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Foot kinematics and loading of professional athletes in American football-specific tasks

Patrick O. Riley [a,*], Richard W. Kent [a], Tracy A. Dierks [b], W. Brent Lievers [a], Rebecca E. Frimenko [a], Jeff R. Crandall [a]

[a] Center for Applied Biomechanics, University of Virginia, Charlottesville, VA, USA
[b] Department of Physical Therapy, Indiana University, Indianapolis, IN, USA

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ABSTRACT

The purpose of this study was to describe stance foot and ankle kinematics and the associated ground reaction forces at the upper end of human performance in professional football players during commonly performed football-specific tasks. Nine participants were recruited from the spring training squad of a professional football team. In a motion analysis laboratory setting, participants performed three activities used at the NFL Scouting Combine to assess player speed and agility: the 3-cone drill, the shuttle run, and the standing high jump. The talocrural and first metatarsophalangial joint dorsiflexion, subtalar joint inversion, and the ground reaction forces were determined for the load bearing portions of each activity. We documented load-bearing foot and ankle kinematics of elite football players performing competition-simulating activities, and confirmed our hypothesis that the talocrural, subtalar, and metatarsophalangeal joint ranges of motion for the activities studied approached or exceeded reported physiological limits.

1. Introduction

Professional American football players must avoid injury while functioning at or near their physiological and biomechanical limits. Their athleticism, often combined with exceptional mass, almost certainly places large loads on muscles, tendons, ligaments, and bony structures, possibly rendering the athletes more susceptible to injuries. Injury susceptibility is likely increased when the players are functioning near their range of motion (RoM) limits, since further contact-induced joint motion would generate structural strain. Because foot and ankle injuries are a major source of morbidity in football, accounting for 15 to 20% of all game-related injuries [1,2], assessing foot and ankle biomechanics in conditions that adequately simulate competition-level activities is especially desirable.

Elite athletes participating in professional sports differ in terms of height, weight, muscle mass, percent body fat, cardiovascular endurance, and muscle fibers, from those competing at the amateur, collegiate, or recreational levels [3]. These athletes have exceptional kinematic and kinetic capabilities contributing to their elite status [3–6]. In American football (hereafter football), players repeatedly perform short bursts of intense effort. Documenting the kinematics of performance at this level with motion analysis techniques demonstrates the range of the performance assessment ability of this technology and provides a more complete context for assessing normal and impaired ambulatory function. Activities used in professional football to assess athletic ability include the 3-cone drill, the shuttle run, and the standing high jump [7]. Conventional performance assessment is limited to measuring task completion times or jump heights, but motion analysis can provide insight into the biomechanics of performance.

Previous studies have reported ankle and foot ranges of motion (RoMs) in sports activities such as running [8–10] and cutting [8,10], but the full spectrum of foot and ankle movements of football players has not been documented. The purpose of this study was to describe stance phase foot and ankle kinematics and the associated ground reaction forces of professional football players during football-specific tasks requiring speed, agility, and overall footwork. We expected to find that elite athletes performing these activities reach or exceed the accepted limits of foot and ankle range of motion. The performance of the foot and ankle are reported as kinematics of the talocrural, subtalar, and metatarsophalangeal (MTP) joints, along with the ground reaction force (GRF).

2. Methods

Nine participants were recruited from the training squad of a professional football team. While not starting players, each had

* Corresponding author at: Center for Applied Biomechanics, University of Virginia, 4040 Lewis and Clark Drive, Charlottesville, VA 22911, USA.
Tel.: +1 434 296 7288x144; fax: +1 434 296 3453.
E-mail address: por2n@virginia.edu (P.O. Riley).

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Table 1
Subject characteristics and event kinematic and force parameters. Kinematic parameters: overall group mean peak joint RoM, *standard deviation* and *SP/HP/PP* class means. Force parameters: overall group mean peak value (maximum or minimum), *standard deviation* and *SP/HP/PP* class mean maximum (or minimum). Final row, the overall Wilcoxon rank sum test group median for the parameters and the corresponding class medians along with the *p*-values of tests for difference of the class and group medians.

Subjects	Mass (kg)	Stature (cm)	Age (year)	Ankle width (cm)	Foot length (cm)	Foot width (cm)
Mean (SD)	**111.6** (**21.7**)	**186.7** (**4.3**)	**24.4** (**1.3**)	**8.5** (**0.5**)	**29.4** (**1.5**)	**11.2** (**0.08**)
SP/HP/PP	*89.4/109.7/135.6*	*184.7/185.2/190.2*	*25.3/24.0/24.0*	*8.0/8.9/8.5*	*28.0/29.9/30.5*	*10.6/11.1/11.9*
Events	Talocural RoM (°)	Subtalar RoM (°)	MTP RoM (°)	Anterior force peak (%BW)	Vertical force peak (%BW)	Medial force peak (%BW)
Walk	**25.2** (**3.1**)	**15.0** (**4.9**)	**53.7** (**6.0**)	**21.4** (**2.6**)	**116** (**12**)	**7.8** (**1.5**)
	25.2/25.8/24.7	*10.6/15.9/18.4*	*54.5/50.0/56.6*	*21.5/21.9/20.9*	*117/111/118*	*7.9/7.2/8.3*
Run	**40.7** (**6.6**)	**14.2** (**5.1**)	**59.5** (**16.1**)	**46.5** (**13.2**)	**242** (**39**)	**22.5** (**16.3**)
	36.0/41.3/44.8	*10.5/13.9/18.1*	*52.5/51.3/72.2*	*50.8/49.4/39.2*	*238/238/251*	*18.1/13.3/36.0*
Reverse	**44.4** (**7.7**)	**25.6** (**8.9**)	**23.4** (**8.4**)	−**102.1** (**11.0**)	**192** (**37**)	**27.8** (**12.6**)
	42.0/43.4/47.8	*25.0/20.9/24.3*	*28.6/17.3/24.2*	*−103.4/−98.1/−104.7*	*179/193.1/206*	*21.8/29.6/32.3*
Cut right leg	**49.7** (**7.8**)	**21.6** (**10.2**)	**38.1** (**10.2**)	−**92.8** (**21.3**)	**253.2** (**66.0**)	**100.2** (**18.9**)
	45.2/50.9/53.0	*20.6/20.1/24.3*	*31.6/46.7/36.0*	*−95.1/−85.2/−98.3*	*266.5/259/231*	*−112.7/−99.2/−86.4*
Cut left leg	**45.5** (**8.9**)	**27.0** (**11.1**)	**31.6** (**10.2**)	−**86.5** (**15.3**)	**230** (**50**)	**86.2** (**10.1**)
	39.9/48.7/47.9	*30.1/17.3/33.7*	*28.1/39.2/27.4*	*−91.4/−76.7/−91.5*	*249/238/202*	*84.3/85.1/89.0*
Start AP	**41.3** (**13.2**)	**22.4** (**10.2**)	**37.3** (**14.7**)	**74.3** (**22.7**)	**157** (**25**)	**30.3** (**12.5**)
	46.0/32.8/45.2	*26.7/15.1/25.4*	*39.8/41.7/29.0*	*93.8/63.5/65.5*	*173/154/136*	*26.7/32.6/32.3*
Start lateral	**48.4** (**7.2**)	**24.1** (**8.7**)	**18.5** (**6.2**)	−**14.6** (**6.0**)	**156** (**17**)	**97.6** (**15.3**)
	44.8/47.2/53.2	*30.7/16.8/25.0*	*17.5/21.9/16.5*	*−16.9/−15.5/−11.5*	*162/164/143*	*104.9/103.7/86.4*
Jump	**67.4** (**6.4**)	**16.8** (**5.9**)	**34.1** (**7.1**)	−**17.3** (**3.8**)	**147** (**12**)	**23.3** (**5.2**)
	69.4/64.2/68.8	*15.4/13.7/21.4*	*35.3/31.3/35.5*	*−19.2/−16.4/−16.2*	*151/149/141*	*22.7/26.0/21.1*
Plant AP	**33.2** (**9.3**)	**14.9** (**6.6**)	**28.7** (**6.2**)	−**88.8** (**21.8**)	**258** (**78**)	**37.2** (**19.6**)
	37.6/26.5/38.1	*12.2/11.0/19.6*	*25.5/28.1/31.7*	*−93.9/−95.9/−78.1*	*266/321/197*	*44.1/32.2/34.3*
Plant lateral	**29.8** (**8.5**)	**13.2** (**8.4**)	**21.1** (**10.4**)	**31.4** (**29.2**)	**208** (**48**)	**56.9** (**54.4**)
	24.6/30.8/33.2	*9.1/14.1/15.8*	*23.0/17.0/23.2*	*17.9/20.1/53.9*	*203/200/219*	*56.3/65.9/48.4*
Jump landing	**49.4** (**9.7**)	**13.1** (**7.5**)	**39.3** (**11.1**)	**71.8** (**41.4**)	**339**(**124**)	**39.9** (**18.7**)
	51.7/46.6/49.9	*14.5/13.8/11.2*	*34.7/38.8/44.1*	*58.8/103.3/53.6*	*301/457/318*	*30.2/63.8/37.7*
Group median	*44.4*	*16.8*	*34.5*	*−14.6*	209	*32.6*
Class median	*47.8/42.0/43.4*	*21.4/15.4/15.1*	*34.3/31.6/33.3*	*−11.5/−16.9/−15.5*	*200/203/210*	*36.0/30.3/28.2*
p value	**0.43/0.69/0.90**	**0.26/0.74/0.21**	**0.95/0.79/1.00**	**0.95/0.74/0.95**	**0.55/0.74/0.90**	**0.84/1.00/1.00**

been judged to have the potential for professional play, and several participated in regular and postseason competition. To represent the breadth of player anthropometry and skill sets, participants were drawn in equal numbers from three player classes: power players (PP, linemen), speed players (SP, running backs and receivers), and hybrid players (HP, linebackers and tight ends). Participants wore basic exercise attire without pads, and activities were performed barefoot. At the time of testing, participants were actively engaged in their team's spring training camp. The participants were self-reported free of injury that might impair their performance. Table 1 presents the participants' anthropometric data. All participants gave written informed consent. The research protocol was approved by both the University of Virginia, and the Indiana University Purdue University Indianapolis and Clarian institutional review boards.

Testing was conducted at the Indiana University Motion Analysis Research Laboratory. Seven cameras (Vicon, Los Angeles, CA, USA) operating at 240 Hz tracked 40 retro-reflective markers. The Vicon Plug-In Gait whole-body marker set, modified to include redundant foot markers, was used (Fig. 1). Data from two AMTI model OR6-7 force plates (AMTI, Watertown, MA, USA) were captured at 1200 Hz. A wooden platform at the level of the force plates, painted to provide reasonable barefoot traction, was approximately 10 m long with the force plates in the center, and 6 m wide with the force Plates 1 m inside one edge.

The activities were modified to suit laboratory constraints. The 3-cone drill cone spacing was 3 m. The shuttle run limits were 4.26 m from the center of the force plate array. Instead of reaching with an extended arm for the high jump target, the participants attempted to hit a target 2.46 m above the floor with their heads. Participants started activities from their usual player position; 6 from a three-point stance, 3 from a two-point stance. The three activities included 10 events of interest: forward (AP) start, lateral start, 90° cut right, 90° cut left, direction reversal, full run, forward (AP) plant, lateral plant, jump, and jump landing. Free speed walking data were also obtained.

The test administrator first walked the subject through each activity, and then observed one or more subject run-throughs. The force plates were clearly identified and the participants were coached to hit a force plate during the events of interest. This level of targeting was considered appropriate, as position awareness is a normal requirement of the athletes' performance. Walking was performed at each participant's comfortable speed, and participants were instructed to perform all running activities as fast as possible under the laboratory conditions. Each activity was repeated to obtain two examples of each event of interest. Two versions of the 3-cone drill were performed, one with the subject starting forward and planting forward on the force plates, and the other with the cuts occurring on the force plates.

The 3D position of each kinematic marker in the laboratory coordinate system was determined using Vicon Nexus software. The motion capture and force plate data were converted to OpenSim input formats using MatLab (Mathworks, Natick, MA, USA) software. Appropriately scaled OpenSim [11] musculoskeletal models were used to estimate the joint kinematics of each participant.

The OpenSim foot model (Fig. 1) consisted of three rigid bodies, (1) the talus, (2) the calcaneus, tarsal bones, and the metatarsals