Human Movement Science 47 (2016) 151–158

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Variability of a "force signature" during windmill softball pitching and relationship between discrete force variables and pitch velocity

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ARTICLE INFO

Article history:
Received 22 April 2015
Revised 6 March 2016
Accepted 7 March 2016

Keywords:
Performance
Kinetics
Softball
Monitoring
Pitching
Fastpitch

ABSTRACT

This study assessed reliability of discrete ground reaction force (GRF) variables over multiple pitching trials, investigated the relationships between discrete GRF variables and pitch velocity (PV) and assessed the variability of the "force signature" or continuous force-time curve during the pitching motion of windmill softball pitchers. Intraclass correlation coefficient (ICC) for all discrete variables was high (0.86–0.99) while the coefficient of variance (CV) was low (1.4–5.2%). Two discrete variables were significantly correlated to PV; second vertical peak force ($r(5) = 0.81$, $p = 0.03$) and time between peak forces ($r(5) = -0.79$; $p = 0.03$). High ICCs and low CVs support the reliability of discrete GRF and PV variables over multiple trials and significant correlations indicate there is a relationship between the ability to produce force and the timing of this force production with PV. The mean of all pitchers' curve-average standard deviation of their continuous force-time curves demonstrated low variability (CV = 4.4%) indicating a repeatable and identifiable "force signature" pattern during this motion. As such, the continuous force-time curve in addition to discrete GRF variables should be examined in future research as a potential method to monitor or explain changes in pitching performance.

1. Introduction

Reliable methods to analyze and monitor changes in technique and performance are critical for coaches and sport scientists. In addition, identifying the critical variables related to performance is a basis for testing and subsequent program design. In the sports of baseball and softball, throwing, and even more importantly pitching, is a critical skill that is vital to success. During the throwing motion, the body acts as a kinetic chain, where the lower body initiates the acceleration of the body by applying force to the ground (Putnam, 1993). The acceleration of a proximal segment allows for transfer of momentum to the distal segment, and in throwing, a transfer of velocity to the ball at release (Putnam, 1993).

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http://dx.doi.org/10.1016/j.humov.2016.03.005
0167-9457/

The kinematics and kinetics associated with baseball pitching have been investigated in several studies (Elliot, Grove, & Gibson, 1988; Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002; Escamilla et al., 2007; Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Fleisig, Escamilla, Andrews, Matsuo, & Barrentine, 1996), with some researchers measuring ground reaction force (GRF) during the pitching motion in baseball (Elliot et al., 1988; MacWilliams, Choi, Perezous, Chao, & McFarland, 1998; McNally, Borstad, Oñate, & Chaudhari, 2015). In the study by MacWilliams et al. (1998), push-off vertical GRF and wrist velocity were highly correlated ($R^2 = 0.74$), displaying the relationship of the GRF produced during the leg drive of the pitching motion and resultant wrist velocity. In addition to the GRF, the timing of the resultant GRF has been hypothesized to differentiate between those that pitch at slower or faster velocities (Elliot et al., 1988). However, MacWilliams et al. (1998) found only a weak relationship between timing and resultant GRF ($R^2 = 0.35$) or vertical GRF ($R^2 = 0.13$).

Although strong relationships have been demonstrated between vertical GRF during the push-off and wrist velocity in baseball pitchers (MacWilliams et al., 1998), there has yet to be a similar investigation in windmill softball pitchers. Pitchers in fastpitch softball perform a unique underhand pitching motion called the windmill from a flat mound, which is in contrast to the overhand action from an elevated mound during baseball pitching. The research to date on windmill pitching has focused on kinematics and kinetics of the upper body or incidence of injury during pitching (Alexander & Haddow, 1982; Barrentine, Fleisig, Whiteside, Escamilla, & Andrews, 1998; Hill, Humphries, Weidner, & Newton, 2004; Maffet, Jobe, Pink, Brault, & Mathiyakom, 1997; Werner et al., 2005; Werner, Jones, Guido, & Brunet, 2006). Only two studies have investigated discrete GRF variables during the windmill softball pitch and neither examined the GRF of the push-off leg (Guido, Werner, & Meister, 2009; Werner et al., 2005). Both Werner et al. (2005) and Guido et al. (2009) reported that the peak vertical GRF as the pitcher posts on the stride leg is similar in baseball and softball, yet the slightly higher loading in baseball was due to absorbing load coming down from the raised mound. Although the previous studies examined the stride leg during the softball pitching motion, there are no known investigations of GRF during the propulsive phase of windmill pitching and its potential relationship with pitch velocity (PV). Despite differences in technique and mound between baseball and softball pitching, a demonstrated relationship between the push-off phase in baseball and PV gives reason to investigate GRF in the propulsion phase of windmill pitching.

In an effort to improve the propulsion phase of pitching, exercises performed in the vertical force plane are prescribed to improve lower body force production (e.g. squatting and weightlifting movements) (Nimphius, 2005; Nimphius, McGuigan, & Newton, 2012; Suchomel, Comfort, & Stone, 2015); however, the relationship between vertical force production and softball windmill performance has not been demonstrated drawing such a training strategy into contention. As a result, the purpose of this study was to: (1) assess the reliability of discrete GRF variables in multiple pitching trials; (2) investigate the relationship between discrete GRF variables and PV; and (3) assess the variability of the "force signature" of windmill softball pitchers.

2. Methods

2.1. Experimental approach to the problem

A cross-sectional design was implemented using softball pitchers that competed at state level or above to determine the reliability of discrete GRF variables during the propulsion phase of windmill softball pitching and their relationship to PV. Further, this design was used to assess the variability of the force-time curve during the pitching motion. The PV of the pitchers in this study (26 ± 2 m·s^{-1}) was comparable to previous studies investigating college softball pitchers (25 ± 2 m·s^{-1}) (Barrentine et al., 1998) and Olympic softball pitchers (27 ± 2 m·s^{-1}) (Werner et al., 2006). All testing was completed in one session. The pitchers completed their typical game day pitching warm-up prior to commencement of data collection. Following the warm-up, GRF and PV data were collected for multiple maximal velocity pitching efforts.

2.2. Subjects

Seven female fastpitch softball pitchers (19.6 ± 3.9 years; 167.4 ± 7.2 cm; 77.3 ± 7.6 kg) competing at either the state (n = 5), national (n = 1), or international (former Olympian) (n = 1) level volunteered to participate in this study. All participants received an information sheet explaining the nature of the study, including the potential risks and benefits of participation. The institutional human ethics committee approved the study and written consent was obtained from each participant before commencement of testing.

2.3. Procedures

Ground reaction forces during the windmill pitching motion were collected with an in-ground force plate (Type 9287BA, Kistler, Switzerland) for five seconds at 1000 Hz (Bioware Version 3.2, Kistler, Switzerland) and exported for later analysis. Pitchers started with both feet on the force plate and data during the propulsion or "push-off" phase of the pitch was collected. The entire force-time curve for a representative pitcher is presented in Fig. 1. In brief, there is preparation to pitch, shift of weight to the push-off leg for the first peak force followed by a more explosive drive off the push-off leg for a second