Journal of Sports Science 4 (2016) 241-246
doi: 10.17265/2332-7839/2016.04.008

Motion Analysis Technologies for Biomechanical Gait and Postural Analysis in Ballet

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Abstract: The dominant element in ballet is the search for flawless performance. The specific training required from early years may cause some changes compared to the normal human anatomy and physiology. The aim of this study was to investigate the potential of motion analysis technologies for the evaluation of frequent changes in biomechanics of posture and dance. This paper presents an overview of the literature on the main postural compensation employed by the dancer; more specifically on the training effect of the fundamental basic techniques in ballet. It then focuses on the characteristics and potential of motion analysis technologies for the biomechanical evaluation of the dancer. The technologies investigated in this study are the optoelectronic system of gait analysis, which is one of the most advanced technologies for multifactorial motion analysis, integrated with the use of the force platform and the electromyography. These technologies enable a quantitative three-dimensional integrated multifactorial motion analysis in relation to kinematics and dynamics. Through specific systems of motion analysis, the instrumental analysis can describe objectively and with reasonable accuracy the biomechanics, the postural compensation, and the gait of the dancer.

Key words: Training in ballet, postural analysis, technologies, motion analysis.

1. Introduction

Perfection, balance and lightness of ballet dancers make up a unique art form in which the body becomes the central character. The lightness of the dancer emerging from the execution of the steps, hides the difficulties in the implementation of the same movements that require years of study in pursuit of the sole objective of perfection. This arduous search deals with the complexity of the classical techniques which requires that the body is adapted to specific requirements from childhood. Elasticity, linearity, lightness, muscle strength, balance, openness and fluidity are only some of the qualities that a dancer in search of impeccable movement must have.

This discipline requires specific training from early years that may cause some modifications in the anatomical and physiological development [1-4]. One of the fundamental positions in this discipline is the *en dehors*. In order to perform this position perfectly, the technique requires the external rotation of the entire lower limb, changing its orientation. Unfortunately, the technical ideal of reaching an angle of 180° of the lower limbs is not feasible for most of the ballet dancers that, except in rare cases, may have an inadequate flexibility or limitations related to bone articulation. In these situations, it leads the dancer to force the rotation, thus putting pressure on muscles and articulations to compensate that limit. The consistent execution of this type of forced movement is one of the most frequent causes of pathologies of the spine and lower limb associated with the study of ballet. The biomechanical evaluation of the gesture, in particular the nature of postural compensation employed by the dancer to optimally execute the position [5-7], appears to have a fundamental importance in understanding the changes that can occur due to a teaching that does not take into account the morpho-functional characteristics of the individual.

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For the evaluation of static posture postural base analysis is usually used. This can be done through the observation of three planes: sagittal, frontal and dorsal [8]. The postural analysis allows you to visually assess the subject in order to establish its position with respect to an ideal position. For dynamic assessment of the posture, it tends to analyze the most natural and convenient that the human body has to move from one position to another: the gait. The simplest approach for an evaluation of the process, consists of a general evaluation, in order to highlight the obvious anomalies. This assessment is made through an observational analysis of the pass, which allows you to analyze carefully the behavior of the different districts, joint and/or segments (from the toes to the ankle, knee, hip and pelvis and trunk) during the individual phases of the gait cycle. However, the poor reliability and the absence of quantitative data represent an important limit of this method [9].

It is therefore essential to be able to use techniques that allow to describe, quantify and evaluate the movement in such a way so as to obtain detailed quantitative information capable of characterizing the gait of a subject. This information may be provided by technological tools of movement analysis that allow to analyze specific aspects of locomotion function: motion analysis defines the extent and timing of any joint action, the dynamic electromyography identifies the period and the relative intensity of muscle activity, the records of the force platforms highlight the functional requirements during the load. In determining the overall effectiveness of the gait, spatio-temporal characteristics of the gait are also measured. The instrumental analysis of the step, or gait analysis, through specific systems of motion analysis, can describe some characteristics of the gait and the mechanisms underlying the alterations in walking objectively and with reasonable accuracy. This analysis enables a quantitative three-dimensional integrated multifactorial motion, relating to kinematics (trajectories, speed, acceleration, angle, etc.); to the dynamics (forces, moments, power, etc.); and finally to muscle activation associated with the movement to be analyzed [10].

2. Objective

The aim of this study was to investigate the potential of motion analysis technologies for the evaluation of changes in posture and biomechanics among dancers. Starting from a literature review on the effects of training to acquire the fundamental techniques in ballet, the study concentrated on the characteristics and potential of motion analysis technologies for the biomechanical evaluation of the dancer. The technologies investigated in this study are the optoelectronic system of gait analysis, which is one of the most advanced technologies for multifactorial motion analysis, integrated with the use of the force platform and the electromyography. These technologies enable a quantitative three-dimensional integrated multifactorial motion analysis in relation to kinematics and dynamics [11].

3. Methodology

3.1 Literature Search

This study was conducted through a literature review in the field of the biomechanical evaluation of the dancers. In particular, the studies selected were those that investigated the nature of postural compensation employed by ballet dancers and the biomechanical and postural alteration and compensation related to this type of training (Table 1). The study then focused on the specific characteristics of advanced technologies able to investigate biomechanics and kinematics of a professional dancer in a more objective and precise manner than traditional assessment tools. The technological system analyzed in this study is the Bts Smart D for integrated multifactor analysis of human movement and the use of the clinical protocol Davis for gait analysis. This system integrates multiple technologies, such as an optoelectronic motion capture system with

Table 1 Overview of the studies regarding the biomechanics and postural analysis in ballet dancers.

Study	Sample	Methodology	Results
Nowacki, Rdana M. E.; Air, Mary E.; Rietveld, A. B. M (2012) Hyperpronation in Dancers. http://www.ingentaconnect.com/content/jmrp/jdmsVolume 16, Number 3, September 2012, pp. 126-132 (7) [12].	2.427 Dancers	Calcaneal angle was measured and correlated with a clinical grading scale based on the Hübscher maneuver.	The incidence of symptomatic hyperpronation resulting in prescription for orthotics was 30% (739 dancers out of 2,427). The most common related diagnosis was retropatellar-chondropathy (10%). Clinical severity of hyperpronation was linearly related to the calcaneal angle (95% CI [1.25, 4.14], $P = 0.0006$; Pearson's $r_2 = 0.97$). The calcaneal angles among mild, moderate, and severe hyperpronators differed significantly (H = 13.45, $P = 0.0012$).
Gamboa, J. M., Roberts, L. A., Maring, J. & Fergus, A. (2008). Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *Journal of Orthopaedic & Sports Physical Therapy* 38 (3): 126-36 [13].	204 Dancers	Postural analysis as described by Kendall et al	It was highlighted the incidence of the: Lumbar hyperlordosis in about 41% of the sample who carried out the assessment; Foot hyperpronation in about 36% of the sample who carried out the assessment; Knee hyperextension in about 25% of the sample who carried out the assessment.
Steinberg, N., Hershkovitz, I., Peleg, S., Dar, G., Masharawi, Y., Zeev, A., & Siev-Ner, I. (2013). Morphological characteristics of the young scoliotic dancer. *Physical Therapy in Sport* 14 (4): 213-220 [14].	1288 Dancers	Adams forward-bend test (Adams, 1965), and Magee's "skyline" view (Magee, 1992) were used to identify scoliosis. Anatomical anomalies were identified following the definition of Magee (1992), and Hoppenfeld (1976).	Three hundred and seven of the 1288 female dancers (23.8%) were identified as having scoliosis. The incidence of Knee varum was 33%. The incidence of hyperextension of knees was 11.3%. Foot anomalies were highlighted in the 28.65% of the sample.
Sonja, N. C., & Sarah, A. C. (2012). Influence of turnout on foot posture and its relationship to overuse musculoskeletal injury in professional contemporary dancers. *Journal of the American Podiatric Medical Association*: January 2012, 102 (1): 25-33 [15].	12 Dancers	The angle of gait and angle of turnout were measured using a quasi-static clinical tracing method. Foot posture was assessed in the base of gait and angle of turnout using the Foot Posture Index.	The results show a tendency toward a pronated foot posture (mean, 9) in the angle of turnout position. A significant relationship was noted between the Foot Posture Index and angle of turnout ($\rho = 0.933–0.968$, $P < 0.01$) and between the number of reported injuries and change in foot posture in the angle of turnout ($\rho = 0.789$, $P < 0.01$) (right foot only).

six cameras, a Kistler force platform and the electromyography. Davis protocol is normally used in clinical analysis for the evaluation of normal and pathological gait. In this study, the technical characteristics of the protocol were analyzed to verify the possibility of use in the field of biomechanical instrumental evaluation of gait of the dancer and the analysis of differences compared to normal walking.

3.2 Inclusion Criteria

To be included in this study, studies had to meet the following criteria: (1) studies needed to have been published between 2000 and 2015; (2) they had to include ballet dancers; (3) the studies had to describe postural compensation employed by the dancer related to the ballet training.

The analysis of the technical characteristics of the optoelectronic motion capture systems will be made considering to the description given by the manufacturer and by the studies in the scientific literature.

4. Results

4.1 Main Components and Characteristics of a Technological System for Motion Analysis

4.1.1 The Optoelectronic System

The optoelectronic system consists of cameras with illuminators and equipped with a CCD sensor. The motion capture systems can be divided into two categories: optical systems (with or without marker) and non-optical systems (electro-magnetic, inertial, acoustic and optical fibers). Particular attention is paid in optical systems, which use passive markers, because the systems are more accurate, but also the most expensive. An optical system for motion capture is constituted by a set of video cameras (infrared) that capture the scene where the subject is moving. Each camera is described by a simple mathematical model and the scanned image is no more than a two-dimensional projection of a three-dimensional scene. In practice, all the light rays pass from the central optical lens before reaching the camera's sensor. Spherical or hemispherical markers are placed on the subject under consideration and the infrared reflection of these is seen by the cameras like points of light on the scene. So thanks to the combined use of flash and reflective markers, you can generate high-contrast images where it is easy to identify the markers themselves. The motion capture optical system reconstructs the three-dimensional position of the marker in each instant of time. The system is able, through the so-called triangulation process, to combine the two-dimensional images from each camera and process a three-dimensional image. By simplifying the operation of the apparatus, it measures the three-dimensional coordinates (XYZ) of marks that are placed on the body of the subject. Measuring and storing the three-dimensional coordinates of the markers, application software supplied with the equipment is capable of calculating trajectories, angular sizes, (and then determine the angles of flexion-extension, abdo-adduction and intra-extra rotation of the main joints), speed and accelerations, and then to know in detail the kinematics of the movement of the body part on which the markers were positioned in an automatic way [16-18].

4.1.2 The force Platform

The force platforms measure the resultant of the reaction of the platform surface at the time of the impact of the subject. The forces are analyzed in the three fundamental levels, broken down into vertical, anterior-posterior and medial-lateral components. Force platforms may be classified as single-pedestal or multi-pedestal and by the transducer (force and moment transducer) type: strain gauge, piezoelectric sensors, capacitance gauge, piezoresistive, etc., each with its advantages and drawbacks [19]. Single pedestal models, sometimes called load cells, are suitable for forces that are applied over a small area. For studies of movements, such as gait analysis, force platforms with at least three pedestals and usually four are used to permit forces that migrate across the plate. For example, during walking ground reaction forces start at the heel and finish near the big toe [20].

4.1.3 The Electromyography

The electromyographic analysis is an indirect means of identifying the timing and relative intensity of muscular function by recording the signals of activation. In response to the neural stimulation of the myoneural end plate, intramuscular electrical signals are generated to activate the force, producing sarcomeres. These myoelectrical signals can be recorded as they spread through the muscle and adjacent soft tissue. The use of surface electrodes greatly simplifies the sampling operations of the signal and, besides the advantage of having a non-invasive technique, recordings that can be collected include both those in conditions of isometric contraction and in dynamic strain, such as during the execution of functional exercises or positions [21, 22].

4.1.4 Davis Protocol

The protocols in motion analysis are used to make clinically-interpretable kinematic and dynamic parameters of the pelvis and lower limbs. A protocol defines a biomechanical model and procedures to acquire, process and analyze data, and obtain results. The Davis protocol has been developed at the Newington Children's Hospital (Newington, USA) and was intended to provide a clinical quantitative assessment of human locomotor function in order to be of help in the management of orthopedic pediatric diseases related to gait. The protocol for the acquisition of the data is developed according to a precise process consisting of various steps. In addition to a series of video recordings of the subjects' gait, the preliminary stages provide the acquisition of the main anthropometric parameters such as weight, height, the length of the tibia, the distance between the femoral condyles (or the diameter of the knee), the distance between the anterior superior iliac spine (ASIS) of both sides (left and right) and the vertical distance between the ASIS and the greater trochanter, in the sagittal plane when the subject is in a supine position.

The next phase constitutes in the positioning of the markers. The marker-set are placed in accordance to the protocols adopted.

Through anthropometric measures it is possible to obtain the masses of the segments and the moments of inertia. Meanwhile, with the paths of the markers, reconstructed with the motion capture system, the relative displacement of the body segments, the joint angles, velocities and accelerations of body segments can be obtained. Finally, on the basis of equations using anthropometric measurements the centers of rotation of the joints are calculated [23].

5. Conclusion

The analysis of the studies in the scientific literature on the postural and biomechanical alterations of the dancer, shows that these issues are of significant interest to the scientific community as well as a function of the high incidence of these critical issues in the field of ballet [24-28]. The studies reported involves, almost exclusively, the use of postural and biomechanical traditional investigations. These studies have investigated aspects concerning only the static posture analysis (alterations of the curves of the spine, knee hyperextension, foot hyperpronation, etc.) [13-15].

Consequently, it is essential to introduce the use of techniques that allow to describe, quantify and evaluate the movement in such a way so as to obtain more detailed quantitative information and open up the field of study to the analysis of the biomechanics of movement in dance, to analyze the body in motion, gait, technical movements, among others [29]. This information may be provided by technological tools of movement analysis that allow to analyze specific aspects of locomotor functions: motion analysis defines the extent and timing of any joint action, the dynamic electromyography identifies the period and the relative intensity of muscle activity, the records of the force platforms highlight the functional requirements during the load. This integrated multifactor analysis of human movement and the use of the clinical Davis protocol for gait analysis can provide more accurate quantitative data to describe, quantify and evaluate the movement in such a way so as to obtain detailed quantitative information capable of identifying the morpho-functional characteristics and the postural alterations and compensation employed by the ballet dancer.

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