SOURCES OF FORWARD BALL VELOCITY IN A PITCHED BASEBALL

Gordon Alderink[1], Thomas Kepple[2], Karen Lohmann Siegel[4], Alexander Razzook[5] & Steven Stanhope[2,3]
[1]Grand Valley State University, College of Health Professions, Grand Rapids, MI, aldering@gvsu.edu
University of Delaware, [2]Departments of Health, Nutrition Exercise Sciences and [3]Mechanical Engineering Newark, DE
[4]Agency for Healthcare Research and Quality, Rockville, MD
[5]Physical Disabilities Branch, National Institutes of Health, Bethesda, MD

INTRODUCTION

During a baseball pitch, the dependence of ball velocity on muscle/joint actions has been inferred (Toyoshima et al., Stodden et al., 2001, Stodden et al., 2005), but not measured directly. Recent advances (Anderson et al., 2004, Goldberg et al., 2004) in musculoskeletal modeling have included the development of techniques that can directly determine the contribution of muscle groups to joint or segment velocities associated with locomotion. This approach (induced velocity analysis) is ideal for studying whole body and upper extremity motions where there is an easily measured goal, such as maximizing ball velocity during pitching. Our purpose was to study high level adolescent pitchers to determine how joint torques, gravity and velocity effects (centripetal/ coriolis) contribute to the forward velocity of a baseball at release.

METHODS AND PROCEDURES

Kinematic and kinetic data were collected from six elite high school male baseball pitchers (mean height = 1.86m, mean weight = 83.9kg) who had no history of arm injury and were able to throw at least 80 mph under game conditions. During testing the subjects threw a straight overhand pitch from the windup on flat ground. Data were collected using a 7-camera Vicon 612 motion capture system (250 Hz) and three AMTI force platforms (1000 Hz). One representative pitch per subject was analyzed from the last instant of zero ball velocity to ball release.

The 14 segment biomechanical model included feet, legs, thighs, a pelvis, a combined thorax-abdomen-head, arms, forearms and hands. The hips and shoulders were modeled as 3 DOF ball and socket joints. The thorax-abdomen-head segment was connected to the proximal end of the pelvis using a ball and socket joint (waist). The knees and wrists were modeled as revolute joints allowing flexion/extension. The elbows and ankles were modeled as 2 DOF universal joints; the elbow allowed flexion/extension and pronation/supination and the ankle allowed dorsi/plantar flexion and inversion/eversion. The pelvis served as the model's root segment and was free to rotate and translate relative to ground.

Visual3D software (C-Motion, Inc.) computed the kinematics and kinetic input for the model. The model was implemented in Visual3D as a dynamic link library built using SD/Fast (PTC Software) software. At each video sample, the model was positioned based on the pelvis and joint kinematic data. Gravity and all velocities were set to zero. The joint torques were turned on, one at a time, to determine the forward acceleration imparted on the ball by that torque. The forward acceleration due to gravity was determined by setting all torques to zero and setting gravity to 9.81 m/s^2. Finally, the centripetal/coriolis effects were determined by setting all torques and gravity to zero and driving the model using the velocities as measured by the motion capture system.

The induced velocity from each source was obtained by calculating the area under each induced acceleration curves. The model was validated by comparing the total induced velocity of the ball computed by the model with the forward velocity of the ball obtained from a radar gun.

RESULTS

Net ball velocity at release determined by the model was 64.5 mph, which was comparable to that recorded by the radar gun (73.8 mph). The induced velocity analysis (Table 1) indicated that acceleration produced by the velocity of the segments (centripetal/coriolis), made the largest contribution to ball velocity (57.8%). In the pitching arm, the shoulder was found to generate forward ball velocity (31.0%) in the period of rapid acceleration just prior to release while the elbow torque tended to increase forward velocity (18.1%) during cocking phase of the pitch. Gravity, the lower extremity joint moments, and wrist joint moment made either small or negative direct contributions to ball velocity.

DISCUSSION

Toyoshima et al. (1974) inferred that the trunk and lower extremity accounted for almost 50% of ball velocity, whereas Stodden et al. (2001, 2005) concluded that ball velocity increased with increases in elbow flexion torque, elbow and shoulder joint forces, and increases in pelvic and upper torso velocity. Results from the induced velocity analysis indicate that the largest contributions came from the centripetal and coriolis effects. The study also found that the lower extremities were unlikely to make a direct contribution to ball velocity while the muscles crossing the shoulder and elbow did indeed make significant contributions.

SUMMARY

Induced velocity analysis has shown that centripetal/coriolis accelerations are the largest contributor to forward ball velocity. It is hoped that decomposing the centripetal/coriolis accelerations back to the muscular sources will further clarify anatomically relevant sources that indirectly contribute to forward ball velocity.

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	lower extremities	waist	shoulder	elbow	wrist	gravity	centripetal/ coriolis
Mean%	-1.3	1.3	31.0	18.1	-6.9	0.0	57.8

Table 1. Mean (n=6) sources of ball velocity as percentages of total induced forward velocities.