A SIMULATION ANALYSIS ON EFFECTS OF THE UPPER BODY MOTION ON BAT-HEAD SPEED IN BASEBALL BATTING

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The purpose of this study was to explore for optimum motions of the upper body in order to generate a high bat-head speed through computer simulation of baseball tee batting. A bat and upper body nine-segment computer simulation model was developed. The model has totally 17 degrees of freedom at individual shoulder, elbow, wrist and torso joints. The optimisation procedure for the performance improvement was carried out by varying values and timings of joint angle in order to increase the bat-head speed to 40 m/s at the ball impact. The changes in the joint angular velocities about the shoulder internal/external rotation and elbow flexion/extension axes of the knob-side contributed to increasing large bat-head speed. These joint angular velocities of the shoulder and elbow affect to the horizontal movement of the in the forward direction before ball impact.

KEY WORDS: angle-driven simulation, optimisation, tee batting.

INTRODUCTION: In baseball batting, a bat-head speed is a major decisive factor of the velocity of the batted ball (Sawichi, Hubbard, & Stronge, 2003). It is likely to be a great advantage for batters to gain the highest possible bat-head speed at ball impact. The bat-head speed is generated by utilising a kinetic link that transfers mechanical energy from the lower to upper limbs and the bat through consecutive body segment motions (Welch, Banks, Cook, & Draovitch, 1995). Motions of the lower body could generate large mechanical energy. High skilled batters demonstrate effective batting techniques to generate and transfer the mechanical energy toward the trunk and upper limbs and the bat to obtain high bat-head speed. Therefore, investigating optimum motions of the upper body consisting of the bat parameters will increase our knowledge that helps to improve batting performance and obtain insights into batting techniques. In sport biomechanics research, a computer simulation approach would enable us to provide suggestions for key motions to improve sports performance. However, no study has reported the simulation analysis on baseball batting which is one of the most complex movements in sports. The purpose of this study was to explore for optimum motions of the upper body in order to generate a high bat-head speed through computer simulation of baseball tee batting.

METHODS: A male skilled collegiate baseball player (height: 1.75 m, mass: 74 kg) performed baseball tee batting, which was set at a middle height hitting point. The participant was asked to perform his bat swing to achieve as high a bat-head speed as possible (37.9 m/s). Three-dimensional coordinate data (body: 47 markers, bat: 6 markers) were obtained with a motion capture system (VICON MX+, 12 cameras, 250 Hz) and were smoothed with a Butterworth low-pass digital filter (7-15 Hz). The locations of the centre of mass and inertia parameters of individual segments were estimated using the body segment parameters of Japanese athletes (Ae, 1996). Kinematic and kinetic data were calculated by using motion analysis programs written in Matlab (Mathworks Inc., USA). The period for analysis was defined from the beginning of the forward swing to the ball impact.
A bat and upper body nine-segment computer simulation model was developed to investigate mechanics of the upper body in baseball batting (Figure 1). The model has totally 17 degrees of freedom at the individual shoulder, elbow, wrist and torso joints. Each joint centre was calculated from a midpoint between the lateral and medial markers.

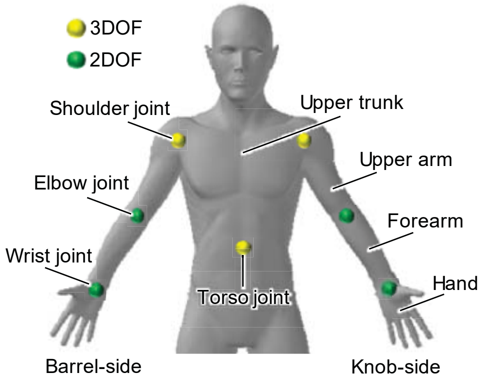

Figure 1: Computer simulation model of the upper body.

Table 1: Bat parameters for measured and optimised performances.

	Measured	Optimised
Bat-head speed		
Translational component	25.9 m/s (68.3%)	28.9 m/s (71.9%)
Rotational component	12.0 m/s (31.7%)	11.3 m/s (28.1%)
Mechanical energy	310.5 J	385.8 J

Figure 2: Motions for the upper body and bat in measured and optimised performances.

The elbow varus/valgus and wrist pronation/supination axes were defined as anatomical constraint axes, which were assumed no angular displacements. Input to the simulation model comprised the joint angle time history of each joint. Output from the model included bat parameters, e.g., the bat-head speed and angular velocities of the upper body segments. In order to evaluate the difference between the measured and simulated performances, an overall norm difference was calculated as differences of the time history of angular velocities for the upper body segments and joints between the measured and simulated data.
The optimisation procedure was carried out to obtain higher bat-head speed. The optimised simulation was varied 89 parameters, e.g., values and timings for joint angle changes, within ±5% of the measured one of the participant by using Simulated Annealing function in Matlab. In this study, node parameters were set at the peaks and zero-crossings of each joint angle curve, and then were fitted to a cubic spline function (Fujii & Hubbard, 2002). The fitted nodes were transformed to add the midpoints between adjacent nodes (Hiley & Yeadon, 2013). The optimisation could increase the bat-head speed to 40 m/s at the ball impact, which was approximately 5% greater than the measured one. In the optimisation process, three limitations were imposed to avoid a non-realistic bat swing, i.e., percentage norm difference of the bat angular velocity as a percentage of the measured one was less than 15%; angle of the vector of bat-head velocity between the measured and optimised ones was less than 5 degrees; norm difference of the impact location on the bat at the ball impact was less than 0.08 m. The ball impact location on the bat was assumed to locate at 0.15 m from the bat head along the longitudinal axis.

RESULTS & DISCUSSION: The overall percentage norm differences of the results between the measured and optimised performances were 3.7% for the segment angular velocity and 3.2% for the joint angular velocity, respectively. These differences would be small in overall observation of the upper body (Figure 2) but there was no study of similar research in baseball. In the simulation, the bat-head speed at the ball impact increased from 37.9 m/s to

Table 2: Differences of time histories of joint angular velocities at the upper limbs and torso joints between measured and optimised performances.

		Difference (%)	
		Barrel-side	Knob-side
Shoulder	Flexion / Extension	2.7	5.8
	Adduction / Abduction	3.3	2.5
	Internal / External rotation	4.4	10.4
Elbow	Flexion / Extension	3.5	17.9
	Pronation / Supination	4.8	2.6
Wrist	Palmar / Dorsal flexion	5.3	3.5
	Radial / Ulnar flexion	3.3	2.9
Torso	Retro / Ante flexion	5.8	
	Right / Left lateral flexion	2.5	
	Right / Left rotation	2.2	

40.2 m/s. The bound of the changed swing time was set within ±5% but there was no change. For the bat parameters (Table 1), the translational component of the bat-head speed increased from 25.9 m/s to 28.9 m/s (4% greater) with the decrease in the rotational component (12.0 to 11.3 m/s). However, the mechanical energy of the bat increased 24.3%, which did not always coincide with the percentage increase in the bat-head speed. The results indicate that the translational component of the bat-head speed contributes to increasing than its rotational one.

Table 2 shows the differences in time history of the joint angular velocity as a percentage of the measured one. For the knob-side (grip end side) upper limb, the difference of the shoulder internal/external rotation axis was 10.4% and that of the elbow flexion/extension axis was 17.9%.

Figure 3 demonstrates the time histories of the joint angular velocities about the shoulder internal/external rotation and elbow flexion/extension axes in which large differences between the measured and optimised ones were observed. The joint angular velocity about the shoulder internal/external rotation axis changed in the last phase, and its peak at 0.05 sec before the ball impact decreased. The initial joint angular velocity about the elbow flexion/extension axis shifted from the extension to flexion, and each timing of flexion and extension in the last phase shifted earlier.

Koike and Mimura (2016) revealed by the forward dynamic analysis that the shoulder joint torque of the knob-side positively contributed to generating the bat-head speed, and the elbow flexion/extension torque of the knob-side did negatively. Since the shoulder joint around which large muscles surround can generate large joint torque than other upper limb joints and affect the bat movement, changing the peak joint angular velocity and its timing about the shoulder internal/external rotation axis could be managed. During the last phase, the bat movement seemed the horizontal one, as shown in Figure 2. The joint angular velocity about the shoulder internal/external rotation axis of the knob-side might contribute to the horizontal movement of the bat. Several researchers have indicated that the elbow flexion/extension of the knob-side plays a role to control the bat movement (Escamilla, Fleisig, DeRenne, & Taylor, 2009; MaIntyre & Pfautsch, 1982). Therefore, changing the timing of the peak elbow extension angular velocity would help to adjust the bat movement in response to the change in the shoulder joint motion of the knob-side.

Although most of computer simulation approaches are likely to be a torque-driven model, the simulation for the motion of baseball batting would be a hard task to obtain acceptable results because the body segment motions of baseball batting are a complex movement in sports. The angle-driven model based on the previous study (Hiley & Yeadon, 2013),

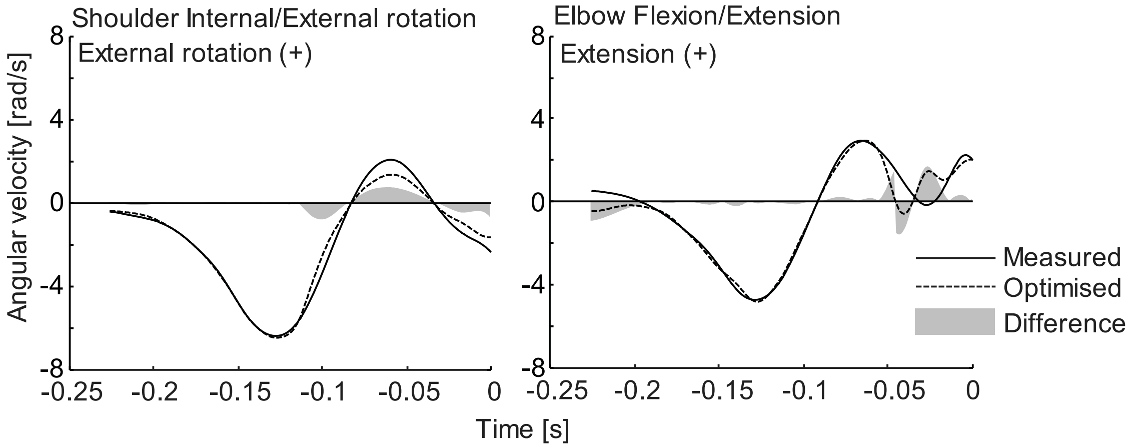

Figure 3: Time histories in joint angular velocities about the shoulder internal/external rotation and elbow flexion/extension axes of the knob-side.

however, will provide an acceptable tool to avoid problems in calculation, re-construction of the body segment motions of baseball batting and so on, and obtain suggestions for coaching. In addition, it might be more useful to conduct the simulation of baseball batting for a real pitched ball to obtain the practical knowledge in the future work.

CONCLUSION: This study proposed an optimised simulation for determining the joint angles of the upper limbs and torso to increase the bat-head speed at ball impact. The changes in the joint angular velocities about the shoulder internal/external rotation and elbow flexion/extension axes of the knob-side in angle-driven simulation contributed to producing large bat-head speed. Findings to increase bat-head speed are as follows; the joint angular velocity about the shoulder internal/external rotation of the knob-side contributes to the horizontal movement of the bat in the forward direction before ball impact, and that of the elbow flexion/extension helps to adjust the bat movement in response to the shoulder joint motion.

REFERENCES:

Ae, M. (1996). Body segment inertia parameters for Japanese children and athletes (in Japanese). Japanese Journal of Sports Sciences, 15, 155-162.

Escamilla, R.F., Fleisig, G.S., DeRenne C., and Taylor, M.K. (2009). Effects of bat grip on baseball hitting kinematics. Journal of Applied. Biomechanics, 25, 203-209.

Fujii, N. & Hubbard, M. (2002). Validation of a three-dimensional baseball pitching model. Journal of Applied Biomechanics, 18(2), 135-154.

Hiley, M.J. & Yeadon, M.R. (2013). Investigating optimal technique in a noisy environment: application to the upstart on uneven bars. Human movement sciences, 32, 181-191.

Koike, S. & Mimura, K. (2016). Effective timing of exerting joint torques to obtain baseball bat head speed. Proceeding of the 34th International Conference on Biomechanics in Sports. Tsukuba: University of Tsukuba.

Mcintyre, D.R. & Pfautsch, E.W. (1982). A kinematic analysis of the baseball batting swings involved in opposite-field and same-field hitting. Research Quarterly for Exercise and Sport, 53 (3), 206-213.

Sawichi, G.S., Hubbard, M., & Stronge, W.J. (2003). How to hit home runs: Optimum baseball bat swing parameters for maximum range trajectories. American Journal of Physics, 71 (11), 1152-1162.

Welch, C.M., Banks, S.A., Cook, F.F., & Draovitch, P. (1995). Hitting a baseball: A biomechanical description. Journal of Orthopaedic & Sports Physical Therapy, 22 (5), 193-201.