LOWER BODY SIMULATION ANALYSIS ON INCREASING ROTATIONAL VELOCITY OF LOWER TRUNK IN BASEBALL TEE BATTING

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The aim of this study was to investigate optimum timings of joint torques of the lower extremities in order to generate larger angular velocity of the lower trunk through baseball tee bating. A lower body seven-segment computer simulation model was developed. The model has totally 17 active torque generators at individual hip, knee and ankle joints, and torso joint. The optimisation procedure for the performance improvement was carried out by varying timings of exerting joint torques to maximise the peak forward angular velocity of the lower trunk about the vertical axis. The difference in exerting timing of the hip and knee joint torques of the stride leg contributed to increasing the peak angular velocity of the lower trunk, and that of the pivot hip flexion/extension joint torque prior to the impact contributed to the inhibition of the excessive rotational movement of the lower trunk.

KEY WORDS: torque-driven simulation, optimisation, lower trunk.

INTRODUCTION: Movements of lower extremities for baseball batting contribute largely to generating a bat-head speed by utilising a kinetic link transferring energy through successive body segments (Welch, Banks, Cook, & Draovitch, 1995). Then, the kinetic link should be caused by exerting proper timing of each joint torque, where the proper timing might be effective to obtain larger angular velocity of the lower trunk in order to increase the bat-head speed. However, previous studies of baseball batting have not reported how kinetics of the lower extremity associates with the rotational movement of the lower trunk. Computer simulation provides insight into the understanding of mechanics in a recorded movement or makes predictions about hypothetical movements (Yeadon & King, 2002). This study also suggests that a torque-driven simulation is useful to determine the joint torques generating human movement. When focusing on obtaining a suggestion for coaching, it is likely to be effective for batters to change the timing rather than the magnitude of joint torques from the viewpoint of strength training. Therefore, the quantification of the difference in timing of exerting joint torque at the lower extremities, which induces large rotational movements of the lower trunk, will provide useful information about the improvement of batting performance. The aim of this study was to investigate optimum timings of exerting joint torques of the lower extremities in order to generate larger angular velocity of the lower trunk through the simulation of baseball tee batting.

METHODS: A lower body seven-segment computer simulation model was developed to investigate the mechanics of the lower extremities in baseball batting (Figure 1). The centres of pressure (COPs) of both legs represent the virtual joints, which are constrained with the ground throughout the analysis of bat swing. The model has totally 17 active torque generators at individual hip, knee and ankle joints, and torso joint.
An analytical form of the equation of motion for the lower body can be expressed, similar to the study (Koike & Harada, 2014), as follows:

$$\dot{\boldsymbol{V}} = \boldsymbol{A}_{T_a}\boldsymbol{T}_a + \boldsymbol{A}_V + \boldsymbol{A}_G\boldsymbol{G} + \boldsymbol{A}_\eta\ddot{\boldsymbol{\eta}} \quad (1)$$

where V is the generalised velocity vector consisting of linear velocity vectors with respect to the centre of mass (CM) and angular velocity vectors for all the segments; A_{Ta} and A_G indicate the coefficient matrices for the active joint torque vector T_a and gravitational force vector G; A_V indicates the motion-dependent term (MDT) consisting of force and moment caused by centrifugal and Coriolis forces and gyro moment. A_η is the coefficient matrix for the vector ij that denotes the component arising from the difference of second order time derivatives of two position vectors: one is from CM of foot to COP, and the other is the vector of the COP.

Twenty-two collegiate baseball players (height: 1.73±0.04 m, mass: 73.9±6.2 kg) performed tee batting, in which the ball was set at middle height hitting point. Three-dimensional coordinate data were obtained with a motion capture system (VICON MX+, 12 cameras, 250 Hz) and were smoothed with a Butterworth digital filter (7-15 Hz). Ground reaction forces of both legs were measured with force platforms (1000 Hz). Kinetic data input for the simulation model were obtained from an inverse dynamics calculation using numerical computation with Matlab (Mathworks Inc.). The locations of the CM and inertia parameters of the individual segments were estimated by using the body segment parameters of Japanese athletes (Ae, 1996). The period for analysis was defined as the time from the instance when the stride foot contacts with the ground to the ball impact. Then, a data for simulation was extracted from the kinetics data of the participant (height: 1.75 m, mass: 74 kg) who performed large bat-head speed (37.9 m/s) with a general swing motion in the participants.

Two types of optimisation procedures were carried out. The first one is initial optimisation named “matched simulation” which finds matched torques between the measured and simulated performances in order to reduce calculation error caused by modelling errors. The second one is optimised simulation that finds the optimum torques of the individual joints in order to maximise the peak forward angular velocity of the lower trunk about the vertical axis.

The initial optimisation varied 388 parameters (e.g., values and timings for joint torques, torso joint force, and free moments) within ±5% of the measured values of the participant by using an optimisation function, fmincon, in Matlab. In this study, node parameters were set at the peaks and zero-crossings of each torque curve (Figure 2), then the nodes were fitted to a cubic spline (Fujii & Hubbard, 2002), and the nodes are transformed to add the midpoints between adjacent nodes (Hiley & Yeadon, 2013). In order to assess the difference between the matched simulation and measured performances, overall %RMS differences were calculated between the time history of the simulation and measured data in segment orientations and joint angles.

The optimised simulation varied 175 timing parameters within ±50 ms by using Simulated annealing function in Matlab. The objective function was set to maximise the peak forward angular velocity of the lower trunk about the vertical axis for the optimised simulation. Penalties were imposed when the segment orientations and joint angles exceeded more than 10% of those in the measured values. In the optimisation processes, the individual foot segment data, such as CM acceleration and orientation, used the measured data for stable optimisation.

Figure 1: Seven-segment computer simulation model of the lower body.

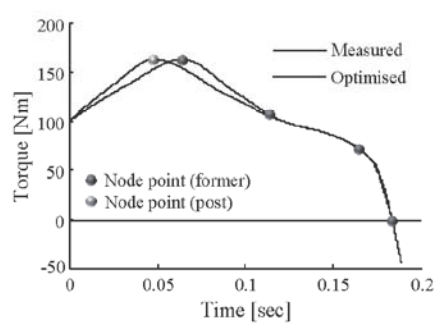

Figure 2: Schematic view of the measured and optimised joint torques about the pivot hip flexion/extension axis.

RESULTS & DISCUSSION: Since the overall %RMS differences of the results in the matched simulation (Figure 3) were quite small; such as, 2.2% for the segment orientation angles (15 DOFs), and 3.9% for the joint angles (14 DOFs), the matched simulation model would be allowed to investigate the mechanism of increasing the forward angular velocity of the lower trunk about the vertical axis. In the optimised simulation, the peak forward angular velocity of the lower trunk about the vertical axis increased up to about 25% (pre: 9.4 rad/s, post: 11.8 rad/s) as shown in Figure 4, where the segment orientation and joint angles were within 2SD of the range of motion in all participants.

Figure 5 shows the results of key kinetic variables of the pivot and stride legs in the optimisation. In comparison with the matched and optimised simulations, relative large differences emerge in the hip and knee joint torques of the stride leg during the first half of the swing motion, and in the hip flexion/extension torque of the pivot leg during the last half of the motion. The results indicate that the differences of exerting timing of the joint torques in the lower extremities affect largely the rotational movement of the lower trunk.

In baseball batting, the lower extremity joints are not required to generate the maximal voluntary torques, being different from other motions; such as vertical jump and sprint running. In addition, since it is suggested that batting motion is generated by a kinetic link through successive body segments (Welch et al.,1995), the difference of exerting timing affect largely the generation of the angular velocity of the lower trunk. This is why the differences in exerting timing of the joint torques could cause the increase in the peak angular velocity without change of the magnitude of the torques. In particular, the ground reaction force of the stride leg was considerably larger than that of the pivot leg during the forward swing (not shown in this paper), and Yanai (2007) reported that the stride leg acts as the primary source of the body rotation for bat swing. Therefore, the large joint torques at the hip and knee joints of the stride leg would affect the peak angular velocity of the lower trunk.

After the peak value of the forward angular velocity of the lower trunk appearing, the angular velocity decreased toward the ball impact (Figure 4). Prior to the ball impact, the difference of the hip flexion/extension torque of the pivot leg showed larger value than that about other joint axes of the legs (Figure 5). Hence, the results indicate that the hip flexion/extension torque of the pivot leg prior to the impact is exerted to inhibit an excessive rotation of the lower trunk rather than to increase the peak forward angular velocity.

In this study, the rotational angle and angular velocity of the lower trunk at the ball impact

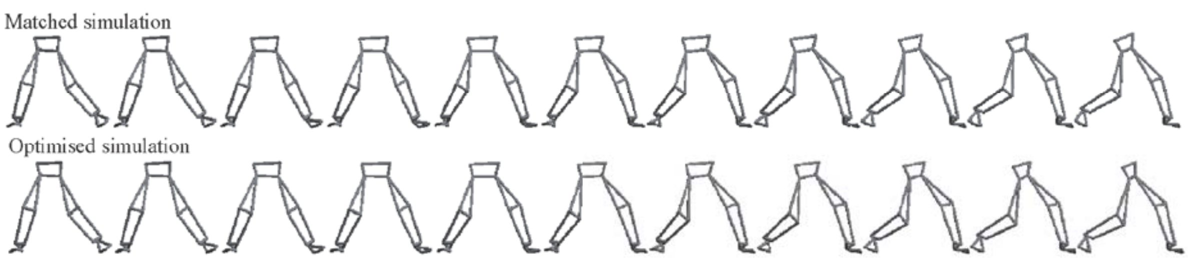

Figure 3: Stick figures of the lower body in the matched and optimised simulations.

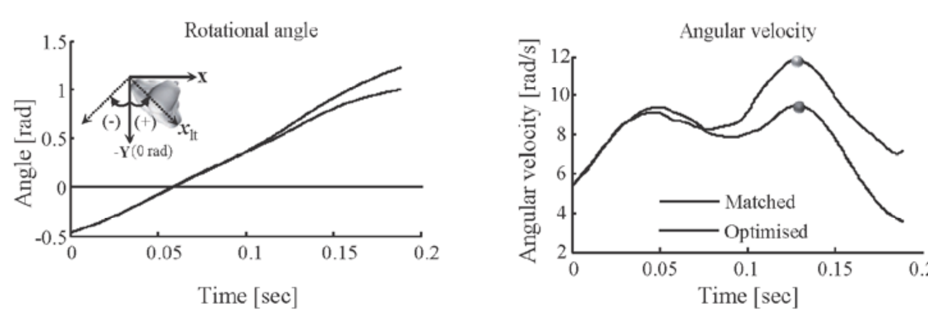

Figure 4: Rotational angle and angular velocity of the lower trunk about the vertical axis.

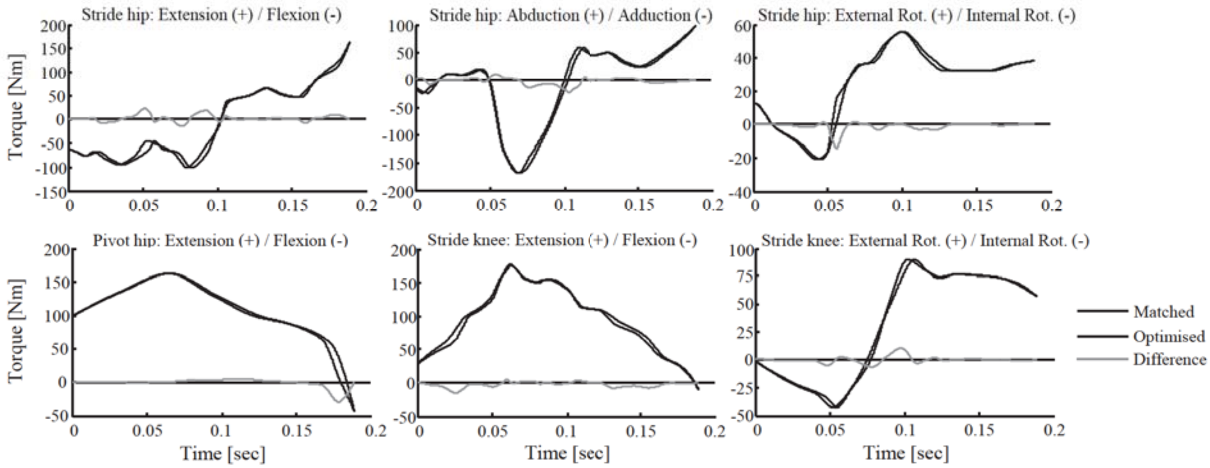

Figure 5: Key joint torques of the pivot and stride legs in the optimisation.

were considerably larger in the optimised simulation than in the matched simulation (Figure 4). The result might suggest that a batter should try to rotate the lower trunk much harder in the forward direction in order to obtain larger angular velocity. The batter, however, is also required to hit a ball accurately by adjusting the lower trunk movement. Although the results of the present study will help to provide useful information to obtain a larger bat-head speed, which is one of the representative parameters of the batting skill, we should set a restriction of the objective function in the optimisation considering a more realistic situation.
Limitations exist in this study: The movements of the individual foot segments were set at the measured data; the swing time was fixed at the time in the measured data. In further research, the interaction between the foot and the ground should be quantified using spring-dampers set at the several points of each foot, based on previous study (Yeadon & King, 2002). Since the swing time affects the peak value of the angular velocity of the lower trunk, changing the swing time might generate a motion that is close to a realistic batting situation.

CONCLUSION: This study proposed an optimised simulation for determining the joint torques of the lower extremities to increase the peak values of the forward angular velocity of the lower trunk segment. The difference in exerting timing of hip and knee joint torques of the stride leg contributed to increasing the peak value of the angular velocity of the lower trunk. The role of hip flexion/extension torque of the pivot leg prior to the ball impact was to inhibit the excessive rotational movement of the lower trunk. The optimised simulation approach will provide us with new information about the lower body movement for baseball studies.

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