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Full Length Article

Finger forces in fastball baseball pitching

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ABSTRACT

Forces imparted by the fingers onto a baseball are the final, critical aspects for pitching, however these forces have not been quantified previously as no biomechanical technology was available. In this study, an instrumented baseball was developed for direct measurement of ball reaction force by individual fingers and used to provide fundamental information on the forces during a fastball pitch. A tri-axial force transducer with a cable having an easily-detachable connector were installed in an official baseball. Data were collected from 11 pitchers who placed the fingertip of their index, middle, ring, or thumb on the transducer, and threw four-seam fastballs to a target cage from a flat mound. For the index and middle fingers, resultant ball reaction force exhibited a bimodal pattern with initial and second peaks at 38–39 ms and 6–7 ms before ball release, and their amplitudes were around 97 N each. The ring finger and thumb produced single-peak forces of approximately 50 and 83 N, respectively. Shear forces for the index and middle fingers formed distinct peak at 4–5 ms before release, and the peaks summed to 102 N; a kinetic source for backspin on the ball. An additional experiment with submaximal pitching effort showed a linear relationship of peak forces with ball velocity. The peak ball reaction force for fastballs exceeded 80% of maximum finger strength measured, suggesting that strengthening of the distal muscles is important both for enhancing performance and for avoiding injuries.

1. Introduction

The motion of baseball pitching is composed of a series of continuous phases starting from a wind-up and followed by stride (or early cocking), late cocking, acceleration, deceleration, and finally follow-through (Dillman, Fleisig, & Andrews, 1993; Fleisig, Barrantine, Zheng, Escamilla, & Andrews, 1999; Seroyer et al., 2010). During the acceleration phase, internal rotation velocity of the humerus at the shoulder joint commonly exceeds 7500°/s and elbow extension prior to ball release reaches 2500°/s or more (Fleisig et al., 1999; Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002). These motions generate strong inertial forces at the fingertips for thrusting the ball towards home plate at high linear velocity. The high rotational velocities at the shoulder, elbow, and wrist joints generate centrifugal and Coriolis forces (Hirashima & Ohtsuki, 2008; Stodden, Fleisig, McLean, & Andrews, 2005). To prevent the ball slipping out of the hand by these forces, a pitcher must supply an adequate amount of finger force on the ball (Hirashima & Ohtsuki, 2008; Hore, Watts, Leschuk, & MacDougall, 2001). In addition, as the pitcher pushes the ball forward during

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the last moment of ball release, the index and middle fingers also contribute to generate a force tangential to the ball's surface for imparting a spin. Recent studies have shown that a common fastball contains backward spins ranging from 28 to 42 rotations/s depending on ball velocity and pitcher (Nagami et al., 2011; Whiteside, McGinnis, Deneweth, Zernicke, & Goulet, 2016).

Although information about finger forces during delivery of a baseball can facilitate an understanding of pitching biomechanics, little research has been conducted into these forces. Hore, Watts, and Tweed (1999), Hore et al. (2001) used small pressure sensors taped on the distal and middle phalanges of the middle finger in order to estimate finger forces during over-hand throws. In their studies, recreational ball players threw tennis balls of different masses and plastic balls of different sizes to a near target at slow (< 12 m/s), medium, and fast (> 16 m/s) ball velocities. Further study is, however, needed to extend their findings to actual baseball pitching where ball velocities are much higher, and thus the gripping and thrusting forces by each of the fingers involved should also be greater. It is also necessary to acquire information on the finger force for giving a forceful spin on the pitched ball, which only can be made by a measurement of forces acting tangential to the ball surface. In order to fulfill these needs, a test ball permitting measurement of normal and tangential forces between uninhibited contact between the fingers and the ball is required.

The aims of the present study were therefore to develop a baseball with an embedded tri-axial force transducer, and to use it to provide fundamental information about the timing and amplitude of ball reaction forces on the index, middle and ring fingers and thumb of baseball pitchers during actual fastball pitching. In addition to maximum effort pitching, a lower effort range was also examined to study the effect of ball velocity on ball reaction forces.

2. Methods

2.1. Subjects

Subjects were 11 healthy male overhand pitchers (mean age ± SD = 21.0 ± 1.5 years) from varsity baseball teams in four universities belonging to Japanese collegiate baseball leagues. Five of them were left-handed. Their mean baseball training experience was 12.1 ± 2.1 years. The mean ball speed of self-reported fastest pitch during past games was 38 m/s (range = 36–40 m/s). The mean height and weight of these subjects were 1.81 ± 0.05 m, and 76.2 ± 6.1 kg. The study was approved by the Ethics Committee at the Graduate School of Medicine, Osaka University, and informed consent was obtained from all subjects.

2.2. Experimental baseball

The current experimental ball was developed in our lab by embedding a miniature tri-axial force transducer (model: USL06-H5-500N-C, Tec Gihan Co., Kyoto, Japan) in a standard Japan college league baseball (Mizuno Co., Japan) (see Fig. 1). This was done in such a way that we first cut out a circular portion (diameter = 35 mm) of the ball's cover with stitches. The cotton and wool yarns under this circular portion were then removed to make a cylindrical hole (diameter = 37 m, and depth = 24 mm) (Fig. 1A). At the bottom of this hole, a 3.2-mm thick duralumin circular disk (diameter = 35 mm) was epoxy glued, and further anchored firmly to the bottom using four 35-mm long wood screws. On this disk, the force transducer was tightened using small bolts (Fig. 1B). With these procedures, deformation and movement of the transducer by the application of finger force were kept to minimum if any. The force sensor was centered 5 mm from the seam. The maximum ranges of measurement for the force transducer were 500 N in the normal direction and 250 N in each of the lateral and longitudinal directions. On top of the force-detecting portion of the transducer, a 2.6-mm thick duralumin disk (diameter 26 mm) was bolted, and on this disk, a rounded circular wooden piece covered by the cut piece of the ball's cover was attached using a strong, thin, double-adhesive tape. The external shape and appearance of the force-detecting portion of the experimental ball were quite similar to those of an ordinary baseball (Fig. 1B). The force sensor had a 10-cm flexible electric twisted type lead wire with a miniature PCB female 8-pin easily detachable electrical connector at the end. This female connector was joined to a male PCB connector with 10-m lightweight electric wire with a plug for connection to a three-channel strain gauge amplifier (DPA-03A, Tec Gihan Co., Japan). The force required to disconnect the male connector from the female side was around 2 N.

The experimental baseball with the 10-cm lead wire and the female electric connector had a mass of 156 g, which was 11 g heavier than its original mass (145 g). The male connector side of this long wire was taped to the throwing arm's wrist and forearm (Fig. 1C). The wire was then lightly tied at the shoulder, back, and hip, with adequate slack for unconstrained throwing. The wire

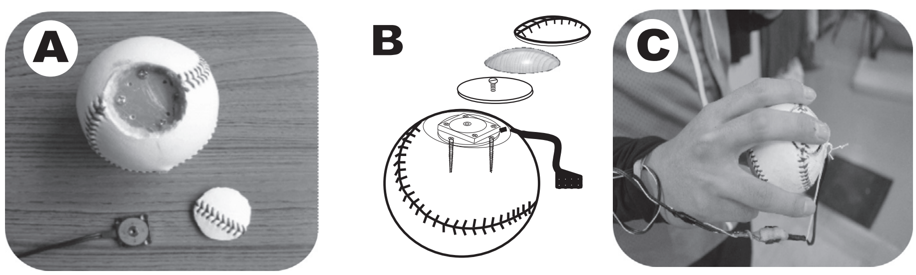

Fig. 1. The experimental baseball. (A) A baseball with a base metal, tri-axial force transducer, and top piece. (B) A schematic drawing showing the construction of the experimental ball. (C) Holding the ball with a four-seam grip while placing the tip of a target finger (in this case, the middle finger) on the force sensing spot.