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Dynamic contribution analysis of tennis-serve-motion in consideration of torque generating mode

Sekiya KOIKE[a]* and Yuhei HARADA[b]

[a]*Faculty of health and sport sciences, Univertsity of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8574, Japan*
[b]*Graduate school of comprehensive human sciences,Master's program in health and sport sciences, University of Tsukuba, Japan*

Abstract

The purpose of this study was to quantify dynamic functional roles of upper body joint torques to the generation of racket head speed in consideration of the joint torque generating mode in the tennis serve motion. The upper body with a racket was modelled as a linked eleven-segment system consisting of the upper limbs, shoulder girdles, head, upper trunk and the racket. The contributions of the joint torque term, motion-dependent term, gravitational term and external force term to the generation of racket head speed were calculated from the equation of motion for the system. Furthermore, the joint torque was divided into two components, such as eccentric torque component, which shows negative sign of its torque power, and concentric torque component, which shows positive sign of its torque power. An algorithm which converts the motion dependent term into other terms was proposed. The results obtained in this study showed that 1) motion dependent term was the great contributor to the generation of racket head speed prior to the impact and 2) after converting motion dependent term into other terms, racket head speed was mainly obtained by eccentric torque component about internal rotational axis at racket side shoulder joint.

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Keywords: Tennis Serve; Torque Generating Mode; Dynamic Contribution

* Corresponding author. Tel.: +81-29853-2677
E-mail address: koike@taiiku.tsukuba.ac.jp

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1. Introduction

Swing motions, such as tennis serve motion (Springings et al., 1994, Elliott et al., 1995; Bahamonde, 2000) and baseball pitching motion, are sports motions that accelerate a tip of hitting tool or distal end of body to high speed within a short time. Although previous studies indicate that motion dependent term (MDT) is a significant contributor to the generation of end-point speed of linked-segment systems in baseball pitching motion (Naito et al., 2008; Hirashima et al., 2008) and the soccer kicking and ball throwing motion (Putnam, 1993), dynamic contributions of joint torques to the generation of racket head speed during the tennis serve motion have not been investigated. From a viewpoint of torque generating mode, joint torques can be divided into eccentric and concentric torque components judged from the sign of joint torque powers. The purpose of this study was to quantify dynamic functional roles of upper body joint torques to the generation of racket head speeds with consideration of the torque generating mode in tennis serve motion.

2. Methods

2.1. Equation of motion for upper body and racket system

The upper body with a racket was modeled as a linked eleven-segment system consisting of the upper limbs, shoulder girdles, head, upper trunk, and the racket as shown in Figure 1.

The translational and rotational equations of motion for each segment of the upper body and racket system can be summed up in a matrix form as follows:

$$\boldsymbol{M}\dot{\boldsymbol{V}} = \boldsymbol{P}\boldsymbol{F} + \boldsymbol{P}_{\text{ext}}\boldsymbol{F}_{\text{ext}} + \boldsymbol{Q}_{\text{act}}\boldsymbol{T}_{\text{act}} + \boldsymbol{H} + \boldsymbol{G} \quad (1)$$

where $\boldsymbol{M}$ is the inertia matrix and $\boldsymbol{V}$ is the vector containing the translational and rotational velocity vectors of each segment's CG, $\boldsymbol{P}$ and $\boldsymbol{P}_{\text{ext}}$ are the coefficient matrix of vector $\boldsymbol{F}$ which contains all joint force vectors and the coefficient matrix of external force vector $\boldsymbol{F}_{\text{ext}}$, $\boldsymbol{Q}$ is the coefficient matrix of vector $\boldsymbol{N}$ which contains moment vectors at all joints, $\boldsymbol{H}$ is the vector containing jyro moment vectors of all segments, and $\boldsymbol{G}$ is the vector of the gravitational component.

The equation for constraint condition in which adjacent segments are connected by joint is expressed as follows:

$$\boldsymbol{C}\boldsymbol{V} = \boldsymbol{0} \quad (2)$$

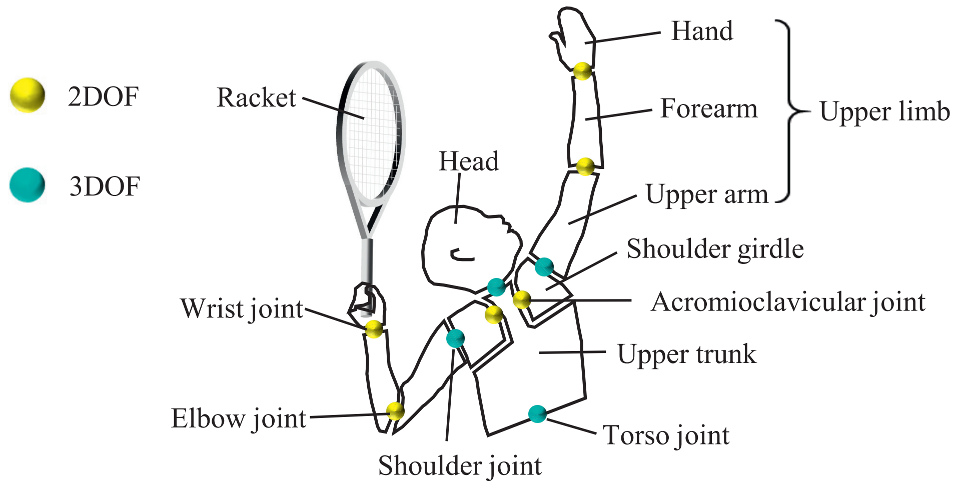

Fig.1 A schematic representation of upper body and racket model consisted of eleven rigid segments