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UPPER LIMB EVALUATION IN ATHLETES: METHODOLOGICAL AND DIDACTIC APPROACHES FOR MOTION ANALYSIS

VALUTAZIONE DELL'ARTO SUPERIORE NEGLI ATLETI: APPROCCI METODOLOGICI E DIDATTICI PER L'ANALISI DEL MOVIMENTO

Marianna Liparoti
University of Rome "La Sapienza"
marianna.liparoti@gmail.com

Abstract

The evaluation of the upper limb movements in sports has two main objectives: the improvement of the athletic gesture and the prevention of injuries. This assessment can be carried out using different methodological approaches, i.e. qualitative or quantitative methods of analysis. In this work, a narrative review is performed on the methodology, applied in sports, for the assessment of the upper limb. Using a didactic-educational approach, this study aims to highlight the advantages and disadvantages of the qualitative and quantitative methods used to estimate the movements of the upper limb in athletes. Furthermore, this work aims to formulate recommendations for carrying out movement analysis, useful for improving performance evaluation in sports and training monitoring.

La valutazione dei movimenti dell'arto superiore in ambito sportivo ha due obiettivi principali: il miglioramento del gesto atletico e la prevenzione degli infortuni. Tale valutazione può essere svolta mediante approcci metodologici differenti, ossia metodi di analisi qualitativi o quantitativi. In questo lavoro viene eseguita una revisione narrativa sulla metodologia, applicata in ambito sportivo, per la valutazione dell'arto superiore. Mediante un approccio didattico-educativo il lavoro mira ad evidenziare i vantaggi e gli svantaggi dei metodi qualitativi e quantitativi utilizzati per stimare i movimenti dell'arto superiore negli atleti. Inoltre, questo lavoro si propone di formulare delle raccomandazioni per l'esecuzione dell'analisi del movimento, utili a migliorare la valutazione della prestazione in ambito sportivo ed il monitoraggio dell'allenamento.

Key-words
Upper limb; Sportive and Motor Sciences; Qualitative methods; Quantitative methods; Arto Superiore; Scienze Motorie e Sportive; Metodi qualitativi; Metodi quantitativi;

Introduction

The shoulder joint complex is composed of three bones (clavicle, scapula, humerus) joined through the anatomical sterno-clavicular, acromio-clavicular and gleno-humeral joints and the scapulo-thoracic joint, whose coordinated and integrated movements contribute to the efficiency of range of motion (RoM) and proper functioning of the upper limb (Kapandji, 1971). Any alteration in the elements that make up the shoulder complex could result in impaired function and could adversely affect associated motor performance. Movement impairments associated with the shoulder joint complex are very common in some throwing sports such as tennis, volleyball, golf, and baseball, primarily caused by repetitive mechanical overload (Asker, Holm, Källberg, Waldén, & Skillgate, 2018; Chung & Lark, 2017; Lyman et al., 2001; Seminati & Minetti, 2013; Yang et al., 2014; Zouzias, Hendra, Stodelle, & Limpisvasti, 2018). Shoulder pain and lack of motor control are the main manifestations of altered upper limb movement, while the most frequent injuries include shoulder dislocation, gleno-humeral instability and rotator cuff injury (da Silva, 2015). These alterations may lead to the loss of degrees of freedom of movement.

The evaluation of the scapular girdle can provide relevant information for the diagnosis and treatment of clinical disorders, rehabilitation treatment, injury prevention and especially information on sports performance and functional recovery after rehabilitation treatment. Current research is focusing on the development of appropriate methods to investigate the characteristics and functions of the shoulder complex and to analyse related alterations (Lin, Wong, & Kazam, 2018). Usually, the shoulder complex is evaluated by radiography, but this measurement technique allows two-dimensional measurement of the body, which means that there is a loss of information on the degrees of freedom of movement. More recently, magnetic resonance imaging and fluoroscopy techniques have tried to overcome this problem. These methodological approaches allow the three-dimensional projection of bones on images and provide information on the position and orientation of the evaluated bone segment. However, these diagnostic techniques involve X-ray irradiation or magnetic fields and only allow static measurements.

Current research has focused on the development of 3D analysis methods that overcome the limitations of static assessment, offering the possibility of biomechanically analysing the dynamics of the shoulder and improving the understanding of its movement (Lefèvre-Colau et al., 2018). The main devices developed are electromagnetic or optoelectronic, allowing precise, reliable and simultaneous kinematic measurement of the humerus, scapula and clavicle. In particular, the International Society of Biomechanics has published recommendations for the definition of joint coordinate systems and rotation information to standardise the analysis of upper limb kinematics (Derrick et al., 2020). More recently, several methods for estimating scapular motion have been described, such as the acromial method and the surface mapping approach. The acromial method is based on the placement of a sensor directly on the acromion and the reference point is digitised as a three-dimensional coordinate. In contrast, the surface mapping approach estimates scapular motion using a series of markers above the scapula. However, these kinematic methods have some limitations, as demonstrated by Leardini et al. marker-based techniques are subject to inaccuracies related to marker placement or the possible presence of soft tissue artefacts (Leardini, Chiari, Della Croce, & Cappozzo, 2005). From this point of view, the validity and reliability of using marker-based techniques for recording scapular motion may be compromised.

Despite the existing literature on kinematic measurements of the upper limb, there is a lack of review in the literature, which highlights the existing knowledge so that a general consensus can be reached on the biomechanical analysis of the upper limb in sport. Therefore, the aim of this review was to report on existing qualitative and quantitative methods used to estimate upper limb movements and their properties. In addition, this work aims to make recommendations for performing movement analysis and to help develop training programmes aimed at improving upper limb movements in athletes.

1. Methodological approaches to upper limb assessment

The functional assessment of the upper limb is mainly based on the detection of RoM, which can be carried out both during the execution of the motor gesture and during a passive movement. The measurement of joint excursion provides information about the quality of movement and the spatio-temporal tracking of the body segments that make up the upper limb.

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The measurement of RoM can be performed through different methodological approaches such as: qualitative assessment (e.g. a visual estimation, which offers the possibility to quickly estimate the joint excursion and allows to detect possible musculoskeletal limitations or laxities) or quantitative assessment (a method that exploits the properties of technological tools and the laws of physics to accurately quantify the joint excursion, such as smartphone technology, wearable sensors or 3D motion capture tools).

1.1 Qualitative approaches for upper limb analysis

Considering the complexity of the shoulder joint, it can be a source of alterations and pathological conditions especially in athletes, so a qualitative physical assessment of shoulder movement is necessary before an objective measurement can be made. Therefore, an initial detailed interview may be necessary to get an idea of the degree of impairment and to direct further parts of the examination. The anamnesis should focus on the identification of possible sources of impairment, identify any functional restrictions, consider the age of the person being assessed, both in terms of stated age and functional aspect, note any previous or ongoing pathologies that could affect the motor function of the upper limb. In athletes, it is important to understand what, if any, movements are repeated during sports practice. The combination of this information may provide clues to understanding the problem underlying the alteration or malfunction that may compromise successful motor performance. The anamnesis should be performed through a pre-established scheme to decrease the probability of overlooking relevant information. The qualitative analysis consists of a physical examination that should start with inspection and proceed with palpation followed by the performance of active and passive movements and muscle strength assessment (van Trijffel, van de Pol, Oostendorp, & Lucas, 2010). The physical examination should be performed with both shoulders uncovered, this allows the detection of any asymmetry between the compromised and the contralateral upper limb.

Any atrophy or changes, swelling, edema, scarring, previous trauma or surgery should be noted. A fundamental component of the qualitative assessment is the detection of the range of motion. Physiologically, the range of motion of the shoulder should be characterised by the following RoM: flexion from 150 to 180 degrees, extension from 40 to 60 degrees, abduction from 150 to 180 degrees, external rotation from 60 to 90 degrees and internal rotation from 50 to 70 degrees (Kapandji, 1971). A limitation of joint range of motion in these movements may indicate the presence of an impairment. The following is an overview of the tests that are predominantly used for the qualitative assessment of shoulder range of motion in sports and clinical rehabilitation (Tab 1).

Test	**Examination techniques**
Apprehension	The participant is supine with the shoulder in abduction (90°), the elbow flexed (90°) and full external rotation.
Relocation	Performed after the apprehension test, a posterior force is applied on the head of the humerus
Load and Shift	The participant is supine with the shoulder in abduction (40°-60°), forward elevation (90°), axial loading of the humerus and an ante-posterior force is applied.
Cross-body abduction	The participant raises the arm forward (90°) and actively abducts the arm

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Belly press	The participant presses the abdomen with the palm of the hand and keeps the shoulder in internal rotation
Jobe	The participant abducts the arm, raises it forward to 30° and rotates internally with the thumb towards the floor. The examiner applies a downward force as the patient attempts to maintain the position

Tab 1. Physical examination of the upper limb

1.2 Quantitative approaches for upper limb analysis

The kinematics of the upper limbs can be studied using the highly sophisticated technology known as Motion Capture, which traditionally includes optical and electromagnetic systems (Lempereur, Brochard, Leboeuf, & Rémy-Néris, 2014). Optical systems are based on the use of markers that can be active (light-emitting diodes (LEDs)) or passive (retro-reflective), whose tracking in time and space offers the possibility of accurately measuring the position of joint segments in 3 dimensions (Rucco, Liparoti, & Agosti, 2020). However, these systems can be prone to motion and tissue artefacts and require expensive equipment. Electromagnetic systems, on the other hand, use the presence of magnetic fields to detect the position of body segments in space. These systems, however, are susceptible to interference from electrical and magnetic components present in the space where the assessment is being made.

Through these systems, alterations in the upper limb can be detected by comparing the resulting kinematics with that observed in a control population or with the contralateral limb with physiological joint excursion. Over the years, motion analysis by means of capture systems has been widely used in the evaluation of the lower limb, in fact they are considered the gold standard for the evaluation of lower limb kinematics (Liparoti, 2021; Liparoti et al., 2019; Minino et al., 2021). This is most likely due to the fact that the arm is part of an open kinetic chain, with few opportunities to measure the forces experienced during activities of daily living or during specific sports performances. In addition to these very sophisticated and expensive capture systems, the use of integrated wearable sensors provides some information on the kinetics of the upper limb joint. Investigations of upper limb kinetics often focus on sports applications, other studies of upper limb kinetics have been performed in rehabilitation and motor re-education contexts.

As an alternative to sophisticated motion capture instruments, quantitative assessment of joint excursion can be performed using wearable sensors that allow monitoring in an environment different from classical motion analysis laboratories, thus also applicable to everyday life contexts and less stressful environments than laboratories (Rucco et al., 2018). Typically, these wearable sensors consist of accelerometers, gyroscopes and magnetometers that allow recording of both linear and angular accelerations in the x, y and z directions. The data is then exported from the device and processed to extract motion characteristics. Despite being considered simple, versatile and easy-to-use tools, these sensors sometimes have low reliability, and this may depend on both the complexity and movement characteristics of the anatomical joint being measured and the level of experience of the assessor. Furthermore, these sensors are limited to measuring joint angles in single planes and in static positions, so much information about the movement of the upper limb is lost.

2. Assessment of the upper limb in sport

The aim of this paper is to provide an overview of the most widely used sensing technologies in sport for the assessment of upper limb movement. Reviewing the state of the art in relation to upper limb assessment can be useful to facilitate the work of the operator involved in upper limb analysis and provide useful information for the preparation of training protocols or motor rehabilitation. Motor gesture assessment can be carried out mainly for two reasons: to improve sporting performance and to prevent injury (Payton, Bartlett, & British Association of Sport and Exercise Sciences, 2008). This evaluation can take place through the previously mentioned methodological approaches, i.e. through qualitative and quantitative methods of analysis.

The qualitative method can be taken into account both in sports and in recreational environments, where the analysis of the movement is based on the knowledge of the coach or teacher, who use their knowledge to correct or improve the technique of motor execution. For example, through qualitative analysis it is possible to evaluate the way in which the stance, pull and push are performed in swimming and to improve sporting performance. For example, Brown and Counsilman analysed the hand gesture in swimming technique and discovered that, in order to improve power and propulsive force when moving forward in the water, the swimmer did not have to grip the water with a flat hand, but had to use a cutting technique. This is a technique that is still used in swimming today, and this is proof that only an experienced practitioner with knowledge of the motor gesture can improve the technical execution by observing the movement. Qualitative analysis may be insufficient when it comes to improving the performance of elite athletes, who already perform a very precise technical gesture but only need to improve certain aspects such as the speed of execution or the positioning of a bone segment during execution, and since these are small imperfections not visible to the naked eye, quantitative analysis may be a good approach to overcome the limitations of qualitative assessment.

Thanks to the quantitative approach, it is possible to effectively improve the technique for performing a sporting gesture through an assessment that involves measuring the athletic gesture in a laboratory equipped with objective assessment tools (Payton et al., 2008). The quantitative method cannot be separated from some key concepts of physics and anatomy, such as the concept of lever, rigid body and kinematic chain. A lever is a rigid rod that can rotate around a fixed point called a fulcrum and can balance or overcome a force (resistance force) with another force (power force) that is not equal and opposite. A lever can be advantageous, disadvantageous or indifferent. A lever is defined as advantageous when the power arm is greater than the resistance arm, so a lower power is required to counterbalance the resistance. A lever is said to be disadvantageous when the power arm is smaller than the resistance arm, so more power is needed to counterbalance resistance. Conversely, a lever is said to be indifferent when the power arm is equal to the resistance arm. Our bone segments can be called bony levers, which move in space through the action of the muscles acting on them. In physics, on the other hand, a rigid body is defined as a body or object consisting of particles whose mutual distances always remain the same. Using various mathematical approaches, it is possible to study the characteristics of a rigid body. In quantitative analysis, if we associate the concept of a rigid body with that of body segments, it is possible to study the characteristics of the movement of these segments in three-dimensional space. A kinematic chain is defined as a system composed of rigid segments joined through moving joints. Our body is made up of many kinematic chains, where the segments represent the rigid bodies and the joints represent the joints. With these basic concepts in mind, it is possible to analyse the movement of the upper limb in sport, using the properties of mechanics and the laws of physics. Several studies on the evaluation of the upper limb in sports have focused, for example, on the rotation techniques of the shoulder during the dunk in volleyball, on the biomechanical evaluation of the athletic gesture of the service in tennis, and finally, many studies have been conducted on the biomechanical evaluation of throwing, which consists of several phases and moments that expose the shoulder, elbow and wrist to high accelerations and decelerations with repeated micro-traumas of the capsule-ligamentous structures.

The following is a review of articles that were critically analysed in order to provide an overview of the general trends and the most widely adopted technologies in the field of upper limb assessment in sport. The analysis was carried out considering three important aspects: the type of sport, the approaches for motion detection, and the type of tasks performed by the participants. The articles resulting from the selection are reported in Tab. 2.

Authors / Year	**Type of sport**	**Type di analysis**	**Tool**	**Measures**
(Camp et al., 2017)	Baseball	Kinematic	Inertial sensor	Arm slot Arm speed and rotation Angular momentum of the elbow
(Fleisig et al., 2017)	Baseball	Kinematic	Motion Capture	Angular momentum of the elbow
(Okoroha et al., 2018)	Baseball	Kinematic	Inertial sensor	Arm rotation Angular momentum of the elbow
(Landolsi et al., 2018)	Baseball	Kinematic	Motion Capture	Arm speed
(Gordon & Dapena, 2013)	Tennis	Kinematic	Motion Capture	Arm rotation
(Vigouroux, et al. 2019)	Climbing	Kinetic	Electromyography	Muscle strength and function
(Touzard, et al. 2019)	Table tennis	Kinematic	Motion Capture	Force, speed and arm rotation
(Naito, et al. 2014)	Baseball	Kinematic	Motion Capture	Angular momentum of the elbow Speed and arm rotation
(Mitchinson, et al. 2013)	Volleyball	Kinematic	Motion Capture	Shoulder RoM Arm speed
(Escamilla, et al. 2017)	Baseball	Kinematic	Motion Capture	Speed and arm rotation

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				Angular momentum of the elbow
(Cortesi et al., 2019)	Swimming	Kinematic	Inertial sensor	Wrist trajectory
(Barfield, et al. 2019)	Softball	Kinematic	Electromagnetic sensor	Arm rotation Angular momentum of the elbow

Tab 2. Upper limb assessment in athletes

3. Conclusion and Recommendations

The aim of this work was to evaluate the state of the art of the most widely adopted sensing technologies in sports for the assessment of the upper limb, with particular attention to the type of instrumentation used (optical or non-optical systems) and the type of sport in which they are used. This work aims to provide an overview of the studies related to this topic, in order to facilitate the work of the operator involved in the biomechanical analysis of the upper limb and provide useful information for the preparation of training protocols or motor rehabilitation. The shoulder is the most mobile joint complex of the human being, whose range of movement is the result of a coordinated movement of the three joints that compose it. The efficiency of the kinematic chain of the upper limb is based on the coordinated and combined movements of the different shoulder joints, so any change in one element of the shoulder complex could affect its overall function. Therefore, there are many demands for the development of appropriate methods to study the shoulder joint complex and the upper limb in general. The upper limb is no longer considered as a body segment disconnected from the rest of the body, but rather as a structure that is part of a more complex system, so alterations or modifications related to the movement of the upper limb could compromise the stability or movement of the whole body.

This work has focused mainly on the observation and evaluation of the movement of the upper limb in sports, because in sports, and in particular in elite sports, the execution of sports performance, with high degrees of precision and efficiency in terms of energy cost, is fundamental for the achievement of the objectives of the individual athlete or the team in general. Even the slightest alteration in movement could compromise the achievement of goals and the successful execution of the performance. There are many qualitative or semi-quantitative tests that allow an evaluation of the movement of the upper limb in sport, but many of these tests are based on subjective evaluations and not objectively evident. Although qualitative tests have the advantage of being inexpensive and allow a direct analysis of the movement, the detection of the correct execution of the movement is operator-dependent, since it depends very much on the degree of experience of the operator observing the movement. Moreover, in a qualitative analysis it is not possible to observe the movement in different planes of space at the same time (frontal, sagittal and transverse).

From the above, it can be seen that a simple qualitative assessment of the movement of the upper limb, especially in sports, is very limited, and the need to associate a qualitative assessment with an objective one that can provide precise quantitative information is fundamental for the assessment of the upper limb as a whole. In recent years, 3D analysis methods for the analysis of the upper limb have been widely used in sports, in particular 3D kinematic analysis techniques (mainly electromagnetic or optoelectronic devices) as they provide very accurate information of the position and orientation of the bones. Although these methods are widely used, they have some limitations, the main one being soft tissue artefacts. Nevertheless, motion analysis using motion capture tools is the gold standard for motion assessment. From the analysis of the scientific literature, movement assessment of the upper limb mainly involves sports such as: tennis, volleyball, climbing, swimming and especially baseball. Particular attention in these sports is paid to joint excursion not only of the shoulder but also of the elbow joint. There is a growing need to identify modifiable factors that can potentially reduce the stress exerted on the upper limb during athletic performance. In particular, a study of the arm slot, the speed of execution of the exercise, the rotation of the arm or the increase in the articular range of the elbow or shoulder can help to identify these factors and to design targeted training programmes to improve movement. In sports, the most widely used instrumental approach is Motion Capture based on optical systems. In fact, this type of instrument allows analysis to be carried out in laboratory contexts, controlled to allow indirect analysis of body movement, and provides extremely precise information on movement. The main limitation of this type of approach is precisely the impossibility of observing movement in game contexts but only in simulation situations. To overcome this kind of limitation it is possible to use inertial sensors, which are in fact the most used tools after Motion Capture. In addition, according to the literature, few studies make use of force platforms or electromyography for the evaluation of the upper limb. This probably depends both on the size of the instrumentation, which could impede the good execution of the motor gesture, and on the hypothesis underlying the investigation to be carried out.

In conclusion, from this study it follows that, in recent years scientific research has focused on the observation and analysis of the upper limb movements, particularly in sports. A quantitative assessment associated with a qualitative assessment is essential in order to improve motor performance. Therefore, the use of 3D-Motion Capture tools and inertial sensors seems to be the appropriate instrumentation for performance assessment but also for monitoring training in sports.

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