Short communication

Effect of shoulder model complexity in upper-body kinematics analysis of the golf swing

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Abstract
The golf swing is a complex full body movement during which the spine and shoulders are highly involved. In order to determine shoulder kinematics during this movement, multibody kinematics optimization (MKO) can be recommended to limit the effect of the soft tissue artifact and to avoid joint dislocations or bone penetration in reconstructed kinematics. Classically, in golf biomechanics research, the shoulder is represented by a 3 degrees-of-freedom model representing the glenohumeral joint. More complex and physiological models are already provided in the scientific literature. Particularly, the model used in this study was a full body model and also described motions of clavicles and scapulae. This study aimed at quantifying the effect of utilizing a more complex and physiological shoulder model when studying the golf swing. Results obtained on 20 golfers showed that a more complex and physiologically-accurate model can more efficiently track experimental markers, which resulted in differences in joint kinematics. Hence, the model with 3 degrees-of-freedom between the humerus and the thorax may be inadequate when combined with MKO and a more physiological model would be beneficial. Finally, results would also be improved through a subject-specific approach for the determination of the segment lengths.

Introduction
The golf swing is a complex movement involving the whole body. If low back pain is the most common injury among golf players (Cole and Grimshaw, 2014; Gluck et al., 2008; McHardy and Pollard, 2005) and represents up to 34% of all injuries linked to the golf swing, shoulder injuries represent up to 18% (McHardy et al., 2006; Perron et al., 2016). From a performance point of view, one of the key-parameters is the X-factor (Joyce et al., 2010; Kwon et al., 2013; Myers et al., 2008) that represents the global dissociation angle between shoulders and pelvic girdle. The relative movement between shoulders and thorax is often assumed to be negligible (Healy et al., 2011). However, in an exploratory study based on medical images, the role of the whole shoulder complex was highlighted in a static position, which was close to top of backswing position. In this study, the axial rotation between shoulders (line between the two acromions) and thorax were found to contribute to more than 40% of the one between shoulder and pelvis (Bourgain et al., 2016). Since the relative contribution of the spine and the shoulders vary between subjects, it could result in excessive participation of shoulder joints and/or spine joints, and could be decisive in the occurrence of low back pain and shoulder injuries. Hence, a biomechanical analysis of the golf swing can be beneficial for the understanding of the etiology of these injuries and the development of prevention procedures.

Quantifying the kinematics during a golf swing is necessary for any biomechanical analysis. However, spine and shoulder motions are difficult to record. Generally, in golf biomechanics, the shoulder is reduced to the glenohumeral joint (GHJ) (Egret et al., 2004, 2003; Nesbit, 2005) which kinematics were obtained from the orientation of the humerus with respect to the thorax. However, the shoulder is a more complex structure that involves several joints working in a closed-loop kinematic chain, *i.e.* the sternoclavicular joint (SCJ) between the sternum and the clavicle; the acromioclavicular joint (ACJ) between the clavicle and the scapula; the scapulothoracic joint (STJ) between the scapula and the thorax, and the GHJ