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Intersegmental dynamics of 3D upper arm and forearm longitudinal axis rotations during baseball pitching

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ABSTRACT

The shoulder internal rotation (IR) and forearm pronation (PR) are important elements for baseball pitching, however, how rapid rotations of IR and PR are produced by muscular torques and inter-segmental forces is not clear. The aim of this study is to clarify how IR and PR angular velocities are maximized, depending on muscular torque and interactive torque effects, and gain a detailed knowledge about inter-segmental interaction within a multi-joint linked chain. The throwing movements of eight collegiate baseball pitchers were recorded by a motion capture system, and induced-acceleration analysis was used to assess the respective contributions of the muscular (MUS) and interactive torques associated with gyroscopic moment (GYR), and Coriolis (COR) and centrifugal forces (CEN) to maximum angular velocities of IR (MIRV) and PR (MPRV). The results showed that the contribution of MUS account for 98.0% of MIRV, while that contribution to MPRV was indicated as negative (−48.1%). It was shown that MPRV depends primarily on the interactive torques associated with GYR and CEN, but the effects of GYR, COR and CEN on MIRV are negligible. In conclusion, rapid PR motion during pitching is created by passive-effect, and is likely a natural movement which arises from 3D throwing movement. Applying the current analysis to IR and PR motions is helpful

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in providing the implications for improving performance and considering conditioning methods for pitchers.

1. Introduction

Throwing a ball is one of the most dynamic skills in all sports (Barrentine, Matsuo, Escamilla, Fleisig, & Andrews, 1998). Baseball pitching is three-dimensional (3D), and includes rapid rotations of multiple segments of the thrower's body. With longitudinal-axis rotations of the upper arm and forearm being important characteristics of 3D throwing (Elliott, Baxter, & Besier, 1999; Marshall & Elliott, 2000), it is widely known that the shoulder internal rotation (IR) is the fastest joint motion among the participating arm joints (Barrentine et al., 1998; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Nissen et al., 2007), and IR angular velocity contributes the most to maximizing the resultant velocity of the throwing hand at ball release (Naito & Maruyama, 2007). It was also demonstrated that the maximum angular velocity of forearm pronation (PR) is greater than that of elbow extension and wrist flexion (Barrentine et al., 1998; Nissen et al., 2009). The upper arm and forearm rotations about the longitudinal-axis are necessary for rapid throwing arm movement, while knowledge of the underlying mechanism of rapid IR and PR motions during pitching is insufficient and more controversial. For example, previous studies emphasized that pronator strengthening is required for improving performance (Keeley, Wicke, Alford, & Oliver, 2010; Laudner, Wilson, & Meister, 2012), because of excessive forearm pronation motion observed in baseball pitching (Nissen et al., 2007, 2009). However, in contrast to the theory that emphasizes pronator strength to generate pronation motion, Pomianowski et al. (2001) suggest that excessive forearm pronation during pitching might increase laxity of the elbow joint in baseball pitchers, leading to increased risk of elbow injuries. It is accepted that shoulder IR torque is an integral part of overarm throwing (Elliott et al., 1999), while Aguinaldo, Buttermore, and Chambers (2007) reported that professional baseball pitchers displayed reduced peak torque of the shoulder IR, compared to college and high school pitchers. Aguinaldo et al. suggest that the coordinated motion of skilled athletes allows the throwing shoulder to move with decreased torque at the shoulder.

Multijoint movements, such as throwing and striking skills, are compounded from complex linkage, because a joint rotation in multi-joint limb system is influenced not only by the muscular torque acting at that joint but also by interactive torque originating from the other joint rotations (Putnam, 1993). Recent work has focused on complexity among multiple segmental interactions, and has increasingly attempted to examine the question of whether a joint motion is generated by the muscular (active) or non-muscular (passive) interactive torques. For example, an induced-acceleration analysis, which examines mechanical relationships between joint accelerations and causal torques, commonly found that an effective utilization of the non-muscular passive interactive torques is a key factor in creating dynamic limb motion (Hirashima, Kudo, Watarai, & Ohtsuki, 2007; Hirashima, Yamane, Nakamura, & Ohtsuki, 2008; Naito & Maruyama, 2007, 2008; Timmann, Lee, Watts, & Hore, 2008). In particular, previous investigations of baseball pitching demonstrated that rapid extension of the throwing elbow occurring prior to ball release is mainly exerted by non-muscular passive torque originating from centrifugal and Coriolis forces due to the trunk and upper arm rotations, and not primarily by the elbow extension muscular torque (Hirashima et al., 2008; Naito & Maruyama, 2008).

From a mechanical perspective, the passive interactive torques can be divided into three primary components (centrifugal force-, Coriolis force-, and gyroscopic moment-related components), depending on different kinematic variables. These three components generally have different effects on making limb rotations in the linked chain with different magnitudes of torques. For example, a centrifugal force arising on a planar two-link chain results in a motion of the distal segment, depending on the