CRITICAL ISSUES IN APPLIED SPORT BIOMECHANICS RESEARCH

Renato Rodano [1,2]
[1] Dipartimento di Bioingegneria, Politecnico di Milano, Milan, Italy
[2] Centro di Bioingegneria, Politecnico di Milano - Fnd. Don Gnocchi, Milan, Italy

Applied sport biomechanics represents one of the most challenging fields of biomechanics of human movement. High-speed sport movements require thorough biomechanical analysis to have a good understanding of the different aspects of the techniques especially when working with elite athletes. Through the presentation of some studies carried out at the Bioengineering Center of Milan over the last five years this paper outlines same critical issues in applied sport movement researches. In particular, we investigated the operational feasibility and the reliability of the resulting quantitative kinematics analysis of using free-floating video cameras with variable optics for field three-dimensional sport movement analysis. In other experiments the critical issue of accuracy and reliability of the biomechanical measures was studied.

KEY WORDS: opto-electronic systems, three-dimensional analysis, coefficient of variation, vertical jump.

INTRODUCTION: In sport movement studies the following aspects of the motion are usually analyzed: movement characteristics (kinematics), causative factors in the motion (kinetics) or muscle activity (electromyography). Consequently the recording techniques may take different forms such as cinematography, videography, electromyography, accelerometry, dynamometry and electrogoniometry. Many of these techniques are low cost, easy to use and available for a wider use while others are very expensive, time consuming, difficult to handle and mainly used in laboratory settings. Different kinds of studies are generally undertaken: descriptive studies in which the general aspects of the biomechanics of a particular sport skill are explained and analyzed studying the athletes' performances; comparative studies in which the technique of two or more subject or group of subjects are compared to assess the most productive or safest of them; longitudinal comparisons in which the technique changes are monitored over the time to assess the effects of training or rehabilitation programs; setups of motor evaluation test (biomechanical testing protocols) to help the athletes to perform at their best potential. In addition, these studies may be carried out in laboratory, training session as well in competitions. The complexity and flexibility as well as the demand of accuracy and reliability of the instrumentation used clearly differ from one kind of study to the other. In the field of imagine analysis for instance opto-electronic measurement systems able to provide very quickly accurate data are usually employed in laboratory. These systems however need marking procedures and experience substantial performance reduction when used outdoors. In the actual field situation, when the experimental set-up must be adapted to a pre-defined competitive environment without interfering with the performances of the athletes, the more flexible video image analysis systems are preferred. In this case, however, manual digitizing, pixel resolution of video image capture boards and computer screen theoretically reduce accuracy. Through the presentation of some studies carried out at the Bioengineering Center of Milan over the last five years this paper outlines same critical issues in applied sport movement researches.

LABORATORY VERSUS FIELD ANALYSIS. For some sports activities may be desirable or even necessary to assess athletes' performance directly in the field. A field test is a measurement that is conducted while the athlete is performing in real or simulated competitive situation. For other cyclic sport activities (such as cycling, running, rowing, swimming) it is possible to use protocols and equipment that simulate the specific field conditions. Treadmills, cycling, rowing and swimming simulators are now widely used in biomechanics research and exercise testing just because they can provide standardized procedures that are simple and inexpensive in a controlled environment. For kinematic data collection in particular, simulators offer a means of attaining a continuous action in a fixed experimental area. This allows the acquisition of a larger number of cycles per trial, which increases considerably the reliability of the kinematic variables.

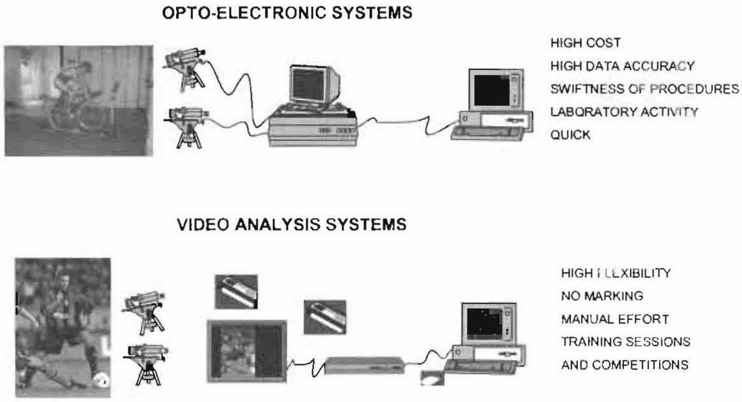

Figure 1. Comparison of opto-electronic and video analysis equipment used for kinematics measurements.

In general, measurements gained from field test are not as reliable (figure 1), and could not be differently, as those gained in a controlled laboratory environment but are often more valid and useful for athletes and coaches because of their greater specificity. Because is not possible to control all the variables, such as wind, temperature, humidity, playing surface or track conditions, athlete performance varies more in the field setting. In addition, is often difficult to acquire many trials for each subject. Our research group investigated the operational feasibility and the reliability of the resulting quantitative kinematics analysis of using free-floating video cameras with variable optics for field three-dimensional sport movement analysis. The use of this methodology allows overcoming the limitation of the traditional methods proper to conventional close-range photogrammetry. In particular, the restriction of the useful calibrated volume to the field of view made possible by fixed pairs of TV cameras. In this case the useful sequence of images (where the dimension of the acquired subject allows one to limit macroscopic digitalization errors) is often insufficient for the analysis of a complete movement cycle. This limitation hinders a fruitful application of video analysis in the frame of sport activities (alpine and nordic skiing, swimming, track and field) in which the execution of the particular technical movement is performed within a large physical space.

RESEARCH METHOD: The use of free moving TV camera with variable optics implies some methodological consequences. The main is the definition and the evaluation of a suitable calibration procedure in order to assure the highest accuracy in three-dimensional movement reconstruction, with a simultaneous speed of operation for the experiment preparation. In our studies calibration was performed by means of the DLT (Direct Linear Transformation) method, requiring a minimum of six control points describing a three dimensional distribution. The calibration procedure can be activated and performed at the same time as the main subject digitalization, by selecting a cluster of points belonging to a unique global set of control points, whose three-dimensional coordinates are previously defined and stored in a plain ASCII file. Each performed calibration is uniquely associated to the specific sequence of frames and exploited during the automatic three-dimensional reconstruction. Another important methodological concern is the definition of the best and fast procedures for the measurement of the control points. Our experience, in line with previous results, reveals that the use of geodetic theodolites allows to speed up the procedure of control points measurement, achieving a suitable trade-off between the effort of acquisition preparation and the methodical advantages of repeated calibration method. Accuracy evaluation (Pedotti and Ferrigno, 1995) in three-dimensional marker localization obtained through repeated calibrations, has been based on laboratory acquisitions with free panning and zooming cameras capturing a moving rigid body (marked stick). An analogous accuracy analysis (figure 2) has been performed on acquisitions made during an international nordic ski competition (skating and classical technique) relative to two high-level athletes. In this case, body segments, supposed to be rigid and to undergo as less as possible to digitalization errors (segment's extremities always well visible), have been taken in consideration and the same accuracy index has been calculated along the acquisition of approximately one movement cycle. Results relative to the right and left shank of both the athletes are presented.

Method

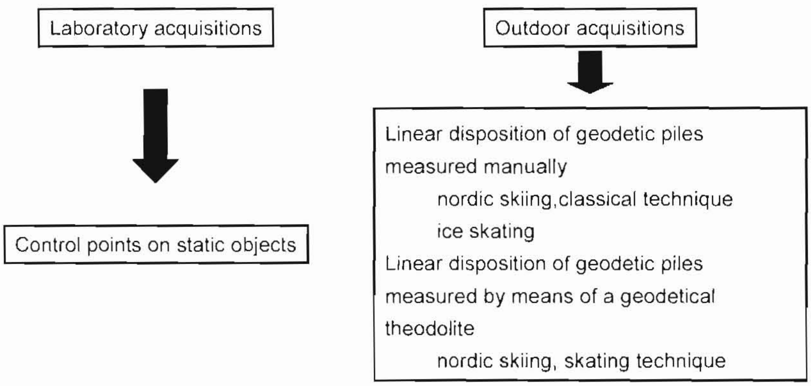

Figure 2. Scheme of the procedure used to assess the method for three-dimensional sport movement analysis by means of free floating TV cameras with variable optics.

RESULTS: Among laboratory acquisitions, performed with 2 active TV cameras and characterized by 4 calibrations with 16 control points on each TV camera for a sequence of 36 images, the accuracy on the distance measurement signal was quantified as 0.22% of the maximal dimension of the calibrated volume (2388 mm). A maximal corresponding error of 5 millimeters in the landmark three-dimensional identification is mainly due to digitalization errors and confirms that no bias was induced by the repeated calibrations. The accuracy assessment performed during competition are reported in table 1.

Table 1. Results of accuracy evaluation

SUBJECT	SKI TECHNIQUE	BODY SEGMENT	FRAMES	DISTANCE MEASUREMENT [mm]
Subject 1	skating	right shank	50	494.4 ± 46.6
Subject 1	skating	left shank	50	487.9 ± 35.7
Subject 2	classical	right shank	50	435.6 ± 34.1
Subject 2	classical	left shank	50	411.7±19.8

Results confirm that the method of repeated calibrations with a reduced number of control points allows to obtain an accuracy suitable for the three dimensional quantitative characterization of the sport performance. The operational advantage during the digitalization process of having available the image of the subject with considerable dimension allows to overcome the inaccuracies of the reduced number of control points used for the calibration. In conclusion, the use of panning and zooming cameras appears to be worth for a systematic application in the analysis of sport activities. However, a suitable trade-off between the quality of the subject's image and the inclusion of a consistent number of control points in the field of view of each active TV camera must be found. In this case, the accuracy of the analysis could be further enhanced by the redundancy of information in the calibration procedure and the most convenient choice of the control points configuration on each frame could be found (Challis and Kerwin, 1992).

ACCURACY AND RELIABILITY ISSUES. One of the main concerns in the application of movement analysis methods is variability. Several researchers identified the importance of clarifying different variation sources in experimental biomechanical research. This issue is particularly relevant when studies comparing intra and intersubject differences are conducted. Most biomechanical comparative studies have involved interindividual comparisons, which can lead to incorrect conclusions about a technique if the intraindividual variation is larger than the interindividual variation. There are two main sources of variability: biological variation or human biovariance, which refers to the relative consistency with which a subject can perform, and experimental errors, which refers to the variations in the test. With regard human biovariance, Hatze (1986) stated that the exact repetition of movements is impossible due to the continuous variations in neuromuscular-skeletal system and in external forces and torques acting on the system. The potential to execute the same motor task through different combinations of muscle forces or of motor equivalent actions may be considered a distinctive feature of the human motor system. Such an operational redundancy or compensating ability may be necessary to more easily accommodate errors and/or perturbation in movement execution. Figure 3 showing four of the contestants at the finishing line of the 100-m final of the Barcelona Olympics can give us an idea of the magnitude of the biovariance in high level athletic performances. In this figure arrows indicate typical variation in an athlete's position if the event were re-run.

Figure 3. Four of the contestants at the finishing line of the 100-m final of the Barcelona Olympics. Arrows indicate typical variation in an athlete's position if the event were re-run. (Original image courtesy of Sporting Images (www.sportingimages.com.au) and photographer Chuck Muhlstock)

Experimental errors are associated by the characteristics of the instrumentation employed to collect and process biomechanical data. For example, larger field of view, manual digitizing, pixel resolution of video image capture boards and computer screen theoretically reduce accuracy when actual videotape-recording systems are used versus direct optoelectronic analyzing system. Using an optoelectronic automatic motion analyzer in a laboratory setting our group conducted several variability studies involving movements like vertical jump, cycling, running etc. In this situation, in close agreement to what previously reported in literature studies (Hamill & McNiven, 1990), we found that the major source of variability should be researched in the biovariance associated with the human movement. Considering the measurement errors, most of them (image distortion, placement of body markers, accuracy of body modeling) give systematic errors, which are relatively harmless, while those arising from skin artifacts, digitization process and from algorithms like distortion corrections and 3-D reconstruction can give random errors that are potentially more serious.

Cycling. In cycling to achieve reliable asymmetry assessments between bilateral angular variables, we tried to analyze the different sources of variability and to assess angular thresholds to identify meaningful asymmetries of the subjects. The protocol reliability tests showed that the marker positioning is the most critical point while the noise of detection and reconstruction of 3-D data accounts for less than the 10% of the final data variability in the worst case. Table 2 reports the effect of marker repositioning on same linear and angular measures. Taking into account the results of the reliability tests, angular thresholds have been fixed for some angular variables (Table 3).

Table 2. Influence of marker repositioning (sagittal plane)

SEGMENT	LENGTH'S CHANGE (mm)	JOINT	ANGLE'S CHANGE (degrees)
Pelvis	3.0 ± 0.7	Hip	3.6 ± 1.5
Tight	4.7 ± 1.5	Knee	1.1 ± 0.3
Shank	2.9 ± 1.0	Ankle	1.1 ± 0.4
Foot	1.1 ± 0.5		

Table 3. Angular thresholds. Values are in degrees. ROM refers to the range of motion and MAX and MIN refers to the maximum and minimum angular joint flexion.

ANGLE	ROM	MAX	MIN
Hip	4°	5°	5°
Knee	3°	4°	4°
Ankle	2°	3°	3°

Vertical jump. In vertical jump we compared the variability of selected kinematic and kinetic parameters in a group of track and field sprinters while executing this exercise. In this experiments after 20 minutes of standard warm-up the subjects performed up 5 series of 5 double-legged maximum-height countermovement vertical jumps (jumps involving significant downward motion of the mass center prior to upward propulsion) while keeping their hands on the waist in order to minimize the influence of the arms and trunk inertia to the movement. For each subject, the variability of the selected parameters was then analyzed computing their coefficient of variation (CV), calculated as the percentage ratio between standard deviation and mean of the 25 trials. The results, reported in table IV, showed a large intersubject and intrasubject variability whose size was found to be subject and joint dependent. These findings suggest the need to adopt multiple trial protocols to assess the athlete characteristics especially when these indices are used for scientific research purpose or for training or rehabilitation program monitoring. As would be expected, the variability of kinetic variables was higher than those found for the kinematic variables. Several researchers previously evidenced similar trend: Winter (1984) indicated that in walking, even thought kinematic pattern were stable, the underlying kinetic data had much greater variability. Smith (1990), in a study on amputee athlete gait, evidenced that there was a tendency towards less variability in kinematics, while Knudson (1990) correctly pointed out that biomechanical studies comparing kinetic variables across subjects should be interpreted with reference to intrasubject variability due to the high variability of them. Differently from what was found by some previous researchers in other movements (van Soest et al, 1985), the data did not show a trend of decreasing variability moving proximally to distally. The lowest variability was indeed found at the ankle joint compared to hip and knee. How might these findings be interpreted? Some reasonable explanations could be resumed as follows:

- the difficulty to standardize the trunk starting position. This might have resulted in a not very consistent pattern at the hip and then in a major variability;
- the less variability at the ankle joint may be explained with the low number of muscles that act on this joint compared to the other two;
- on the hip and knee joints act a considerable number of biarticular muscles which function mainly as power distributors during the push-off phase (Bobbert & V. I. Schenau, 1988), and display not very consistent pattern of activation compared with the monoarticular extensors of hip and knee (Ryan & Gregor, 1991). This may results in a greater total variability of the hip and knee Kinetic output.

Table 4. Individual variability computed through the coefficient of variation (CV).

VARIABLES	COEFFICIENT OF VARIATION
Seasonal Performance times on 60m indoor n=8	0.6
Bilateral Vertical Jumping height n=15	2.4
Unilateral Vertical Jumping height n=16	4.8
Joint Angular Range of Motion n=15	hip: 3.18; knee: 2.82; ankle: 1.84
Joint Moment n=12	hip: 9.36; knee: 8.81; ankle 6.24
Joint Power n=12	hip: 10.22; knee: 11.6; ankle 7.53

In a following experiment we focused our attention on the reproducibility of the kinetic variables (peak joint moments and powers at the lower limbs) trying to determine the minimum number of trials required to obtain a stable mean for peak hip, knee and ankle moments and powers.

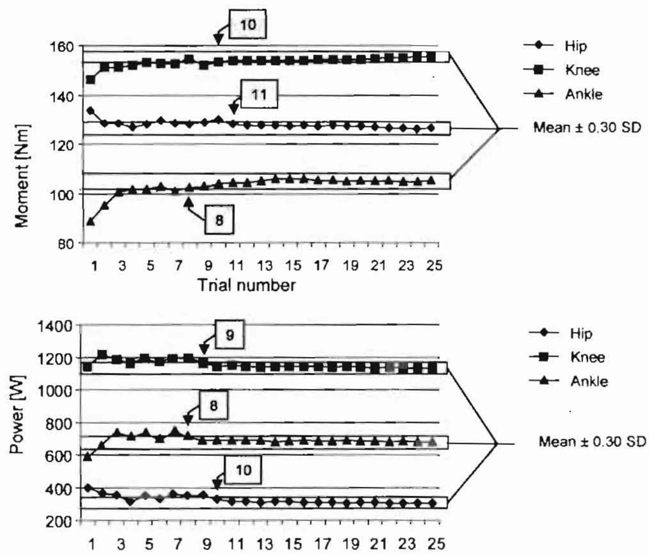

Figure 4. Graphic display of the sequential technique used to determine the number of trials needed to obtain stable values of peak moments and powers. Inside the dashed squares is reported the minimum number of trials for each variable.

For each participant the minimum number of trials required to reach a stable mean was calculated by applying the sequential estimation procedure. In the sequential estimation procedure (Hamill & McNiven, 1990) a value is generated for the cumulative mean adding one trial at time. In this study the criterion to obtain a stable mean for each parameter was met when the cumulative mean fell within the 25-trial mean ± 0.30 the standard deviation of the 25 trials and remained there for the remaining trials. The above criterion was arbitrarily chosen as a compromise between the need to obtain quite stable results and the attempt to keep the total number of trials as low as possible. Figure 4 displays a graphical example of the sequential estimation technique for a subject of this study. As it can be seen, in this case the hip peak moments get stable after 11 trials, while knee and ankle peak moment takes respectively 10 and 8 trials to reach stability. Considering powers, hip, knee, and ankle peak power get stable after 10, 9 and 8 trials, respectively. The study revealed that at least a 12-trial protocol is needed to establish a true measure for all the selected parameters. The comparison of the data reported in this study with those reported in literature clearly indicates that, in order to exchange information among research groups of different laboratories, it is fundamental to spend time and energies to set up, not only common test procedures, but also basic data elaboration.

CONCLUSION. This lecture presented some critical issues that require consideration when kinematic and kinetic variables are collected to describe and analyze sport movements both in laboratory and in the field. In particular, in planning experiments it should be remembered that even the most skilled athletes can repeat their performances within certain limits. Additionally, the total accuracy and reliability may be different among the different experimental situations: laboratory, training and competition. This implies that researches should carefully evaluate and report the conditions in which they collected their data to avoid incorrect interpretation of the results. The availability of basic standard guidelines for sport biomechanics studies could be of great help, especially for young researchers. Thanks to the multifarious competencies of its members, ISBS posses the skill to organize and lead an international working group of experienced and practicing researchers, whose mission should be the drawing of the above mentioned guidelines. The logical conclusion of this paper is an invitation to ISBS to consider and discuss this topic.

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