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Main contributors to the baseball bat head speed considering the generating factor of motion-dependent term

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Abstract

Motion-dependent term (MDT), which consists of centrifugal force, Coriolis force and gyro moment expressed in the equation of motion for a multi-link system, plays significant roles in the generation of tip speed in a high speed swing motion. A phenomenon caused by the MDT is usually called as "whip-like effect" and "kinetic chain". Since the baseball batting is one of high speed swing motion manipulating a bat by both hands, it is important to make clear the generating factor of MDT and main contributors to the generation of bat head speed. The purpose of this study was to quantify main contributors to the bat head speed considering the generating factor of MDT. The whole-body segments with bat were modelled as a system of sixteen-rigid linked segments. The equation of motion for the system was obtained by considering anatomical constraint axes at joints and modelling errors. A recurrence formula with respect to the generalized velocity vector consisting of linear and angular velocity vectors of all segments was derived. Five collegiate baseball players, participated as subjects, hit a teed ball as strong as possible. The kinematic and kinetic data were measured with the motion capture system with 3 force platforms and an instrumented bat. The results indicates that the abduction and extension torques at the knob-side shoulder joint and the forward rotation torque at the torso joint are the main positive contributors to the generation of bat head speed among the participants.

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Keywords: Baseball tee batting; Cumulative effect; Recurrence formula; Closed-loop problem; Multi-body dynamics; Kinetic chain; Whip-like effect

1. Introduction

The baseball batting is one of high speed swing motions [1-7]. A batter is required to accelerate a baseball bat into a proper hitting point in a short period of time because the batter tries to strongly hit a thrown ball with a large head speed and precise timing. The movement of the batter with a bat, which consists of a large number of segments, is determined by the equation of motion for the system. The equation shows that linear and angular accelerations of the segments, including rotational acceleration of the individual joints, are expressed by the sums of joint torque term, motion dependent term (MDT) and gravitational term. The MDT, which consists of centrifugal force, Coriolis force and gyro moment, plays significant roles in the generation of tip speed in high speed swing motions [8-11]. Although the joint torque term shows instantaneous effect to the generation of the accelerations of the segments [10, 13], the MDT shows cumulative effect to the generation of tip speed and acceleration. That is, the MDT is generated by time history of the inputs; such as joint torques and gravitational forces.

Like other high speed swing motions; such as soccer kicking [8], baseball pitching [9, 10] and tennis serve [11], batters probably utilize the cumulative effect, which is generated by the MDT, to obtain a large bat head speed. A phenomenon regarding the cumulative effect is usually called as "whip-like effect" and "kinetic chain". In order to investigate the cumulative effect, a method which can quantify the generating factors of the MDT was proposed [11]. The method derives a recurrence formula, regarding the generalized velocity vector consisting of the linear and angular velocity vectors of the all segment in the target system, from the combination of the equation of motion for the system and the difference formula with respect to the generalized acceleration vector. Furthermore, since the baseball batting is a swing motion with manipulating a bat by both hands

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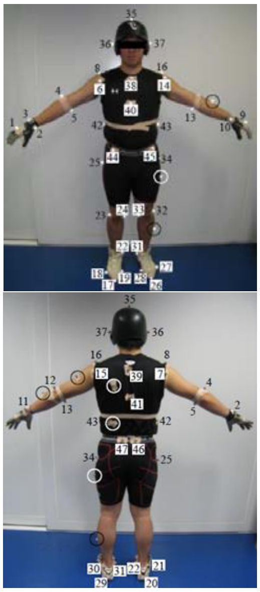
[12, 14], it is also important to make clear how the individual upper limb joints contribute to the generation of bat head speed. The purpose of this study was to quantify main contributors to the bat head speed by considering the generating factor of MDT.

2. Method

2.1. Data collection and modeling

Five male collegiate baseball left-handed batters were instructed to hit a teed ball in the pitcher's direction as strongly as possible. Kinematic data, 47 markers on the body and 6 markers on the bat (Fig.1), were captured using a motion capture system (VICON-MX, Vicon Motion Systems, UK; 12-camera; 250 Hz). Kinetic data of the individual hands were measured with an instrumented grip-handle (28 strain gauges; 1000 Hz), which has a similar structure to the instrumented bat [12]. Kinetic data of the individual feet were measured with three force platforms (9281A [$\times$2], 9287B, Kistler Instruments AG, Switzerland; 1000Hz). The motion capture system, the instrumented bat and the force platforms were electronically synchronized. A forward swing phase was defined as a period from the start of bat swing to the ball impact. The time history of data was normalized by the period of the forward swing phase as 0 to 100%.

The whole body with a bat was modelled as a system of sixteen-rigid linked segments. The system consists of head, upper and lower trunks, upper arms, forearms, hands, thighs, shanks, feet and bat. A virtual joint, named torso joint, is assumed to be between the upper and lower trunk segments. The bat is assumed to be connected to each hand by a virtual joint with 0 degree of freedom. Each lower limb is assumed to be connected with the ground via a virtual joint at the center of pressure (COP) of the foot [15]. Anatomical constraint axes (e.g. varus/valgus axis at elbow and knee joints; internal/external rotation axis at wrist joint) are considered in the modeling. The joint torques were obtained via inverse dynamics calculation using body segment parameters with respect to Japanese athletes [16].



1. Right 3rd metacarpal
2. Right wrist lateral side
3. Right wrist medial side
4. Right elbow lateral side
5. Right elbow medial side
6. Right shoulder foreside
7. Right shoulder backside
8. Right acromion
9. Left 3rd metacarpal
10. Left wrist lateral side
11. Left wrist medial side
12. Left elbow lateral side
13. Left elbow medial side
14. Left shoulder foreside
15. Left shoulder backside
16. Left acromion
17. Right toe
18. Right 5th metatarsal
19. Right 1st metatarsal
20. Right calcaneus
21. Right malleolus lateralis
22. Right malleolus medialis
23. Right knee lateral side
24. Right knee medial side
25. Right trochanter major
26. Left toe
27. Left 5th metatarsal
28. Left 1st metatarsal
29. Left calcaneus
30. Left malleolus lateralis
31. Left malleolus medialis
32. Left knee lateral side
33. Left knee medial side
34. Left trochanter major
35. Top of head
36. Right ear
37. Left ear
38. Suprasternals front side
39. Suprasternals back side
40. Xiphoid process front side
41. Xiphoid process back side
42. Right lowest edge of rib
43. Left lowest edge of rib
44. Right anterior superior iliac spine
45. Left anterior superior iliac spine
46. Right posterior superior iliac spine
47. Left posterior superior iliac spine
48. Bat head top
49. Bat taper right side
50. Bat taper left side
51. Bat label side
52. Bat handle right side
53. Bat handle left side

Circles: Dummy markers

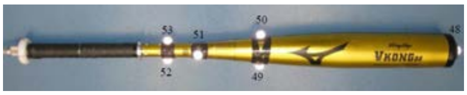


Fig.1. Marker placement

2.2. Equation of motion for whole body and bat system

An analytical form of the equation of motion for the whole body with bat system can be expressed, similar to the study [11], as follows:

$$\dot{\boldsymbol{V}} = \boldsymbol{A}_{T\mathrm{a}}\boldsymbol{T}_{\mathrm{a}} + \boldsymbol{A}_{V} + \boldsymbol{A}_{G}\boldsymbol{G} + \boldsymbol{A}_{f\mathrm{r}}\boldsymbol{f}_{\mathrm{r}} + \boldsymbol{A}_{n\mathrm{r}}\boldsymbol{n}_{\mathrm{r}} + \boldsymbol{A}_{\eta}\ddot{\boldsymbol{\eta}} + \boldsymbol{A}_{\varphi}\ddot{\boldsymbol{\varphi}} \qquad (1)$$

where $\boldsymbol{V}$ is the generalized velocity vector consisting of linear velocity vectors with respect to the center of gravity (CG) and angular velocity vectors for all the segments; $\boldsymbol{A}_{Ta}$ and $\boldsymbol{A}_{G}$ indicate the coefficient matrices for the active joint torque vector $\boldsymbol{T}_{\mathrm{a}}$ and gravitational force vector $\boldsymbol{G}$; $\boldsymbol{A}_{V}$ indicates the motion-dependent term (MDT) consisting of force and moment caused by centrifugal and Coriolis forces and gyro moment; $\boldsymbol{A}_{G}$ is the coefficient matrix of gravitational acceleration vector; $\boldsymbol{A}_{fr}$ is the coefficient matrix of residual joint force; $\boldsymbol{A}_{fr}$ and $\boldsymbol{A}_{nr}$ are the coefficient matrices for the compensation force and moment inputs $\boldsymbol{f}_{\mathrm{r}}$