[43]	Football	Kinovea software, consensus decision by experts	Approach for intra-articular lesions by late phases of ACL injury
[44]	Football	Force plate Type 9285, Kistler Instruments, high-speed camera	Injury risk by hip loading under diving in goalkeepers
[45]	Football	Consensus decision by experts	ACL injury cases and contact mechanisms
[46]	Volleyball	Dartfish motion analysis software	Improving landing techniques to prevent ACL injuries
[47]	Volleyball	Visual3D tracking system	Wearing ankle braces effect and tendency to injury development
[48]	Baseball	Stalker pro radar gun (Stalker Radar, Plano, TX, USA)	Biomechanics of the stride length and knee angle with high ball speeds
[49]	Beach volleyball	Peak Motus Software (Version 9, Vicon Motion Systems. Inc.)	Biomechanics of float serve
[50]	Rugby	Kinovea (v.0.8.15)	Biomechanics of sprint initial steps

Table 1. *Cont.*

Reference	Sport	Method/Software	Analysis
[51]	Football soccer	Ariel Performance Analysis System (Ariel Dynamics, Trabuco Canyon, CA, USA)	Measurement of soccer goalkeeper punt kick optimum projection angle
[52]	Swimming	Kinovea software (Version 0.8.15)	Biomechanics on the optimal start performance in backstroke swimming
[53]	Swimming	Accelerometer waterproof X6-2mini (Gulf Coast Data Concepts, Waveland, MA, USA); Sensors	Multiple sensor systems for biomechanical analysis in front crawl swimming
[54]	Swimming	24 anatomical markers; linear transformation algorithm	Use of differing handgrips in backstroke swimming start performance
[55]	Swimming	Ariel Dynamics Inc., San Diego, CA, USA	
[56]	Swimming	Digitizing system (FrameDIAS V, DKH, Inc., Itabashi-ku, Tokyo, Japan)	Involvement of center of mass and flight distance in a proper track start
[57]	Swimming	Inertial sensors	Analysis of the use of inertial sensors and detection algorithms in swimming phases
[58]	Swimming	SIMI Motion 7.2 software (SIMI Reality Motion Systems GmbH, Unterschleißheim, Germany)	Biomechanics of the leg to arm coordination in unilateral arm amputee swimmers
[59]	Swimming	"Cinalysis" software (Elipot et al., 2010)	Use of software for auto-digitization and proper analysis of glide posture
[60]	Swimming	Wearable measurement system including six IMUs (Physilog R IV, GaitUp, CH)	Motion phase approach for covering the analysis of full swimming training sessions
[61]	Swimming	Dartfish software	Effect of aerobic training towards the increasing of swimming speed
[62]	Taekwondo	Vicon Motion Capture System, Los Angeles, CA, USA	Kinematic characteristics for improving roundhouse kick technique performance
[63]	Taekwondo	LINCE v.1.2.1 software	Analysis of technical and tactical move patterns towards scoring during combat
[64]	Taekwondo	Kwon3D XP Motion Analysis Suite (Version 4.1, Visol, Seoul, Korea)	Target distance analysis during Taekwondo roundhouse kick movement
[65]	Taekwondo	Kinovea, version 0.8.25	Analysis on the levels of anxiety and mental challenge during fighting in competition

Given the aforementioned context, it is clear that smart tools for fracture prevention in sports would benefit greatly the field of sports sciences. The same tool could have important impact in elderly healthcare [66]. A plausible solution for this method is the combination of artificial intelligence (AI) and biomechanics. The combination of AI and video-based biomechanics tools could foster the development of intelligent methods for fracture prevention in athletes and/or for the elderly, by predicting risk of fracture via video assessment of body movements [67].

In this study, we focused on the analysis of scientific literature which describes video-based biomechanics tools in different sports. A categorization (see Table 1) was performed on the selected literature based on the sport, software and analysis used, which can be provide researchers in the field a notion of the current state of art. Special attention was given to sports with high-risk of development of fractures and injuries such as football (soccer), and swimming.

Difficulties and challenges for the development of the present work included the absence of existing studies towards the accurate prediction modalities of applied stresses in focused in specific bones and joints with tendencies for fracturing by fatigue. As far as the authors of this work know, this is the first time that it has been shown that it is possible

to measure the concentration of stresses in determined body joints from videos. Work was carried out on the establishment of a relatively simple tracking modality to apply, where, from videos on body movements it will be possible to establish variables of considerable importance such as force, acceleration, and position, towards the correct estimation of stresses generated in areas fracture tendency in bones and joints.

This paper opens the possibility of developing determined stress calculations on specific areas where fatigue fractures are possible, such as joints and bones. The case studies presented in this paper show that it is possible to estimate forces, acceleration, and positions by the analysis of body movements through video recordings of athletes in various disciplines. These estimates will allow shortly to establish prediction models for fatigue injuries towards the prevention of fatigue fractures in sports in which specific fatigue fractures are common. A simple modality for tracking movements performed by athletes is reported and will allow soon to estimate the conditions of physical motions towards the correct implementation of training routines, minimizing the possibility of developing fatigue fractures.

Section 2 presents applications and uses in different fields for video-based biomechanics (movement, injury prevention, sports and ergonomy). Section 3 shows three examples (case studies) of the proposed video assessment; then in Section 4 a roadmap of the current worldwide state of the field, and a perspective of future opportunities respectively is presented. Finally, Section 5 closes with the conclusions of the paper.

1.3. Video-Based Biomechanics

Biomechanical analysis can be performed by either video and/or kinematic sensors. In video analysis, 3D and 2D are typically found in the literature, as well as depth detection images [5,68,69]. In these types of procedures, in some cases, optical markers are used to detect different body parts and thus detect their position in real time in a given coordinate frame [70]. Some of the most used sensors in the literature to represent human kinematics are: electromagnetic, acoustic, and inertial sensors, Kinect platform (RGB, depth sensors, IR, accelerometers, and microphones), as well as mobile applications [70]. While different sensors provide useful information, video analysis is typically preferred by non-specialized customers because the outputs of the models, expressed as angles or coordinates which complement the videos, are easier to understand [6].

Video analysis for biomechanical purposes has been increasing in recent years. Depending on the complexity of the desired model, this type of analysis can be performed manually, by manually selecting the positions of relevant body parts at different video frames, or automatically, by involving image recognition/processing algorithms to perform this procedure in an automated manner [71]. Although manual digitizing is not often considered as a difficult process, when analyzing large videos with several frames, it becomes a time-consuming task which could be solved in a more efficient way by an algorithm. Other more simple video analysis have been reported in the literature to assess concussions in Australian football [72] and bicycle accidents [73], however also require manual supervision and thus, are time-consuming.

3D Video analysis involving multiple cameras allow to perform three-dimensional reconstructions of the environment, thus obtaining three-dimensional position, speed, and acceleration measurements in human models. 3D video analysis is usually referred to in biomechanics as the gold standard due to its precision and degree of information provided [6]. However, expensive, and specialized software and equipment are needed to perform this type of analysis. Even more so if the analysis is performed using optical markers.

Biomechanical analysis through 2D video offers a relatively simple and low-cost solution to analyze human motion, as it can be easily performed using cellphones, and low-cost cameras. Hence, making biomechanical analysis feasible to general users outside laboratory-like environments, which makes it appealing for risk assessment and training in sports, medical and industry fields. The downside of video analysis is that proper setup about the angle and environmental lighting of the films need to be considered to obtain

reliable measurements. However, many studies in the literature have reported successful biomechanical analyses using 2D video protocols, such as race walking, vertical jump squats, baseball pitching, martial arts [6,68,70,74]. Some of the studies also compare the performance of 2D vs 3D video analysis and report no significant differences between both when using proper filming setups [5,74,75].

Marker-less image processing algorithms offer a solution for automated biomechanical assessment for low-cost video analysis. Some of the reported algorithms include image processing techniques such as model reconstruction from multiple views using silhouette recognition algorithms [71] and 2D stick-like models of the human body based on polynomial regression [76].

1.4. Software

Different softwares are available for biomechanics research. This section describes briefly few softwares commonly used in this field, while a more detailed description can be found in Table 2. An open source tool, Biomechanical ToolKit, based in Python language for biomechanical analysis is presented in [77]. Conventional softwares for Biomechanical analysis include Vicon [78], Kinovea [79], Coach'e eye, Dartfish [4], Tracker [80], and SkillSpector [81]. OpenSim allows its users to create and analyze dynamic simulations of movement [82]. A Matlab package for biomechanical analysis has also been described, such as the BoB (Biomechanics of Bodies) [83]. It is based on m-coding, so it is specific to the Matlab environment. FeBio allows to implement finite element analysis for biomechanics on rigid solids [84].

Table 2. Softwares used for Video-based Biomechanics research and their distinctive features.

Software	Ease of Access	Distinctive Features
Kinovea	Open source	Utilities to capture, slow down, compare, annotate and measure motion in videos.
Dartfish	Monthly subscription	Available for PC and cell phone. Allows to annotate, compare videos, perform angle measurements.
SkillSpector	Free software	Manual digitization of joints and transformation to real coordinates using DLT transform. Can handle 2D and 3D movement analysis. Advanced analysis of linear and angular kinematic data, inertia calculation, 3D movement animations, and video calibration.
Coach's Eye	Paid app, available on iOS, Android and Windows	Interactive and user-friendly GUI for sports assessment. Slowmotion and playback functions.
Tracker	Open source, continuously updated	Automated tracking based on image recognition which can help in marker-less studies. Ample data analysis tools.
Biomechanical Toolkit	Open source, Python-based	Several online repositories, ease of communication with data formats from other softwares used in biomechanics research.
OpenSim	Open source	Development of models of musculoskeletal structures and generation of dynamic simulations.
Vicon	Paid	High-tech software and algorithms. Multiple solutions for different needs of the research and athletes, both marker-less and with markers.
Ariel Performance Analysis System	Free software	3D motion analysis system. Automated biomechanical analysis from multiple, simultaneous video recordings. Can integrate information of EMG, force platforms and video.
Visual3D	Free and paid options	Users can import motion and force data and perform computations, transformations, models and analysis with reports.

2. Discipline and Uses

2.1. Movement Studies

Biomechanical analyses have been used in various areas of study, including the study of body movement in postures of specific actions [85], body coordination [86], speed or impact force on diverse regions of the body, among others. The applications of such studies can help to understand better the human body and its movement from a clinical point of view; for example, when a person is subjected to different forces or circumstances, either while walking [87], jogging, running, or notable differences in various diseases or disabilities. It can also be applied in sports, to carry out an extensive analysis of sports techniques [88] and the consideration of certain factors such as weight or height to test the accurate effectiveness at a competitive level [89], or for the design of sports equipment that can meet the true needs of athletes.

2.2. Injury Prevention

Biomechanical analysis can also be applied to injury prevention, where biomechanical studies are carried out to identify actions and movements that stress certain areas of the body, and are shown affected by factors such as torque, impact force, coordination, among others, and how this can contribute to the development of physical damage and possible injury [90]. It is also used for the study of diverse diseases and further exploration for a proper and fuller understanding of said disease [91]. In addition, through the previously mentioned analyses, alternative processes for the diagnosis and management of these diseases and injuries can be found.

2.3. Sports

The analysis of biomechanics using video in sports is very well documented in the literature. The study of different biomechanical features in several sports have been reported in the literature. In Table 1, a list of studies are presented, describing the analyzed sport, software and analysis used. Among the most common sports are: Australian Football, American Football, Soccer, Volleyball, Swimming and Taekwondo. High-jump, Baseball, Basketball, Gaellic Sports, Rugby, Alpine Skiing, Snowboarding and Rugby are also included, although in less quantity.

2.4. Ergonomy

Biomechanical analyses have also been implemented in the ergonomics field. Ergonomics is an important factor to consider in different daily life activities, such as load handling [92], laptop carrying [93] and use, backpack carrying [94] and office work [95]. It is important for employers and companies to ensure their workers' safety and comfort during specific tasks. In manual labor, injuries associated to tasks such as load handling can represent important direct and indirect medical costs to companies around the world [92]. A biomechanical analysis of spinal forces during load handling was implemented in [92] to calculate the safest and most comfortable position to perform load handling, by measuring EMG signals in muscles in the back and neck.

The use of laptop in no-desk settings has also been reported as uncomfortable in the literature, and some authors agree that ergonomy needs to be taken into account in the design of such devices [93]. Specifically, during the COVID pandemic, a great amount of people were forced to work from home; some without appropriate office equipment, which increases this ergonomics problem. Back pain problems have also been linked to prolonged standing or sitting while working. A recent study analyzed the use of a sitting-standing approach where participants were able to alternate between sitting and standing while performing specific tasks [95]. Discomfort levels and biomechanical parameters were obtained and compared between prolonged sitting or standing and the sitting-standing approach. The results showed lower back discomfort levels when using the sitting-standing approach, while productivity was not affected.

Among the revised literature, different methods, applications, scopes of analysis and challenges in the field of biometry and biomechanical analysis of body movement were identified; all of which were organized in the taxonomy presented in Figure 1.

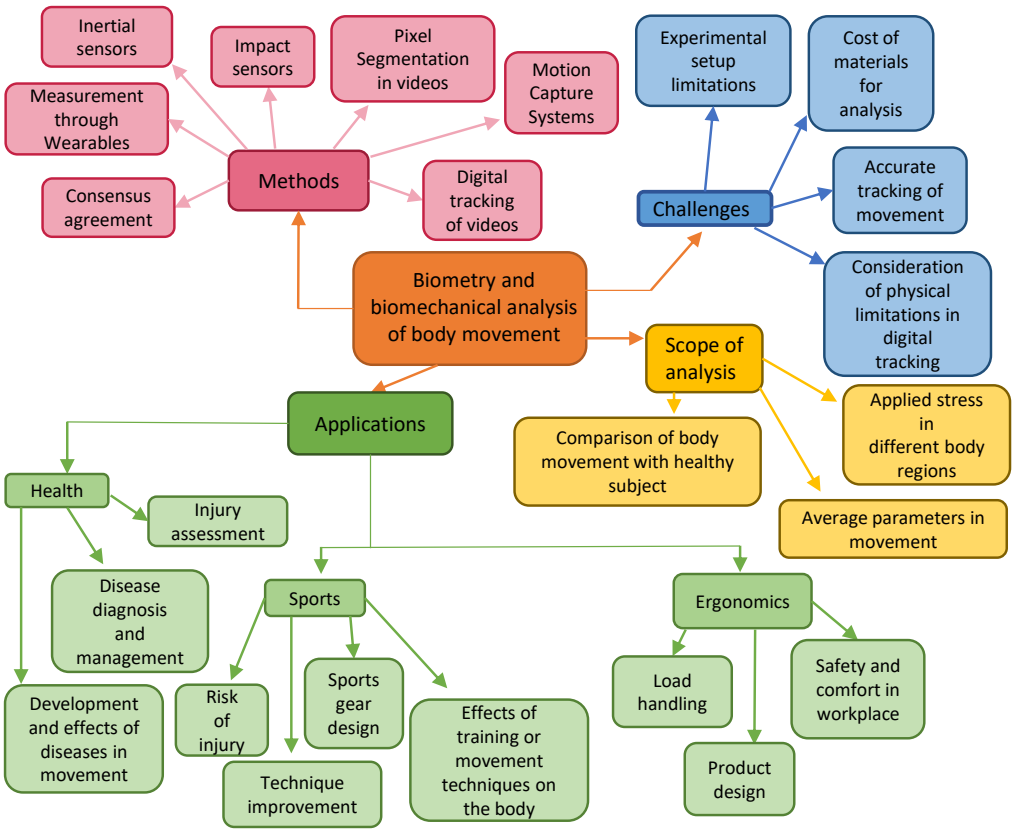


Figure 1. Taxonomy of the revised literature for methods, applications, scopes of analysis and challenges in Biometry and biomechanical analysis of body movement.

3. Case Studies

It can be observed in Table 1 that among the reported studies in the literature when it comes to the analysis of biomechanical parameters in sports using video; swimming, taekwondo and football soccer are among the most common. In this work, three case studies were selected to analyze specific movements and techniques of such sports due to their presence in sports biomechanics studies.

A manual joint tracking approach was used, and an analysis of kinematic parameters was implemented on the video-based data analysis system SkillSpector. SkillSpector software was used because it allows to manually digitize positions of human joints in videoframes, and to perform a pixel-coordinate transformation to obtain the real-world positions of each digitized joint using the Direct Linear Transform (DLT) after a calibration process [96]. In each case study, joints of interest were manually selected in SkillSpector (digitized) in a set of frames where athletes performed a given technique from each Sports Calculations on desired variables were carried out using movement, speed, and acceleration analysis with visual representations, such as graphs of measurements of linear and angular kinematics of specific points (joints or body part), as well as animations of the tracked movements in a 3D space with coordinates based on the calibration of each specific case.

From a wide variety of videos available in the web (mainly Youtube) for biomechanical analysis of movements, one swimming video was selected, and analysed. For the analysis of taekwondo and football soccer, videos were personally recorded by the authors with the help of external participants.

3.1. Swimming

The swimming video was selected to show the movements of a male swimmer, extended horizontally while swimming in "front crawl" style, from a perpendicular point of view. Manual digitization of 10 points was performed: Left (L) toe, L ankle, L knee, L hip, L shoulder, L elbow, L wrist, L finger, chin, and forehead; and since this case of study was obtained from an online video, the following assumptions were made. A height of 1.5 m, and a weight of 78 kg were assumed. The approximated area of the hand was estimated as $A_{hand} = 0.017161256\ \mathrm{m}^2$ [97], and the drag coefficient was considered as $C_d = 1.8262$. In this case study, we were interested in estimating instantaneous force and torque (in a specific videoframe), as well as the average swimming power. Due to the water imposing drag forces onto the swimmer, the equations proposed in [98] were exploited to improve the force estimation made by SkillSpector that doesn't take into account drag forces.

The velocity of the hand in the x axis was estimated via the manual digitization in SkillSpector. A specific frame (∼2.5 s) of Figure 2 was selected to estimate and observe the generated force, when the swimmer was pushing the water with the arm flexed (close to finishing the stroke). At that point, the estimated force ($F_{freeswim}$) measured at the finger, despite the active drag related to free swimming was calculated using the following formula [98]:

$$F_{free\ swim} = \frac{1}{2}\rho V^2_{free\ swim}\, A_{hand}\, C_d \tag{1}$$

where ρ is the density of water of $\frac{997\mathrm{kg}}{\mathrm{m}^3}$, and considering the instantaneous velocity at 2.5 s (see Figure 2), $V^2_{free\ swim} = (2.3\,\mathrm{m/s})^2$, the estimated average force is $F_{free\ swim} = 82.65\,\mathrm{N}$.

The maximum distance from the normal position to the hand was obtained with another graph from SkillSpector, subtracting the distance in the y axis of the shoulder minus the distance in the indicated position of the hand.

The distance was 0.63 m in the position where the arm was practically extended and perpendicular to the body, so for the torque in the shoulder we multiplied the force with the distance:

$$\tau = F_{free\ swim} * d = 82.65\,\mathrm{N}(0.63\,\mathrm{m}) = 52.07\,\mathrm{Nm} \tag{2}$$

Such results indicate that the dimensions of the estimated torque are consistent with the ones obtained in different biomechanical studies of athletes during crawl swimming, which have reported values of maximal torques of 69 and 91 and Nm [99].

For the calculations that we found on the clinical method [98], we wanted to obtain the average swimming power, which was given by the following equation:

$$Swimming\ Power = (Towing\ Force)(Swimming\ Velocity) \tag{3}$$

The average swimming velocity was obtained from the video we are analyzing, which indicates that the athlete swam 50 m (length of an olympic pool) in 38.8 s, and therefore, an average velocity (V_{swim}) of 1.2886 m/s was considered.

For the towing force, we calculated the resistance in the whole body of swimming, with the sum of the resistance of wave R_{wave} and the resistance due to friction $R_{frictional}$:

$$R_{wave} = 0.5\rho V^2_{swim}\, A_{wetted}\, C_w, \quad R_{frictional} = 0.5\rho V^2_{swim}\, A_{wetted}\, C_f \tag{4}$$

The coefficient of wave C_w for a streamlined body is approximately 0.04 and the area wetted for the body is:

$$A_{wetted} = 0.20247\, H^{0.725}\, W^{0.425} = 1.935\,\mathrm{m}^2, \tag{5}$$

where H is the height of the participant, and W is the weight, which brings us to $R_{wave} = 63.22\,\mathrm{N}$.

For the frictional coefficient C_f the calculations were:

$$C_f = \frac{0.75}{(log\, log(Re) - 2)^2} = 4.6875 * 10^{-3}, \quad (6)$$

using a Reynolds number (Re) estimated as 10^6 for human swimming, therefore:

$$R_{frictional} = 0.5(\frac{997\ \text{kg}}{\text{m}^3})\ (1.2886\ \text{m/s})^2\ (1.9351)\ (4.6875 \times 10^{-3}) = 7.508\ \text{N} \quad (7)$$

And the total sum of the two, which will give us the towing force

$$R_{total} = 63.22\ \text{N} + 7.508\ \text{N} = 70.728\ \text{N} \quad (8)$$

And finally, the swimming power would be calculated as

$$Swimming\ Power = (70.728\ \text{N})\ (1.2886\ \text{m/s}) = 91.13\ \text{W} \quad (9)$$

Figure 2 shows the position, velocity, and estimated force at the left finger of the swimmer while doing a front crawl exercise for three seconds. Pictures of the swimmer are also shown to represent the different phases of movement.

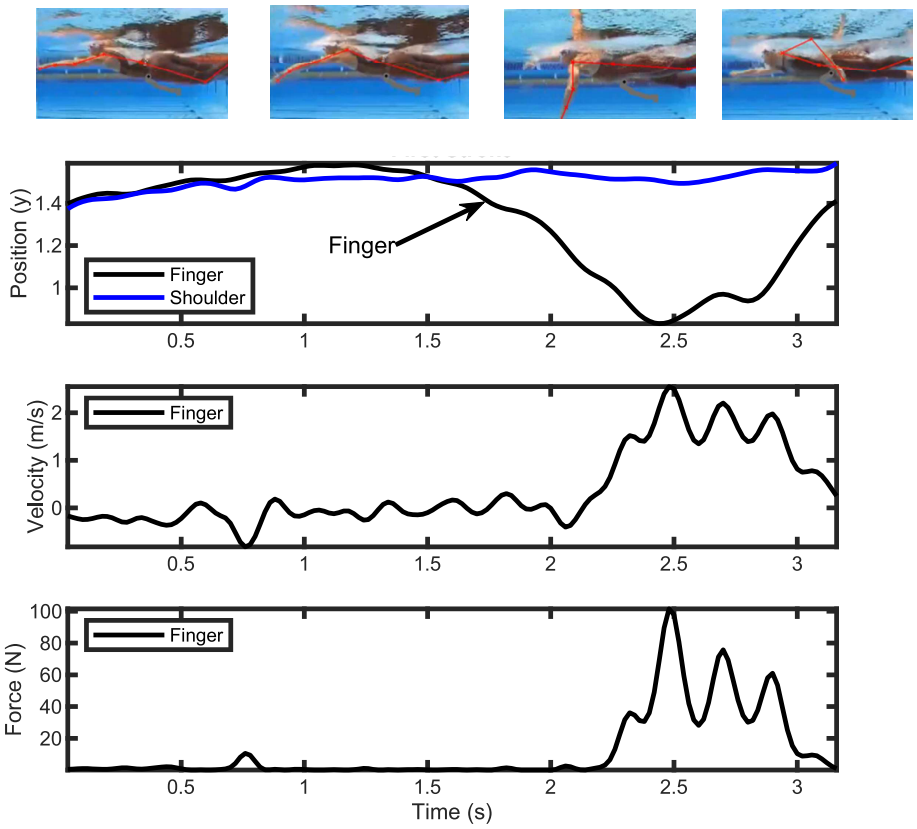


Figure 2. Temporal tracking of position, velocity and estimated force of the left finger of the swimmer during front crawl arm stroke. The insets at the top of the figure depict the sequence of movements that the swimmer was performing while completing one stroke with the left arm.

The position graph in Figure 2, shows the tracking of the L finger drawing water during the stroke in crawl, in a starting position, arm aligned with the rest of the body next to the head, and the lowest point as the arm goes to a second position, completely perpendicular position to the athlete's shoulder at 2.4 s and returns to the horizontal axis of the body.

Velocity started with a negative value of -0.1 m/s and got to its highest point of velocity just a few milliseconds after the lowest position shown in the graphic above, reaching approximately 2.3 m/s at 2.45 s, and progressively lowering the velocity as the hand came back to a third position, arm aligned and close to the body. The applied force began in 0 N as no movement was performed yet, and the value elevated as the stroke began and the hand drew water, with a maximum force of approximately 100 N applied in the moment just before the arm reaches its second position, decreasing as the stroke ends up in the third position.

3.2. Taekwondo

A taekwondo demonstration was performed; in this study case, the dynamical force at the ankle of an athlete during a taewkondo kick was explored. For this scenario, a personally recorded video was used.

In this video, a young female athlete performs a series of punches, stances, and kicks. However, we focused on a particular roundhouse kick with her left leg. A total of 342 frames were manually digitized, and 18 points were used per frame digitization from both left and right (R) sides: (LR toes, LR ankles, LR knees, LR hips, LR shoulder, LR elbows, LR wrists, LR fingers, chin, and forehead). The height and weight of the athlete were of 1.45 m and 35 kg respectively. Figure 3 shows the position, acceleration and estimated force at the left ankle of the athlete, during the roundhouse kick, as well as two manually digitized frames of the video. Here, force was obtained by multiplying the mass times the acceleration estimated by SkillSpector ($\vec{F} = m\vec{a}$).

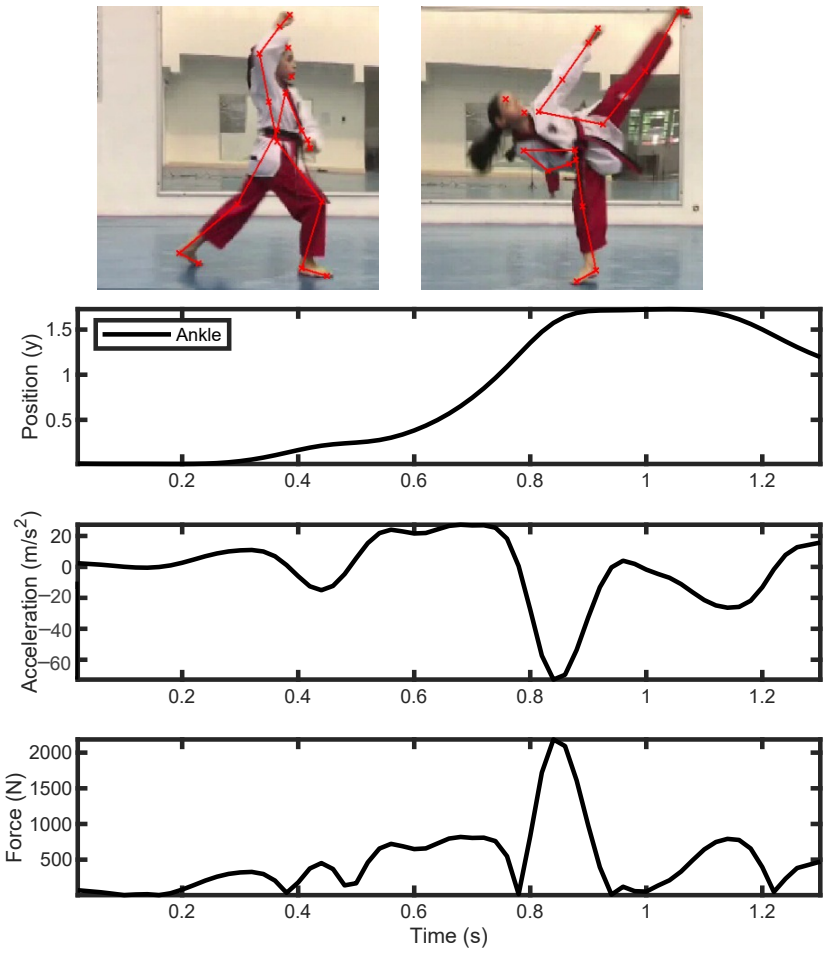


Figure 3. Temporal tracking of position, acceleration and estimated force of the left ankle of the taekwondoist during a high roundhouse kick. The insets at the top of the figure depict the sequence of movements that the taewkwondoist was performing; preparing stance, and high kick.

In Figure 3, it can be observed that, prior to the execution of the kick, the position (y-axis) remains at ground level, close to 0 m; then, the position constantly increases, representing the upward movement of the kick, reaching 1.6 m in the y-axis. Regarding the acceleration, similarly, it starts approximately at 0 m/s^2, representing no movement; the acceleration begins to increase after 0.4 s, reaches a peak acceleration of 65 m/s^2 at 0.85 s, and then decreases by the final stages of the kick. By analyzing the Force experimented in the athlete's left ankle, it can be observed that low forces are presented in the initial stage, intermediate forces (500–1000 N) are observed in different moments (0.6 s, 1.18 s), and a maximum force of approximately 2200 N at the 0.85 s mark, where the kick reaches its highest acceleration.

The obtained maximal force of 2.2 kN for a 35 kg participant during a roundhouse kick lies within a consistent range, when compared to reports of average forces in the foot during roundhouse kicks up to 5.5 kN for 60 kg practitioners [100].

3.3. Football Soccer

For this particular demonstration, a participant was filmed instead of using an online video. In this case, a young (18 years) male participant was recruited. The height and weight of the participant at the moment of the experiment were 1.72 m and 65.5 kg, respectively.

The video was filmed at 50 fps using a Huawei Mate 20 Lite mobile phone (Huawei, Monterrey, Mexico). The procedure involved a lateral view of a soccer ball kick with the dominant leg of the participant. Before the kick, the ball remained in a fixed position, at approximately 0.7 m from the participant. The participant proceeded to reach the soccer ball and kick it using an average force level. Figure 4 shows the position, acceleration, and estimated force at the left ankle of the participant during the kick, as well as two manually digitized frames of the video. Hence, manual digitization entailed forty-six frames (1 s) for this analysis, with 18 points: (LR toes, LR ankles, LR knees, LR hips, LR shoulder, LR elbows, LR wrists, LR fingers, chin, and forehead) per frame. Force was obtained by multiplying the mass times the acceleration estimated by SkillSpector ($\vec{F} = m\vec{a}$).

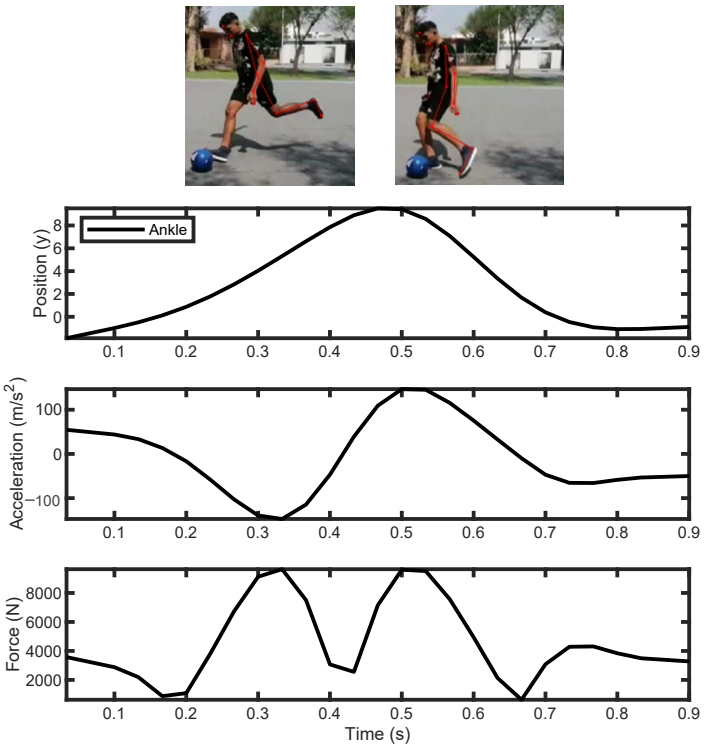


Figure 4. Temporal tracking of position, acceleration and estimated force of the left ankle of the volunteer during a football soccer kick. The insets at the top of the figure depict the sequence of movements that the volunteer was performing; before and after shooting.

As shown in Figure 4, Position tracking in the vertical orientation displays the raising of the foot from ground level until reaching its maximum height at the instance of 0.48 s. Subsequently, the foot lowered towards the ground level with higher velocity, as shown during the lapses 0.49 towards 0.8 s.

Regarding acceleration, the movement began with a positive value close to 50 m/s^2, which decreased to allow the foot to raise. The acceleration reached a maximum negative acceleration level surpassing the region of -100 m/s^2 and increasing again until reaching a level over 100 m/s^2 at the moment of maximum height of the foot. After this moment, acceleration decreased again until getting the foot in touch with the ball, at 0.72 s.

In the case of the applied force, the movement began at approximately 4 kN, reaching a minimum value of 0 N at 0.17 s and increasing steeply towards the raising of the foot. The motion achieved a maximum force of 10 kN at 0.32 s to permit the foot to reach its top height, lowering until reaching a value close to the 3 kN at 0.42 s and rising again to a maximum of 10 kN at 0.5 s. The force decreased again while the foot lowered its height, reaching a minimum of 0 N at 0.68 s and rising when impacting the ball towards 4050 N. Similar studies in the literature have been reported maximal forces during in-step kicking in football soccer of 8.5 kN [101].

4. Discussion

Whereas the results discussed are based on numerical calculations, which can be useful for coaches to a certain extent, a more contextual interpretation can further improve the athelete's performance. It is here where the role of the biomechanical analysts take importance, as they can interpret the estimations, and translate them from the science into the sports performance domain in order to achieve the goals in mind [102]. In this context, the analyst can use methods considered in the proposed tool for performance forecasting, and data-based decision-making in training [102].

The presented case studies were selected due to the the feasibility of the existence of videos in various media. In future studies, a more extensive search for web videos could facilitate the application of the methods presented for other sports. Other biomechanical studies have been considered by tracking in alternative sports, such as American football [35], rugby [39], baseball [6], basketball [33], Gaelic field [37], snowboard [41], skiing [40], among others. However, such mentioned studies are limited to the analysis of the efforts generated on sensors when stepping or making direct contact, or by consensus decision by experts in the area in case.

4.1. Worlwide Roadmap in Biomechanics

A 30 year-trend study of biomechanics literature is provided in [103], focusing on how the experimental design and practices of biomechanics studies has (or not) changed in the last 30 years. Interesting findings are provided. This report notes that there have not been any significant changes in the sample sizes, groups of participants across the years. Linear increases in the following trends were observed: number of studies including group randomization, number of independent variables, number of trials per participant, number of papers including recommendations and limitations, usage of parametric and non-parametric statistics, while a decrease of the usage of simple correlations, descriptive statistics and number of dependent variables was observed. Although the use of more complex statistical methods has increased over the years, not much progress has been attained concerning the sample sizes of the studies. Authors remark the importance of including sample size estimation in biomechanical studies in order to improve future research in the field.

A survey was implemented across different biomechanics research groups across the world to identify opinions and needs regarding current biomechanics sensor devices. The survey was implemented via online to members of the International Society of Biomechanics in Sports (ISBS), and researchers were asked about their main areas of expertise, main features or variables to study, main devices used, and their desires for an optimal

measurement device [104]. The study was able to identify the most frequent research area (biomechanics in sports), features (sports performance) and devices (force platform) and unveiled that little research has focused on the simulation and modelling of internal forces. It was also unveiled that most groups agree on a more integrated device, able to measure multiple features in non-laboratory like settings to provide ecological validity to their research. Also, the need of open-source software tools for biomechanics analysis, compatible with different systems was observed from the results of the survey [104].

4.2. Perspectives

Some of the trends in biomechanics analysis is the implementation of Big Data approaches. A very detailed review on different machine learning and big data implementations on biomechanics of human gait is provided in [105]. This work remarks the benefits of performing such techniques, such as multivariate analysis of complex variables, automatic relevant feature selection, obtaining insight on different populations and accounting for inter-subject variability. The 3D GAIT system was developed by a research group in the University of Calgary, as an automatic biomechanical data collection system that can be used by different research groups, and therefore contribute to Big Data approaches in biomechanics [105]. This system allows to obtain high-dimensional (74 variables) measurements of gait cycles at 200 Hz, and then all the data from each recording is transferred to a research database with demographic information (e.g., mass, height, age, etc.). All this massive amount of data can be used to obtain high-quality models after implementing carefully designed machine or deep learning methodologies.

Other authors have pointed out that artificial intelligence and the Big Data approaches are offering emergent solutions with the proposal of large scale data analysis, such as the development of automated pattern recognition for injury identification in joints [106], and individualized sport teaching between coaches and students, using the historical information available from the users [107]. In a similar context, the transmission of such data will need powerful methods to be transferred in real-time and perform analysis; hence, another important technology that will take importance in Sports Biomechanics research is that of Internet of Things (IoT) to alleviate this challenge [108].

5. Conclusions

Concerning existing studies where tracking modalities were applied in video sports activities, as far as we know, this is the first time that tracking procedures are used based on existing videos from sources of immediate access such as YouTube. Thus, making possible the estimation of position, force, and speed. We confirm that these procedures will have considerable application opportunities in future studies where video motion tracking is essential for calculating moving physical variables.

As indicated previously, the studies to estimate mechanical properties in movements carried out by high-performance sports activities were limited to the use of sensors that calculated the force applied through the direct impact of the limb. The tracking proposed in this work opens up new possibilities through the specific trace of forces and speeds through movements carried out in actual physical activity conditions.

Additionally, future use of deep learning techniques will allow us to estimate movements and calculate the forces applied by physical activities by default. New options will be available for data acquisition to clarify trends of fractures and fatigue injuries caused by repetitive movements determined as extreme for in-vivo conditions. It will then be possible to develop methods for the prediction and prevention of these types of fractures, to be applied clinically in the proper training of high-performance exercise, and towards the prevention of fatigue fractures in bones with osteoporosis.

The case studies discussed in this paper have shown that in the future the prevention of fatigue fractures through the estimation of concentrated stresses on body regions via video analysis will be possible. The collected literature allows us to clarify that, up to our knowledge, there are no studies on the concentration of stresses in specific regions of the

anatomy in athletes through tracking modalities from existing videos in the media through the use of specialized software. We estimate that in future studies under the application of deep learning modalities for the appropriate tracking of body movements, it will be possible to validate specific tracking towards the establishment of optimal exercise routines in which the minimization of the development of injuries due to fatigue will be possible.

Author Contributions: Conceptualization, M.A.R.-M., G.P.-E. and J.d.J.L.-S.; methodology, V.E.O.-P., M.A.R.-M. and G.P.-E.; validation, M.A.R.-M. and G.P.-E.; formal analysis, V.E.O.-P., M.A.R.-M. and G.P.-E.; investigation, V.E.O.-P., M.A.R.-M. and G.P.-E.; resources, M.A.R.-M., G.P.-E. and J.d.J.L.-S.; data curation, V.E.O.-P., M.A.R.-M. and G.P.-E.; writing—original draft preparation, V.E.O.-P., M.A.R.-M. and G.P.-E.; writing—review and editing, J.d.J.L.-S. and R.A.R.-M.; visualization, V.E.O.-P., M.A.R.-M. and G.P.-E. and J.d.J.L.-S.; supervision, J.d.J.L.-S.; project administration, J.d.J.L.-S. and R.A.R.-M.; funding acquisition, J.d.J.L.-S. and R.A.R.-M. All authors have read and agreed to the published version of the manuscript.

Funding: The APC of this publication was funded by Tecnologico de Monterrey.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Authors would like to thank Tecnologico de Monterrey for the support in the development of this project.

Conflicts of Interest: The authors declare no conflicts of interest.

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