ADVANCED APPLICATIONS OF MOTION ANALYSIS IN SPORTS BIOMECHANICS

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Motion analysis is utilized to capture various raw linear positional data of markers placed on a body performing a movement sequence in sport. The application of motion analysis involves biomechanical modeling to calculate various kinematic and kinetic derived variables to understand the principles of motion. Since biomechanists are recruited as consultants to teams and coaches in sport teams, it is essential that they apply motion analysis to not only evaluate individual performance, but suggest methods of optimizing technique for enhanced performance and injury risk reduction. This presentation will show how advanced applications of motion analysis can lead to the biomechanical enhancement of sports performance.

KEYWORDS: motion analysis, kinematics, kinetics, performance analysis, talent identification.

INTRODUCTION & OVERVIEW:

A detailed understanding of the biomechanics of human motion in sports generally requires the service of a multiple camera three-dimensional motion analysis system to film, capture, track, digitize and analyze motion over time. A variety of motion analysis capture methods such as optical, electromagnetic and image-based techniques can be used. However, they all serve a common objective to obtain raw positional data of segment points that can be filtered and used to calculate various kinematic and kinetic derived variables. These variables are applied to quantify and experimentally validate descriptions of sports technique, and also provide biomechanical explanations of the motion patterns observed in sports.

If aided by a qualitative analysis, then coaches can use biomechanical descriptors of technique to improve the quality and clarity of teaching instruction (Knudson, 2007). In addition, a biomechanical understanding of sports technique potentially leads to the optimization of technique with respect to various performance outcomes for different sets of constraint functions (Hatze, 1983; Gonzalez, 1989). Hence, the aim of this presentation is to show how the advanced application of motion analysis in sports has the potential to significantly improve the performance of athletes.

EXTENDING MOTION ANALYSIS METHODOLGY:

Apart from performing the standard preliminary methodology for using a motion analysis system, such as defining the capture volume, synchronizing force platform data with the cameras, completing calibrations and developing appropriate marker systems, there are a number of other external procedures that need to be completed for sports biomechanical analysis:

1. Export motion analysis positional data into a numeric computational software such as Matlab (The Mathworks, Inc.) or symbolic manipulation software such as Maple (MapleSoft, Inc.) or Mathematica (WolframResearch, Inc.).
2. Use an algorithm to automatically calculate the cut-off frequency and smooth data with appropriate filter, such as fourth-order low pass Butterworth filter.
3. Write algorithms that will automate the full range of kinematic calculations such as:
    a. Relative temporal differences of linear and angular velocity maxima to quantify segmental sequencing (Ferdinands et al., in review)
    b. Three-dimension rotation or angular velocity vectors to calculate the segmental planes of motion

   c. Angular velocity vectors and moment arms from axes of rotation to end-effector to calculate segment velocity contributions (Sprigings et al., 1994).
   d. Derivation of segment interaction equations and calculation of interactive moments (Putnam, 1993).
4. Use software to calculate inverse dynamics such as Kintrak (University of Calgary), KinTools RT (MotionAnalysis), Vicon BodyBuilder (Vicon), Mathematical Mechanical Systems Pack (Wolfram Research, Inc.), etc
5. Export inverse dynamics into numeric computational software or symbolic manipulation software to perform further kinetic analysis such as:
   a. Joint and muscle powers
   b. Segment interaction analysis
   c. Power flows
6. Create multi-segment forward solution model in human simulation software such as MADYMO (TASS, Inc.), LifeMOD (LifeModeler, Inc.), OpenSIM, Mechanical Systems Pack (Wolfram Research, Inc.). Export inverse dynamic data into forward solution model.

SPORTS BIOMECHANICS ANALYSIS

Motion phase characteristics: Traditionally, in sports biomechanics a motion is divided into phases. There are four generic phases of motion: backswing, transition, downswing and follow-through. Each phase has its own defining mechanical characteristics: the backswing phase creates the end-effector arc length, the transition phase activates the stretch shortening cycle, the downswing phase accelerates the end-effector, and the follow-through phase slows down the end-effector. Motion analysis procedures need to be applied to precisely define and evaluate the biomechanical characteristics of each phase of motion that determine the overall performance outcomes of the motion.

Planes of motion: In sports, body segments are invariably forced to move in different planes of motion. In some field studies, these planes of motion are determined by projecting vectors on two-dimensional planes. However, such analyses are subject to projection errors. To gain an accurate assessment of global and relative planes of motion, three-dimensional angular rotation and velocity vectors have to be calculated. This is particularly important for sports such as golf, which place a coaching emphasis on shoulder, hip, arm and shaft planes.

Segmental sequencing: Angular velocity vectors are calculated to determine the segmental sequencing patterns in athletic motion. A general adherence to the proximal to distal sequencing scheme promotes effective performance in most sports that produce high-end effector velocities, such as in the golf swing, cricket bowling and baseball pitching. However, there are a number of violations in this classical sequencing scheme, such as the timing of long axis rotation in the tennis serve (Marshall and Elliott, 2000). Sequencing patterns are particular to each sport, and may also differentiate between elite and amateur athletes.

Kinetic analysis: Although sequencing patterns can be observed and quantified, there is no account of the causal mechanisms underlying these patterns without a kinetic analysis. For instance, it has been shown that the shank lags behind the thigh during the early swing phase in kicking due largely to the interactive moment resulting from the forward acceleration of the thigh (Putnam, 1993). The identification of the causal mechanisms of movements requires a combination of joint torque, power flow and segment interaction analysis.

Summation of segmental velocities: In the classic kinetic link principle, each succeeding distal segment is activated after the corresponding proximal segment has reached its maximum linear or angular velocity (Marshall and Elliott, 2000). Such a scheme describes the sequential summation of segmental velocities: the maximum velocity of the proximal segment or joint is added to its corresponding distal segment throughout the kinematic chain. This scheme does not occur ideally in actual motion sequences. However, mathematically, certain percentages of segmental velocities, both linear and angular, are added throughout the kinetic link chain.

Stretch-shortening cycle activation: Physiologically, it is well-established that the pre-stretching of muscles increases the strength of the subsequent concentric contraction. Stretch shortening cycles are activated at various times in sports. However, there is a distinct phase known as the transition phase in which the stretch shortening cycles of the major power actuating muscles are most strongly activated during eccentric contractions. Motion analysis techniques need to identify the various stretch shortening cycles that occur in movement patterns. Traditional approaches have used static separation angles, such as X-factor and X-factor stretch in the golf swing (Cheethan et al., 2001). Since the stretch shortening cycle is activated dynamically, it may be more effective to study accelerations and kinetics together.

PRACTICAL APPLICATIONS:

As the mechanisms of movement sequences in sport are multi-layered and interdependent, biomechanists often have to apply several motion analysis technqiues to meaningfully assess sports performance. Examples that will be presented are listed below:

Baseball pitching:

- Relative temporal phase of motion differences and throwing accuracy
- Identification of sub-transition phases in pitching
- Differences in segmental sequencing in elite and amateur pitchers (Matsuo et al., 2001)
- Activation of stretch shortening cycle in terms of pelvic-shoulder separation angle
- Causal mechanisms of arm segment angular velocities through segment-interaction analysis (Hirashima et al., 2008)

Kicking:

- Activation of stretch shortening cycle in terms of thigh flexion, knee flexion, time occurrence of maximum knee flexion and knee flexion angular acceleration
- Segmental sequencing in maximal velocity instep kicking (Nunome et al., 2002)
- Causal mechanisms of proximal to distal sequencing in kicking (Putnam, 1993)

Golf swing:

- Identification of swing plane types (Coleman and Rankin, 2005)
- Activation of static stretch shortening cycle in terms of X-factor and dynamic stretch shortening cycle in terms of X-factor stretch (Cheethan et al., 2001)
- Major segment velocity contributions in the golf swing (Ferdinands et al., 2004)

Cricket bowling:

- Segmental sequencing of elite fast bowlers (Ferdinands et al., in review)
- Forward solution model to reduce shoulder counter-rotation in bowlers (Ferdinands et al., 2008)
- Spinal kinetics and lumbar injury in fast bowlers (Ferdinands et al., 2009)
- Bowling legality analysis (Ferdinands et al., 2007)

Tennis serving:

- Identification of violations in segmental sequencing of the tennis serve (Marshall et al., 2000)
- Major segment velocity contributions in serving

CONCLUSIONS:

Biomechanists are becoming increasingly recruited as consultants to teams and coaches in sport teams. If they are to be successful, then it is essential that they apply motion analysis to not only evaluate individual performance, but suggest methods of optimizing technique for enhanced performance and injury risk reduction. As in all scientific fields, the most successful biomechanists will be innovative and pioneers in the technical development of their specialised sport. In this presentation, it will be shown that biomechanists can apply motion analysis to improve sports performance in the following ways:

1. To develop a detailed descriptive biomechanical analysis of sports technique
2. To establish the biomechanical criteria that are characteristic of optimal technique
3. To establish the validity of coaching intervention measures on selected performance outcomes
4. To perform a biomechanical performance blueprint or profile
5. To perform a quantitative talent identification survey

REFERENCES:

Cheetham, P.J., Martin, P.E., Mottram, R.E., and St Laurent, B.F. The importance of stretching the "X-Factor" in the downswing of golf: The "X-Factor Stretch." In P.R. Thomas (Ed.), Optimising performance in golf (pp. 192-199). Brisbane, Australia: Australian Academic Press. ISBN 1 875378 37 5. 2001.

Ferdinands, R.E.D., Marshall, R.N. and Kersting, U. (in review). Segmental sequencing of fast bowling in cricket. *Sports Biomechanics*.

Ferdinands, R.E.D., Kersting, U. Marshall, R.N. (2009). Three-dimensional lumbar segment kinetics of fast bowling. *Journal of Biomechanics* 42,1616–1621.

Ferdinands, R.E.D., Kersting, U. and Marshall, R. N. (2008). A Preliminary Forward Solution Model of Cricket Bowling. *International Journal of Sports Science and Engineering* 2 (4), 211-215.

Ferdinands, R.E.D., and Kersting, U. (2007). An evaluation of biomechanical measures of bowling action legality in cricket. *Sports Biomechanics* 6 (3), 315-333.

Ferdinands, R.E.D. and Marshall, R.N. 2004. Mechanical differences between an optimal swing model and the conventional swing. In Proceedings of the XXII International Symposium on Biomechanics in Sports, edited by Lamontagne, M., Robertson, D.G.E., and Sveistrup, H. (Ottawa: Faculty of Health Sciences) University of Ottawa, Ottawa, Canada, pp. 284-285.

Gonzalez, H. and Hull, M. (1989). Multi variable optimization of cycling biomechanics. *Journal of Biomechanics* 22 (11), 1151-1161.

Hatze, H. (1983). Computerized optimization of sports motions: An overview of possibilities, methods and recent developments. *Journal of Sports Science* 1 (1), 3-12.

Hirashima, M., Yamane, K. Nakamura, Y. and Ohtsuki, T. (2008). Kinetic chain of overarm throwing in terms of joint rotations revealed by induced acceleration analysis. Journal of Biomechanics 41, 2874-2883.

Knudson, D. (2007). Qualitative biomechanical principles for application in coaching. *Sports Biomechanics* 6 (1), 109–118.

Marshall, R.N. and Elliott, B.C. (2000). Long-axis rotation: The missing link in proximal-to-distal sequencing. *Journal of Sports Sciences* 18, 247-254.

Matsuo, T., Escamilla, R.F., Fleisig, G.S., Barrentine, S.W. and Andrews, J.R. (2001). Comparison of kinematic and temporal parameters between different pitch velocity groups. *Journal of Applied Biomechanics* 17, 1-13.

Nunome, H., Asai, T., Ikegami, Y. and Sakurai, S. (2002). Three-dimensional kinetic analysis of side-foot and instep soccer kicks. Medicine & Science in Sports & Exercise 34 (12), 2028–2036.

Putnam, C.A. (1993). Sequential motions of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics* 26 (Supp.1), 125-135.

Sprigings, E., Marshall, R., Elliott, B. and Jennings, L. (1994). A three-dimensional kinematic method for determining the effectiveness of arm segment rotations in producing racquet-head speed. *J. Biomechanics* 21 (3), 245-254.