The biomechanical modeling for the understanding of the shoulder pathology in overhead athletes: Application to the shoulder of tennis players'

Isabelle Rogowski & Violaine Sevrez

The shoulder plays a crucial role in overhead activity as it funnels the force and energy produced by the legs and trunk first to the upper-limb, and finally to the racket. Its contradictory role of stability and mobility makes it a vulnerable region, where problems commonly occur. The development of comprehensive biomechanical models remains a challenge in tennis because of the large range of motion and of the complexity of the shoulder joint. *B. Elliott and J. Alderson* will open this session through an historical approach by presenting key findings on the shoulder joint during the tennis serve. Then, *C. Martin* will talk about the compromise between performance enhancement and prevention of shoulder overuse injury during the tennis serve. *C. Charbonnier* will next discuss the combination of imagery and motion analysis for the study of shoulder impingements and instability during the tennis serve. *Y. Blache* will finally propose a new implementation of kinematic and musculoskeletal models to limit the classical issues in motion analysis and to estimate muscle force during dynamic movements.

Pre-opening session of ICBS on Monday the 29th of June from 8.30 to 10.30 am on the topics: '**The biomechanical modeling for the understanding of the shoulder pathology in overhead athletes: Application to the shoulder of tennis players'** organized by Isabelle ROGOWSKI & Violaine SEVREZ (University of Lyon) for the Cluster "Physical activity, performance, sport & health" of the French Society of Biomechanics

8:30 - Considerations for the Shoulder Joint in the Tennis Serve
Bruce Elliott and Jacqueline Alderson
The University of Western Australia

9:00 – Tennis Serve Biomechanics in Relation to Ball Velocity and Shoulder Joint Injuries
Caroline Martin
Université de Rennes, France

9:30 - Patient-Specific Analysis of Shoulder Kinematics and Impingement in Tennis Players
Caecilia Charbonnier
Artanim Foundation, Switzerland

10:00 - Improvement of Kinematic and Musculoskeletal Models is Necessary to Better Understand Shoulder Injuries in Athletes.
Yoann Blache
Université de Montréal, Canada

Considerations for the Shoulder Joint in the Tennis Serve

Bruce Elliott and Jacqueline Alderson
The University of Western Australia

This presentation takes an historical approach by looking at key findings from research at the University of Western Australia into the shoulder joint during the tennis serve. Since Elliott et al. (1995) identified the importance of shoulder internal rotation as the primary contributor (~40%) to racquet velocity in the serve; the shoulder has received special attention from players and coaches alike.

Biomechanical analyses in the1990s typically employed multiple (cine or video) cameras with interlocking fields of view to create 3D displacement data using the DLT approach. The upper limb was modelled as a rigid system, where shoulder, elbow and wrist joint centres were linked. These centres were calculated from digitising externally placed markers, typically on easily identifiable bony landmarks. The following topics with respect to shoulder movement and loading were completed using this approach:

1. Does technique affect shoulder range of motion (ROM) and loading? (Elliott et al., 2003; Fleisig et al., 2003; Reid et al., 2007a, b; 2008)
2. Does the reliance on internal rotation to produce racquet velocity alter shoulder ROM, and glenohumeral internal rotation deficit (GIRD)? (Kibler et al., 1996)
3. Does timing play a role in shoulder mechanics? (Elliott et al., 1999)
4. Does velocity alter shoulder loading in the serve? (Elliott et al., 2003)

The new century saw great changes in technology and automatic digitising using online marker tracking systems (e.g. Vicon, Motion Analysis, Qualisys**)** was more commonly used in sport biomechanics research. Improved hardware and musculoskeletal modelling methods were developed concurrently. Extensive efforts from a number of research groups set about to improve the accuracy and reliability of upper limb 3D modelling approaches. Particular emphasis was placed on the difficult task of recording and reconstructing the shoulder (Campbell et al., 2009 a, b) during overhead sporting activities and the integration of kinetics to assess shoulder loading during the tennis serve (Reid et al., 2008).

Performance optimisation and injury reduction in sport is a challenging task, particularly where the shoulder is concerned. We hope that this brief journey has motivated you to better understand shoulder pathology by looking at different ways to analyse the tennis serve, so this lifetime activity may be enjoyed in an injury free environment.

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Bruce Elliott and Jacqueline Alderson

Emeritus Professor Elliott is a Senior Honorary Research Fellow in Biomechanics and Associate Professor Jacqueline Alderson, the Senior Biomechanist at the School of Sport Science, Exercise and Health at the University of Western Australia. Both have a keen interest in performance optimisation and injury reduction in sport, having published over 350 refereed articles, together with 70 books or book chapters on these topics. Collectively they are currently supervising 15 PhD students, many in the area of sport biomechanics. Both are Fellows of ISBS, with Bruce a former President and Jacqueline a current Director.

Bruce, a former Dyson Lecturer, is a much sought-after international speaker on the application of biomechanics to sport, particularly tennis. He was the Keynote speaker at the inaugural World Congress on Racket Sports, the World Congress of Medicine and Science in Tennis and an invited speaker at each International Tennis Federation Conference from 2001 (Thailand - 2001; Portugal - 2003; Turkey - 2005; Paraguay - 2007; Spain - 2009; Egypt - 2011; Mexico - 2013; Turkey - 2015). Jacqueline, whose interests also include technical innovation, has also developed a reputation as a scientific speaker, having given keynotes for ISBS in Melbourne - 2012, the Korean Society of Biomechanics - 2012 , and for Vicon in Japan - 2010. This year she will present the ISBS special session keynote at the ISB conference in Glasgow.

Tennis Serve Biomechanics in Relation to Ball Velocity and Shoulder Joint Injuries

Caroline Martin
Université de Rennes, France

Tennis players are confronted with a crucial problem: how being more efficient by increasing serve's ball velocity and limiting risks of shoulder overuse injuries? The aim of this presentation is to analyze, identify and understand the biomechanical determinants of the tennis serve responsible for the performance's enhancement and the arrival of overuse upper limb joint injuries. Any kinematic or temporal pattern that significantly increases joint kinetic values without increasing ball velocity is thus considered as ''pathomechanical''. Indeed, even minor technical and temporal errors during the tennis serve, which are continually repeated throughout a match, a competitive season, or a career, may affect the performance, increase kinetics, and consequently cause tendon overuse instability problems in dominant shoulder. Conversely, proper temporal mechanics may enable players to achieve maximum performance with minimum chances of injury. Among these pathomechanical factors, an improper energy transfer during the tennis serve can decrease ball velocity, increase upper limb joint kinetics, and thus increase upper limb overuse injuries.

Caroline Martin

Research

2013 – 2015: Sport biomechanist, M2S Laboratory, Rennes 2 University. My research interests focus on the biomechanical analysis of the tennis serve and more especially on these particular points: identification of mechanical factors influencing ball velocity, energy transfer, prevention of the upper limb joint injuries, identification of pathomechanical factors, fatigue effects (9 refereed international publications)

2010 - 2013 PhD in Sports Sciences, M2S Laboratory, Rennes 2 University: "*Biomechanical analysis of the tennis serve: relationships with performance and upper limb joint injuries"*

Teaching

2013 – **2015** Sport and physical education professor, UFR APS, Rennes 2 University
2010 - 2013 Sport Science and Physical Education Department, ENS de Rennes

Tennis activity

2013 – 2015 Biomechanical analyst of tennis serve performance in professional players
2006 – 2015 High level tennis player (best ranking: ITN 1, -15)
2008 – 2015 Tennis coach (BEES 1)

Awards

2012: "For women in science" Grant, L'Oréal - UNESCO - Académie des Sciences (2012)
2013: STMS Tennis Medicine Research Grant (2013)

Patient-Specific Analysis of Shoulder Kinematics and Impingement in Tennis Players

Caecilia Charbonnier
Artanim Foundation, Switzerland

Instability and impingement of the shoulder are commonly described causes of shoulder pain in the overhead athlete, particularly in tennis players (prevalence of 50% for middle-aged players). During tennis movements, several impingements could occur: subcoracoid and anterosuperior impingements at the follow-through phase of forehand and the backhand preparation phase; subacromial and posterosuperior impingements at the cocking phase of serve when the arm is in extreme abduction and external rotation. The precise causes for these impingements remain unclear, but it is believed that repetitive contact, glenohumeral instability, etc., may play a role in the development of symptomatic impingement.

To verify these hypotheses, we developed a patient-specific measurement technique based on optical motion capture and Magnetic Resonance Imaging (MRI) to accurately determine glenohumeral kinematics and to evaluate impingement and stability in tennis. Our results showed that anterosuperior and subacromial impingements were less frequent in this population compared to posterosuperior impingements that often occurred during serving. No shoulder instability could be noted. Tennis players presented frequent radiographic signs of structural lesions which seem to be mainly related to posterosuperior impingement due to repetitive abnormal motion contacts. Our methodology combining motion capture and medical imaging offers novel insights into the analysis of shoulder impingement and instability that could, with future studies, be generalized to other shoulder pathologies and sports.

Caecilia Charbonnier

Caecilia Charbonnier was a professional tennis player (4th in Switzerland, WTA 256 in 1999). Following an injury to her shoulder, she became interested in computer graphics and sports medicine. She first obtained a Master of Advanced Studies (MAS) in 2006 in Computer Graphics at EPFL and a PhD degree in Computer Science in 2010 at MIRALab - University of Geneva. She is currently president and research director at Artanim Foundation, a center specialized in motion capture technologies. She is also lecturer in biomechanics and 3D imaging at the Department of Radiology and Medical Informatics, Faculty of Medicine, University of Geneva.

Her work focus on the interdisciplinary use of motion capture from 3D animation, live performances to movement science, orthopedics and sports medicine. Her research interests include joint biomechanics – in particular the 3D modeling, motion analysis and simulation of native or prosthetic joints – virtual reality, real time motion interaction and 3D body scanning. The results of her research have been published in more than forty international journals and conferences.

Caecilia Charbonnier has been awarded the 2009 Eurographics Medical 1st Prize in Münich, the 2011 ISAKOS Achilles Orthopaedic Sports Medicine Research Award in Rio de Janeiro, the 2014 Best Technical Paper Award at the 14th CAOS Meeting in Milan, and a special distinction for the best poster discussion at the 15th EFORT Congress in London in 2014. She is also the recipient of the 2009 Walthard Prize from the University of Geneva.

Improvement of Kinematic and Musculoskeletal Models is Necessary to Better Understand Shoulder Injuries in Athletes.

Yoann Blache
Université de Montéral, Canada

Shoulder injuries are common in sport especially when repetitive over-head movements are performed. A better understanding of shoulder mechanics, through kinematic and musculoskeletal models implementation, is necessary to improve the prevention and rehabilitation of shoulder injuries. The general purpose of this presentation is to discuss i) the interest of intra cortical pins to assess shoulder kinematics ii) kinematic model to improve shoulder movement tracking iii) musculoskeletal model to estimate muscle force during dynamic movements. Our researches using intra-cortical pins enabled to assess glenohumeral translation and subacromial space to determine dangerous movements. Analyses of intra-cortical pins coupled to skin markers have enabled to identify soft tissue artifacts of the upper-limb. These outcomes confirm that raw skin marker kinematics cannot be trusted to assess shoulder movements. Global optimization coupled to the implementation of an ellipsoid to constrain scapula movements may improve upper-limb movement tracking. Musculoskeletal model of the upper-limb, including constraint of glenohumeral non-dislocation and glenohumeral ligaments, has been implemented. From this model, index of co-activation and simulation of glenohumeral instability have been developed to assess the stabilization function of superficial and rotator cuff muscles. Efforts to improve kinematic and musculoskeletal models are still needed to assess accurately shoulder mechanics and get a better knowledge of shoulder injury risk in sports.

Yoann Blache

Yoann Blache obtained his PhD in Sports Biomechanics from the University of Lyon (France) in 2012. He is currently a post-doctoral researcher in the Simulation & Movement Modeling team at the University of Montréal (QC, Canada). His main research interest includes musculoskeletal modeling applied to sport, ergonomic and rehabilitation fields. Thus he used, in collaboration with the University of Amsterdam, a forward simulation model during his PhD to better estimate trunk function in vertical jumping. Then, he implemented an Opensim musculoskeletal model of the shoulder to firstly evaluate the shoulder muscle works in manual handling task, and secondly to assess the function of shoulder muscles in glenohumeral stability. Besides he contributes to other research projects of the Simulation & Movement Modeling team managed by the associate professor Mickaël Begon. These projects include the implementation of kinematic model of the upper-limbs, estimation and reduction of soft tissue artifacts, rotator cuff muscles activation and stress post-surgery, simulation musculoskeletal model with multiple shooting optimizations. The Simulation & Movement Modeling team has more than 20 submitted or published papers which are related to shoulder and upper-limb biomechanics since 2009.