Accuracy in determining kinetic parameters with force plates embedded under soil-filled baseball mound

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We developed a force measurement system embedded in a soil-filled mound for measuring ground reaction forces (GRF) acting on baseball pitchers and examined the accuracy of determining the point of force application (PFA) and kinetic parameters computed from GRF. Three 1.0 x 0.9 m^2 force platforms were placed on the concrete foundation of an indoor sports facility and three trays were fixed onto the aluminum plates of the force platforms. In each tray, clay-blocks were laid tightly and a mixture of red sand and volcanic-ash was used to make a smooth surface layer. The mean absolute error was 6.0 ± 4.0 mm in determining PFA, less than 15.5 Ns (5% of the true value) in determining linear impulse. These results suggest that the present method is valid for measuring the PFA and GRF acting on the pitcher's legs for analyzing kinetics of pitching performances.

KEY WORDS: angular momentum, center of mass, impulse, point of force application

INTRODUCTION: In baseball games, the pitcher delivers the ball to the batter from the pitcher's plate fixed in the elevated section of the field, called pitcher's mound. The pitcher's mound is built with pre-compressed clay blocks, high-density clay and a mixture of sand and clay, so that the precise dimensions can be maintained easily to observe the official baseball rules while assuring safety and playability. When baseball pitchers pitch on the mound, they wear shoes with cleats to maximize traction on the soil. Their pitching techniques, therefore, are specifically adjusted to the height, slope and surface material of the mound and the amount of traction they receive from the cleats of the shoes.
Several studies have reported the ground reaction forces (GRF) created by pitchers on artificial mounds (Elliott et al., 1988; MacWilliams et al., 1998; Kageyama et al., 2014; McNally et al., 2015). No studies, however, have provided the pitchers with a soil-filled mound for the experiment. Lack of firm grip on the metal force platform and a potential risk of slipping may have affected the biomechanics of pitching as they altered the lower extremity mechanics in gait (Cham & Redfern, 2002). In this study, we developed a force measurement system embedded under a soil-filled mound so that the mechanism of baseball pitching in game/practice situations could be analyzed accurately. The purpose of this study was to elucidate the static and dynamic accuracies of the force measurement system developed for determining GRF during baseball pitching and to confirm previous measures of GRF in pitching from artificial mounds.

METHOD: Three 1.0 × 0.9 m platforms (Tec-Gihan co., ltd. Japan) were embedded in the 70 × 60 m baseball practice field in an indoor sports facility (Figure 1). Each force platform consisted of a light-weight aluminum plate, 12 strain gauges and a built-in amplifier. Twelve channels of data were amplified and fed into a control unit, in which the analog data were converted to digital data at 500 Hz and transformed into three components of the resultant force exerted on the force platform and three components of resultant moment around the geometric center of the force platform. These forces and moments were expressed with respect to the reference system fixed to the force platforms, having x-axis pointed toward the home base, y-axis pointing towards the third base and z-axis pointing vertically downwards.
Three trays with the horizontal dimensions of 1.3 × 0.9 m and various heights were constructed with aluminum material and fixed onto the aluminum plates of the force platforms (Figure 1). The

sidewalls were shaped in specified dimensions so that, when the trays are filled up with soil, the dimension of the mound could meet the official baseball rules. A pitcher's plate (YPA901, SSK corp, Japan) was placed at a 254 mm height with a metal frame which was firmly fixed to one tray. In each tray, clay-blocks (Mount master®, Turface AthleticsTM, USA) were laid tightly to the height approximately 60 mm below the surface of the mound and a mixture of red sand (en-tout-cas) and volcanic-ash was used to cover the clay blocks to make a smooth surface layer of a typical mound in Japan. Water was sprayed to each section of the mound and the surface was tamped firm to harden the soil.

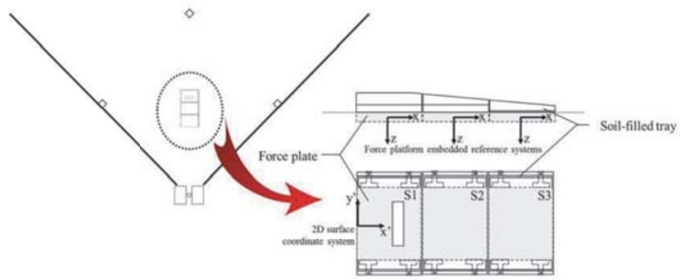

Figure 1: Schematics of the soil-filled mound and the force platforms embedded underneath.

A right-handed collegiate baseball pitcher (height 1.74 m, body mass 71.2 kg) was asked to throw 5 fast balls towards a catcher sitting behind home base with his maximum effort. This pitcher used the so called set position -- having his pivot foot in contact with, and the other foot in front of, the pitcher's plate – to initiate ball delivery. He was allowed to wear baseball shoes with metal cleats. The force signals were set zero before the pitcher stepped on the mound for each trial of pitch. The pitcher on the mound was asked to stay still for about 2 seconds before pitching so that the trajectory of the center of mass of the body (CM) could be determined during the pitch.

A series of static tests was conducted to examine the accuracy in determining the point of force application (PFA). A triangular metal frame with three legs was constructed. One leg was positioned at 35 locations with 0.2 m intervals for each section of the mound and a 30 kg weight was mounted on the frame at each location. The total of 105 measurements (35 locations/section × 3 sections) was taken and the known positions of force application and the determined PFA values were compared in the 2D surface coordinate system.

A series of dynamic tests (vertical and horizontal jump tests) were conducted to examine the accuracy of measuring the impulse exerted to a human body in motion. In vertical jump test, a subject of 75.2 kg body mass standing still on one section was asked to jump vertically and, after the landing on the same section, self-stabilized to the initial position. The subject was judged to be stabilized when the resultant force was < 10 N in all direction for >0.5 seconds. Three trials were analyzed. In horizontal jump test, the subject standing still was asked to jump horizontally, land on an adjacent section and self-stabilize to the initial position. Four trials were analyzed. The subject made the maximum effort to generate powerful push-off and landing forces, in order to deform the soil surface and possibly displace some soil. The total vertical impulse exerted to the subject during take-off and landing should be equal in magnitude to the impulse of the gravitational force exerted to the body during the flight.

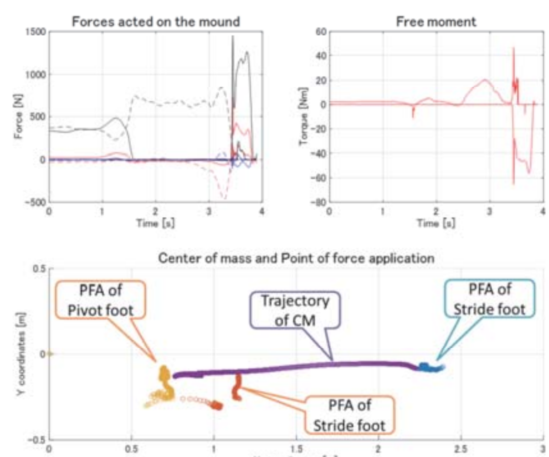

Figure 2: A typical example of the forces, free moment, PFA and the trajectory of CM

The vertical force of 5 N was set as threshold to determine take-off and landing. The deviation from the true value (i.e., the impulse of the gravitational force during the flight) was determined as the measurement error. The horizontal impulse exerted to the body during take-off should be equal in magnitude to the horizontal impulse in landing. The true value of magnitude, however, was not known in this case, so it was estimated as the average magnitude of horizontal impulse across take-off and landing. The deviation from the estimated true value was determined as the measurement error.

RESULTS: A typical example of the forces, free moment around the PFA, PFA and the trajectory of CM during a pitch is presented (Figure 2). Ball speed was 121 ± 1.3 km/h. After the stride foot was lifted off the mound (t ≈ 1.6 s), the PFA was located in the anterior half of the sole of the pivot foot while his body weight was fully supported by the pivot leg. The PFA was then moved forward as the horizontal force of up to 469 ± 8.9 N (67 ± 1% BW) acted on the pivot foot and the CM shifted forward. The free moment acting on the pivot foot also increased rapidly to initiate body rotation. At the instant of landing of the stride foot (t ≈ 3.4 s), the large vertical impact force of 1536 ± 142.9 N (220 ± 20% BW) and the braking force of 838 ± 142.3 N (119 ± 20% BW) acted on the stride foot. The PFA of the stride foot shifted along the mid-line during the delivery.

The root mean square error in the determined PFA was 1.4 ± 3.4 mm in x-direction and 3.8 ± 5.0 mm in y-direction, comprising the mean absolute error of 6.0 ± 4.0 mm. The mean absolute errors in the impulses determined in the series of jump tests were 5.1 Ns, 2.3 Ns, and 7.6 Ns for x-, y-, and z-directions, respectively (Table 1). The error in z-direction comprised 2.6 % of the true value and the corresponding value in the x- directions was 4.8 % of the non-zero true value.

Table 1
Estimated errors in vertical- and horizontal-jump tests

	Error in x, Ns		Error in y, Ns		Error in z, Ns	
Vertical jumps	7.5 ± 5.0	(0)	2.4 ± 3.1	(0)	6.7 ± 0.8	(313± 16)
Horizontal jumps	3.3 ± 1.4	[71± 7.7]	2.2 ± 1.9	[6± 5.7]	8.2 ± 6.6	(282± 18)
	5.1 ± 3.8		2.3 ± 2.2		7.6 ± 4.8	

*The values in parentheses indicate true values and the values in brackets indicate the best estimates of the true values.

DISCUSSION: No data have been reported on the accuracy of force platform systems with deformable surfaces/coverings, whereas the accuracy in the measurements of PFA were reported on the standard force platform systems. Bobbert and Scamhardt (1990) reported the error ranged from -20 to 20 mm and the mean absolute error of 3.5 mm along the short-axis and 6.3 mm along the long-axis for a 600 × 900 mm piezoelectric force platform system. Similar size of error has been observed for a small (600 × 400 mm) piezoelectric force platform system (Middleton et al., 1999). In the prior study, the central region of the force plate was more accurate (mean absolute error was 1.8 mm along short-axis and 3.6 mm along long-axis) than near edges of the plate (error up to 6.2 mm along short-axis and 11.6 mm along long-axis). Furthermore, Cedraro et al. (2009) reported the mean absolute errors of various force platform systems ranged 2.3 - 14.0 mm. The error in PFA measurement on the soil-filled mound fell within the range of those reported in the literature, indicating that the static accuracy of the presented system is as good as that of other systems with no covering.

The largest measurement error in the dynamic tests was 15.5 Ns which was the z-component recorded in a horizontal jump test. The average error in measuring the force was limited to 3.0 N as this impulse was determined by integrating force over the time interval of 5.1 s. This amount of error causes computational errors of 0.04 m/s^2 of CM acceleration and 0.2 m/s of the CM velocity, calculated over the 5.1 s period for the 75.2 kg subject. These results indicate that the effects of surface deformation and soil displacement that may occur in response to the powerful push-off and landing forces on the accuracy of measurements is minimal and the present method is valid for measuring the PFA and GRF acting on the pitcher's legs.

In the pitching trials, the peak forces recorded in the present study are greater than those (35-60% BW for push-off horizontal force & 170% BW of vertical impact force at landing) reported in the previous studies (Elliot et al., 1988; MacWilliams et al., 1998; McNally et al., 2015). The limited amount of measurement error with the present method and the reliability of the peak forces recorded in the pitching trials suggest that the difference in the GRF between the previous studies and the present study should not be resulted from inaccuracy in the measurements. The difference may be partially explained by the use of shoes with cleats on a soil-filled mound for determining GRF in the present study. We speculate that the soil-filled mound developed here enables the pitcher to perform with movement pattern and intensity in game/practice situations. Further study is indicated to confirm this speculation.

CONCLUSION: The results suggest that the present method is valid for measuring the PFA and GRF acting on the pitcher's legs for analyzing kinetics of pitching performances.

REFERENCES:

Bobbert, M.F. & Schamhardt, H.C. (1990). Accuracy of determining the point of force application with piezoelectric force plates. *Journal of biomechanics*, 23, 705-710.

Cedraro, A., Cappello, A. & Chiari, L. (2009). A portable system for in-situ re-calibration of force platforms: Experimental validation. *Gait & posture*, 29, 449-453.

Cham, R. & Redfern, M.S. (2002). Changes in gait when anticipating slippery floors. *Gait and Posture* 15, 159-171.

Elliott, B. Grove, J.R. & Gibson, B. (1988). Timing of the lower limb drive and throwing limb movement in baseball pitching. *International Journal of Sport Biomechanics*,4, 59-67.

Kageyama, M., Sugiyama, T., Takai, Y., Kanehisa, H. & Maeda, A. (2014). Kinematic and Kinetic Profiles of Trunk and Lower Limbs during Baseball Pitching in Collegiate Pitchers. *Journal of sports science & medicine*,13, 742-750.

MacWilliams, B., Choi, T., Perezous, M., Chao, E. & McFarland, E. (1998). Characteristic ground-reaction forces in baseball pitching. *The American journal of sports medicine*, 26, 66-71.

McNally, M.P., Borstad, J.D., Onate, J.A. & Chaudhari, Ajit M.W. (2015). Stride leg ground reaction forces predict throwing velocity in adult recreational basegball pitchers. *Journal of Strength and Conditioning Research*, 29, 2708-2715.

Middleton, J., Sinclair, P. & Patton, R. (1999). Accuracy of centre of pressure measurement using a piezoelectric force platform. *Clinical biomechanics*, 14, 357-360.