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FOOT PLACEMENT DURING SPRINTING AND ITS EFFECT ON BIOMECHANICS OF SPRINT PERFORMANCE IN NCAA DIVISION-I FEMALE TRACK AND FIELD RUNNERS

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Part I

Introduction

Sprinting success is achieved by a fast start such that maximal horizontal velocity can be achieved and maintained (Johnson and Buckley, 2000; Mann and Herman, 1985). Sprint velocity can be defined as the product of stride rate and stride length. Consequently, velocity can be increased by increasing stride rate or stride length or both; however, both factors are interdependent and individual morphologic and physiologic characteristics may influence the individual's motor abilities and utilization of the energy system (Čoh et. al., 2001).

Research indicates that elite and non-elite sprinters display significantly different joint angles during sprinting (Novacheck, 1998). It has been reported that world class sprinters demonstrate increases in stride length and cadence, thigh acceleration, trunk inclination, and trunk/thigh angle and decreases in components such as ground contact time, landing angle, and thigh angle (Kunz and Kaufmann, 1981). For instance, maximum knee flexion angles for elite and non-elite sprinters during the swing phase of sprinting reaches up to 130° and 105°, respectfully (Novacheck, 1998).

However, it is the ratio between the contact time and the flight time that is the most crucial factor in the kinematic structure of the sprinting stride. Successful sprinters demonstrated a shorter contact phase and longer flight phase than less successful sprinters (Čoh et. al., 2001). Reaction time, technique, electromyographic (EMG) activity, force production, neural factors, and musculoskeletal structures are other biomechanical factors that can influence performance in sprinting (Mero et. al., 1992). Hypothetically, a successful sprinter must have the ability to exert great force against the surface of the ground in a shorter time period than a less successful sprinter, which indicates that the successful sprinter generates greater power or ground reaction forces (Alexander, 1989; Kunz and Kaufmann, 1981; Weyand et. al., 2000).

Ground reaction forces are only achievable when the body is instantaneously in contact with the surface of the ground, therefore, a delicate balance of stride length and stride rate contributes to normal human locomotion and sprinting success. Nett (1964) studied foot contact during sprinting and reported that running speed influenced ground contact. He reported that initial ground contact occurred on the lateral aspect of the 5th metatarsophalangeal joint, high on the ball. As the running speed decreased, the contact point shifted to a more posterior position, or toward the heel. This can be seen in the 400-meter run, where ground contact shifts back toward the heel and foot plant is somewhat flatter. In distances greater than 1500 meters, the initial ground contact of the foot occurs on the lateral edge of the longitudinal arch between the heel and the head of 5th metatarsal. Nett further noted that during the load-phase of the ground contact of the foot, the heel strikes the ground, even in the case of sprinters; especially when the sprinters are fatigued (1964).

Conversely, Mann (1980) and Novacheck (1998) reported that the heel of sprinters did not or “may never” touch the ground throughout the sprint, and that initial ground contact is dependent on gait speed, consequently, as speed increases initial contact changes from the hind-foot to the forefoot. This issue remains unclear because only five studies have involved examination of foot placement during sprinting and its effect on biomechanics of sprint performance (Nett, 1964; Mann, 1980; Payne, 1983; Novacheck, 1995, Novacheck, 1998).

Differences between sprinters and non-sprinters have been observed biomechanically; however, present kinematic research generally does not extend to the influence of foot placement during the ground contact phase of the sprinting gait cycle. Although two main biomechanical factors – stride length and stride rate – have been widely accepted by researchers as key factors in sprint performance, it is also necessary to address the potential importance of foot placement during the ground contact phase.

Therefore, the purpose of this research study was to investigate ground foot contact and its effect on the biomechanics of the 200m sprint.

Statement of the Problem

The purpose of this study was to investigate selected kinematic variables and initial foot placement during the ground contact phase of sprinting and its effect on 200m sprint performance.

Research Questions

(1) How does the ground contact time of forefoot and heel affect 200m sprint performance?

(2) How does the ground contact time of forefoot and heel affect the type of foot placement?

(3) How do types of initial ground contact: Heel and ball-of-foot landing, Flat, Ball-of-foot/Flat landing, and Ball-of-foot-only landing affect 200m sprint performance?

Methodology

Subjects

A total of thirteen (n = 13) well conditioned National Collegiate Athletic Association (NCAA) Division I female track and field athletes participated in this study. Subjects in our study consist of four sprinters, four middle distance runners, three filed events athletes, one heptathlete, and one long distance runner. Consent forms approved by the University of Hawaiʻi, Committee on Human Studies were signed by all subjects. Prior to participation, subjects were screened for musculoskeletal and medical pathologies via medical history, PAR-Q, and a physical examination. Descriptive data of the subjects are presented in Table 1.

Table: 1 Descriptive data for the subjects (mean ± SD)

Subjects (n)	Age (yr)	Heights (cm)	Weight (Kg)
13	20.2 ± 1.2	170.2± 7.9	65.2 ± 14.9

The 200 meter Sprinting Test

The 200 meter sprint tests were performed on a Mondo track (Mondo USA, Lynnwood, WA). Testing protocol included a 5-minute warm up, 5-minute resting and stretching period, followed by the sprinting test. Subjects were positioned in a standing start without starting blocks and instructed to sprint as hard and as fast as possible throughout the entire 200-meter distance. The sprinting tests involved a standard track gun start (standing start). Sprint times were recorded using Speedtrap II (Brower Timing Systems, Draper, UT, USA) photoelectric timing cells placed at 25, 50, 100, 150, 175, and 200 meters to determine the points of peak velocity. Timing was initiated automatically as the cells were triggered by the starting gun and split times were collected as subjects disrupted the infrared signal between timing cells. A Skymate wind meter (Speedtech, Great Falls, VA, USA) was also used to factor out wind assistance (<2.0 mph). Subjects participated in two trials of the 200 meter sprinting tests, separated by a 20-minute rest period. Track competition footwear (e.g. spikes) were worn by all subjects during the tests.

Data Reduction and Film Analysis

Film data were collected from the sagittal plane via placement of two high speed analog video cameras (Peak Performance Technologies, Inc., Centennial, Colorado, USA) placed at the 30 m and 45 m marks of the 200 m sprint. The speed of both cameras was set at 180 fps and they were secured to photographic heads on tripods (Model 3221, Bogen Photo Corp., Ramsey, NJ, USA) and positioned with the optical axes of the cameras centered on the plane of motion of the runner at a distance of 5.7m, and 80cm off the ground (field of view sufficient to record the foot placement of the right leg of the subjects). Horizontal scale length (2.0m) and vertical scale length (1.0m) were adopted for calibration by using a custom made calibration frame (2.0 × 1.0 meter). Semi-hemisphere reflectors (Peak Performance Technologies, Inc., Centennial, Colorado, USA) were placed at subjects' hip (greater trochanter), knee (lateral epicondyle of femur), ankle (lateral maleolus), forefoot (head of 5^{th} metatarsal), and heel (calcaneus) by the same National Athletic Trainers' Association certified athletic trainer.

The kinematic data (Table: 2 – Table: 20) were reduced from the video and analyzed via the Peak Motus motion measurement system Version 8.0 (Peak Performance Technologies, Inc., Centennial, Colorado, USA). Processing of kinematics data via the motion measurement system involved scaling the raw coordinates and interpolating gaps in the scaled data but not to extrapolate gaps at the endpoints. Output data rate (Hz) of the scaled data was set at 60 Hz by the system.

Foot placement was analyzed both qualitatively and quantitatively and categorized into four ground contact types: Heel and ball-of-foot landing (HBF), Flat

(FLAT) landing, Ball-of-foot/Flat landing (BFF), and Ball-of-foot-only (BFO) (Figure 1 & Appendix A).

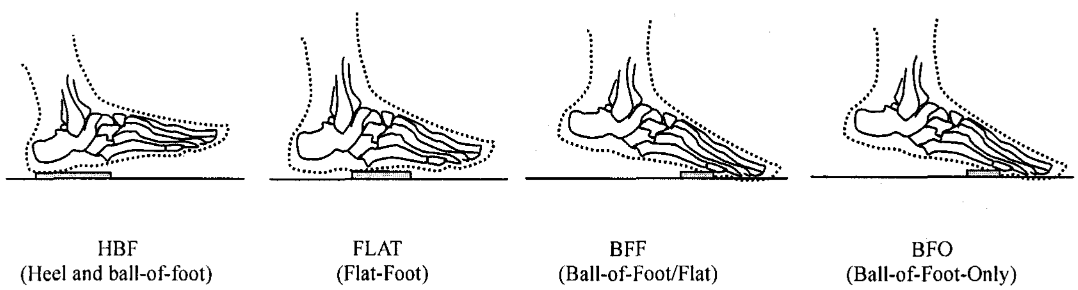

Figure: 1 Representation of foot placement at initial ground contact of sprinting

Statistical Analyses

Statistical computer software SPSS Version12.0 (SPSS Inc., Chicago, Illinois, USA) was used to analyze the data. Logistic regression analyses were used to test the prediction of the type of foot placement by models. Multiple regression analyses were used to test the 200 m sprint time by models. Correlation analysis was used to determine the relationship between the 200 m sprint time and the type of initial foot contact on the ground. The alpha level was set at 0.05.

Results

Descriptive data of 13 subjects Division I-A track sprinters, heptathletes, and field events athletes who volunteered to participate in this study are presented in Table: 1. T-test results of high speed video data indicated no significant differences in data collection at 30m and 45m. Consequently, the video data collected at 30m and 45m were averaged for Trial 1 and 2. The averaged support phase lower body kinematic data are presented in Tables: 2 – 6.

Table: 2 Joint angles during the support phase of the 200m sprint

Variables[a]	Trial 1				Trial 2			
	FLAT (n = 5)	(SD)	BFF (n = 6)	(SD)	FLAT[d] (n = 3)	(SD)	BFF (n = 5)	(SD)
Hip (deg)								
Initial contact	30.75	4.65	30.33	4.63	26.76	2.92	22.20	6.54
Mid-stance	31.67	7.58	23.77	6.72	19.66	5.39	24.31	12.24
Push-off	-1.48	6.51	-4.01	5.39	2.81	10.17	-6.02	9.19
Knee (deg)								
Initial contact	27.44	1.67	22.69	5.52	22.31	5.28	18.13	2.50
Mid-stance	42.48	10.01	35.69	4.67	39.45	11.87	29.97	5.30
Push-off	24.88	5.87	14.27	4.63	22.45	4.93	15.97	4.30
Ankle (deg)								
Initial contact	8.06	3.86	11.97	9.24	7.96	4.71	15.90	2.71
Mid-stance	-12.84	6.92	-8.03	7.89	-14.36	7.07	-3.50	4.71
Push-off	21.40	7.36	25.73	8.91	17.75	11.08	17.12	7.61

FLAT = Flat Landing; BFF = Ball-of-foot/Flat Landing
[a]Results at 30m and 45m are averaged.
[b]Positive values indicate flexion. Negative values indicate extension.
[c]Positive values indicate dorsiflexion. Negative values indicate plantarflexion.
[d]Type of foot contact was changed from BFF (Trial 1) to FLAT (Trial 2) in two subjects.

Table: 3 Angular velocities of joints during the support phase of the 200m sprint

Variable[a]	Trial 1				Trial 2			
	FLAT (n = 5)	(SD)	BFF (n = 6)	(SD)	FLAT[b] (n = 3)	(SD)	BFF (n = 5)	(SD)
Hip (deg/s)								
Initial contact	-98.27	146.01	-173.44	168.84	-130.31	132.49	-144.00	323.23
Mid-stance	23.47	336.07	-119.95	145.06	-159.89	173.39	-1.01	90.01
Push-off	-285.68	84.33	-195.16	271.78	-356.51	369.12	-338.04	260.96
Knee (deg/s)								
Initial contact	290.07	108.33	279.77	168.63	288.61	190.97	304.19	199.00
Mid-stance	397.43	210.80	366.2035	120.18	330.49	231.69	416.44	139.38
Push-off	-623.02	183.41	-503.59	219.18	-683.58	177.36	-589.59	157.40
Ankle (deg/s)								
Initial contact	-379.59	103.47	-293.05	199.77	-244.60	64.43	-356.30	143.18
Mid-stance	-416.78	190.99	-560.24	270.52	-546.10	333.29	-548.33	272.29
Push-off	1094.43	183.08	1063.05	261.11	1288.46	338.60	1160.71	172.82

FLAT = Flat Landing; BFF = Ball-of-foot/Flat Landing
[a]Results at 30m and 45m are averaged.
[b]Type of foot contact was changed from BFF (Trial 1) to FLAT (Trial 2) in two subjects.

Table: 4 Angular accelerations of joints during the support phase of the 200m sprint

Variable[a]	Trial 1				Trial 2			
	FLAT (n = 5)	(SD)	BFF (n = 6)	(SD)	FLAT[b] (n = 3)	(SD)	BFF (n = 5)	(SD)
Hip (deg/s^2)								
Initial contact	1716.68	11112.69	-3265.05	3624.62	-3820.23	3507.32	11901.42	6715.21
Mid-stance	-3878.47	11177.68	-5986.05	8669.57	3198.02	1174.53	-11168.65	13423.84
Push-off	21418.88	10273.77	8924.06	12162.82	11133.02	1046.79	25837.64	8697.60
Knee (deg/s^2)								
Initial contact	9187.11	3297.45	7589.27	7689.26	11504.91	5897.20	10181.56	4266.40
Mid-stance	-5708.90	14764.42	-7069.10	9210.37	-3996.81	15696.49	-4028.00	5376.51
Push-off	22186.67	7715.54	21976.81	6930.42	11483.73	21461.22	15398.15	10393.21
Ankle (deg/s^2)								
Initial contact	-21818.0044	3782.69	-23654.58	4077.72	-24635.83	5528.89	-24670.36	2246.77
Mid-stance	12835.22	10401.44	3740.37	10869.39	8905.62	15456.15	5425.01	5037.86
Push-off	-21950.70	12204.63	516.55	11534.35	-34515.49	48880.34	-5675.80	10450.66

FLAT = Flat Landing; BFF = Ball-of-foot/Flat Landing
[a]Results at 30m and 45m are averaged.
[b]Type of foot contact was changed from BFF (Trial 1) to FLAT (Trial 2) in two subjects.

Table: 5 Linear velocities of the body during the 200m sprint

Variable	Trial 1				Trial 2			
	FLAT (n = 5)	(SD)	BFF (n = 6)	(SD)	FLAT[b] (n = 3)	(SD)	BFF (n = 5)	(SD)
Horizontal velocities (m/s)								
Initial contact	7.54	0.57	6.95	0.66	6.82	0.23	6.98	0.63
Mid-stance	7.32	0.75	6.92	0.87	7.30	0.47	7.18	0.80
Push-off	10.08	0.96	9.32	1.23	7.30	2.42	9.07	0.88
Vertical velocities (m/s)[a]								
Initial contact	-0.54	0.28	-0.62	0.36	-0.03	0.55	-0.60	0.41
Mid-stance	-0.63	0.37	-0.53	0.35	-0.45	0.25	-0.66	0.29
Push-off	0.02	0.43	-0.04	0.22	-0.07	0.03	-0.13	0.26

FLAT = Flat Landing; BFF = Ball-of-foot/Flat Landing
[a]Negative values indicate the center of body is moving downward and positive value indicate for upward movement.
[b]Type of foot contact was changed from BFF (Trial 1) to FLAT (Trial 2) in two subjects.

Table: 6 Percentage contact time of the heel during the support phase of the 200m sprint

	Trial 1		Trial 2	
	FLAT (n = 5)	BFF (n = 6)	FLAT[a] (n = 3)	BFF (n = 5)
	59.52	15.38	14.29	28.57
	80.00	28.57	33.33	14.29
	42.86	38.89	33.33	37.50
	33.33	46.15		38.46
	33.33	35.71		36.36
		27.27		
Mean	49.81	32.00	26.98	31.04
SD	19.98	10.69	11.00	10.15

FLAT = Flat Landing; BFF = Ball-of-foot/Flat Landing
[a]Type of foot contact was changed from BFF (Trial 1) to FLAT (Trial 2) in two subjects.

Logistic regression analyses were used to explore the ability of different sets of predictor variables to predict the dependent variable (two types of foot placement). Results of the logistic regression analyses are presented in Tables: 7 – 12. Model Chi-square (χ^2) results indicate "goodness" of fit of the models. Cox & Snell R square and Nagelkerke R square are designed to provide the same basic information that the R-square statistic provides in ordinary least squares regression, and indicate how well the model fit the data. The accuracy of prediction is also indicated in the table, along with a measure of the improvement in prediction that a model provides over a baseline (null model with no predictor variables). According to the analyses, the model "Contact time of heel and forefoot" during the ground contact phase in Trial 1 was significant ($p < 0.05$). Conversely, the same model that was in Trial 2 was identified as non significant. During the push-off phase of Trial 1, and all three phases of Trial 2, the model "Angles of hip, knee, and ankle" and the model "Angular accelerations of hip, knee, and ankle" were identified as significant predictors of initial foot contact type.

Among significant models, we further attempted to determine which kinematic variables in the models best predicted the modeled type of foot placement (BFF) by examining the odds ratios of the individual predictor variables in the models. The odds ratio of the variable “Contact time of heel and forefoot” of Trial 1 was 4.87, which indicated that subjects with longer foot contact times tended to utilize the BFF landing method during initial ground contact. The odds ratio of the variables “Angular accelerations of hip, knee, and ankle” during the mid-stance phase of Trial 1 and 2, and the push-off phase of Trial 2 indicated that subjects with greater angular accelerations in all the joints tended to utilized the BFF landing method during initial ground contact. The odds ratio of the variables (Angles of hip, knee, and ankle) could not be calculated due to the small sample size relative to the number of kinematic variables.

Table: 7 Logistic regression analysis of the models predicting type of foot placement during initial contact of the 200m sprint in Trial 1

Model Predicting Type of Foot Placement	Model χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	2.508	0.285	0.222	0.296	70.0	40.0
Angles of hip, knee, and ankle	5.641	0.130	0.431	0.575	80.0	60.0
Angular velocities of hip, knee, and ankle	5.360	0.147	0.415	0.553	90.0	80.0
Angular accelerations of hip, knee, and ankle	2.643	0.450	0.255	0.341	77.8	50.0
Contact time of heel and forefoot	5.908	0.052	0.416	0.556	54.5	0.0

Table: 8 Logistic regression analysis of the models predicting type of foot placement during mid-stance of the 200m sprint in Trial 1

Model Predicting Type of Foot Contact	χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	0.829	0.661	0.088	0.118	55.6	0.0
Angles of hip, knee, and ankle	3.122	0.373	0.293	0.392	66.7	25.0
Angular velocities of hip, knee, and ankle	2.890	0.409	0.275	0.368	55.6	0.0
Angular accelerations of hip, knee, and ankle	7.210	0.065	0.551	0.738	77.8	50.0
Contact time of heel and Ball-of-foot/Flat	5.908	0.052	0.416	0.556	54.5	0.0

Table: 9 Logistic regression analysis of the models predicting type of foot placement during push-off of the 200m sprint in Trial 1

Model Predicting Type of Foot Contact	χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	1.933	0.380	0.215	0.293	75.0	33.3
Angles of hip, knee, and ankle	11.457	0.009	0.720	1.000		
Angular velocities of hip, knee, and ankle	1.768	0.622	0.198	0.270	75.0	33.3
Angular accelerations of hip, knee, and ankle	10.585	0.014	0.734	1.000	100.0	100.0
Contact time of heel and forefoot	5.908	0.052	0.416	0.556	54.5	0.0

Table: 10 Logistic regression analysis of the models predicting type of foot placement during initial contact of the 200m sprint in Trial 2

Model Predicting Type of Foot Contact	χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	2.739	0.254	0.324	0.435	85.7	66.7
Angles of hip, knee, and ankle	9.561	0.023	0.745	1.000		
Angular velocities of hip, knee, and ankle	1.910	0.591	0.239	0.321	57.1	0.0
Angular accelerations of hip, knee, and ankle	9.561	0.023	0.745	1.000		
Contact time of heel and forefoot	2.661	0.264	0.283	0.386	75.0	33.3

Table: 11 Logistic regression analysis of the models predicting type of foot placement during mid-stance of the 200m sprint in Trial 2

Model Predicting Type of Foot Contact	χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	1.341	0.511	0.174	0.234	71.4	33.3
Angles of hip, knee, and ankle	9.561	0.023	0.745	1.000		
Angular velocities of hip, knee, and ankle	2.961	0.398	0.345	0.463	85.7	66.7
Angular accelerations of hip, knee, and ankle	9.561	0.023	0.745	1.000	100.0	100.0
Contact time of heel and forefoot	2.661	0.264	0.283	0.386	75.0	33.3

Table: 12 Logistic regression analysis of the models predicting type of foot placement during push-off of the 200m sprint in Trial 2

Model Predicting Type of Foot Contact	χ^2	Sig.	Cox & Snell R^2	Nagelkerke R^2	Percentage correct predicted	Model Improvement Over Baseline
Horizontal and Vertical velocities of the body	2.565	0.277	0.274	0.374	75.0	33.3
Angles of hip, knee, and ankle	10.585	0.014	0.734	1.000	100.0	100.0
Angular velocities of hip, knee, and ankle	2.201	0.532	0.241	0.328	75.0	33.3
Angular accelerations of hip, knee, and ankle	8.376	0.039	0.698	1.000		
Contact time of heel and forefoot	2.661	0.264	0.283	0.386	75.0	33.3

Multiple regression analyses were used to determine whether the model of selected kinematic variables could predict 200 m sprint performance times. The proportion of variance in the dependent variable (200m time) that is explained by each model is indicated in the R-square column. This figure can be adjusted to reflect the ratio of sample size to independent variables in the model; this adjusted figure is indicated in the Adjusted R-square column. The *F* and Sig. columns indicated whether the entire model explained a significant amount of variation in the dependent variable (200m time). Results relative to the model "Contact time of heel and forefoot" during initial contact on the ground as predictor of the 200-meter time in Trial 1 were significant ($p < 0.05$) and are revealed in Tables: 13 – 15. According to the model, since it is true that 200m time = 93.846(Heel) + 69.086(Forefoot), and when the value of forefoot is set constant, it indicates that an increase in heel contact on the ground by 1/100 sec predicts a 0.938 sec increase in 200-meter time. Note that unit of contact time in tables are presented in seconds so interpretation of *B* value of the model "Contact time of heel and forefoot" is converted to the unit of 1/100 sec to make the number more practical.

Results relative to the model "Horizontal and Vertical velocities of the body" during the mid-stance of the ground contact as predictor of 200-meter time in Trial 1 was significant ($p < 0.05$) and is revealed in Table: 14. An increase in horizontal velocity of the body by 1.0 m/s predicts a 2.954 sec decrease in 200-meter time. Similarly, an increase in vertical velocity of the body by 1.0 m/s in upward direction predicts a 3.741 sec decrease in 200-meter time. Yet, an additional increase of horizontal velocity of the body by 1.0 m/s would be very difficult in sprinting; therefore, the number should be interpreted as based on theoretical prediction equation.

Results relative to the model "Horizontal and Vertical velocities of the body" during the push-off as predictor of the 200-meter time in Trial 1 was significant ($p < 0.05$) and is revealed in Table: 15. An increase in horizontal velocity of the body by 1.0 m/s predicts a 1.694 sec decrease in 200-meter time. An increase in vertical velocity of the body by 1.0 m/s predicts a 4.328 sec decrease in 200-meter time. In reality, an additional increase of horizontal velocity of the body by 1.0 m/s would be very difficult in sprinting and increase or decrease in vertical velocity of the body may not be significant because only the horizontal velocity of the body directly related to running time. Results of the model "Angular velocities of hip, knee, and ankle" during the push-off as predictor of the 200-meter time in Trial 1 indicate angular velocity of ankle is a significant predictor, which can be interpreted as an increase in angular velocity of ankle by 1.0 deg/s predicts a 0.012 sec decrease in 200-meter time.

Results relative to the model "Horizontal and Vertical velocities of the body" during the initial contact and the mid-stance as predictor of the 200-meter time in the Trial 2 was significant ($p < 0.05$) and is revealed in Table: 16 and 17. In these models, however, only the horizontal velocity of the body is significantly predicting the 200-meter time.

Results relative to the model "Angular velocities of hip, knee, and ankle" during the push-off as a predictor of the 200 meter time in Trial 2 indicated that an angular velocity was a significant predictor ($p < 0.05$) as revealed in Table: 18. These results can be interpreted such that increase in ankle angular velocity of ankle by 1.0 deg/s predicts a 0.006 sec decrease in 200-meter time.

Table: 13 Multiple regression analysis of the models predicting 200m sprint performance during initial contact of the 200m sprint in Trial 1

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	Sig.
Horizontal and Vertical velocities of the body	0.457	0.301	2.940	0.118			
Angles of hip, knee, and ankle	0.392	0.088	1.289	0.361			
Angular velocities of hip, knee, and ankle	0.361	0.042	1.131	0.409			
Angular accelerations of hip, knee, and ankle	0.441	0.105	1.313	0.368			
Contact time of heel and forefoot	0.591	0.489	5.787	0.028	Forefoot	69.086	0.059
					Heel	93.846	0.046

Table: 14 Multiple regression analysis of the models predicting 200m sprint performance during mid-stance of the 200m sprint in Trial 1

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	Sig.
Horizontal and Vertical velocities of the body	0.861	0.814	18.511	0.003	Horizontal velocity	-2.954	0.001
					Vertical velocity	-3.741	0.025
Angles of hip, knee, and ankle	0.234	-0.225	0.510	0.693			
Angular velocities of hip, knee, and ankle	0.628	0.405	2.816	0.147			
Angular accelerations of hip, knee, and ankle	0.266	-0.174	0.605	0.640			
Contact time of heel and forefoot	0.591	0.489	5.787	0.028	Forefoot	69.086	0.059
					Heel	93.846	0.046

Table: 15 Multiple regression analysis of the models predicting 200m sprint performance during push-off of the 200m sprint in Trial 1

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	Sig.
Horizontal and Vertical velocities of the body	0.843	0.780	13.390	0.010	Horizontal velocity	-1.694	0.023
					Vertical velocity	4.328	0.095
Angles of hip, knee, and ankle	0.283	-0.148	0.657	0.613			
Angular velocities of hip, knee, and ankle	0.896	0.818	11.502	0.020	Angular velocity of ankle	-0.012	0.013
Angular accelerations of hip, knee, and ankle	0.726	0.520	3.526	0.127			
Contact time of heel and forefoot	0.591	0.489	5.787	0.028	Forefoot	69.086	0.059
					Heel	93.846	0.046

Table: 16 Multiple regression analysis of the models predicting 200m sprint performance during initial contact of the 200m sprint in Trial 2

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	Sig.
Horizontal and Vertical velocities of the body	0.823	0.735	9.307	0.031	Horizontal velocity	-5.101	0.015
Angles of hip, knee, and ankle	0.703	0.406	2.364	0.249			
Angular velocities of hip, knee, and ankle	0.864	0.729	6.373	0.081			
Angular accelerations of hip, knee, and ankle	0.294	-0.412	0.416	0.755			
Contact time of heel and forefoot	0.248	-0.053	0.825	0.490			

Table: 17 Multiple regression analysis of the models predicting 200m sprint performance during mid-stance of the 200m sprint in Trial 2

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	*Sig.*
Horizontal and Vertical velocities of the body	0.685	0.528	4.354	0.099	Horizontal velocity	-3.577	0.064
Angles of hip, knee, and ankle	0.371	-0.257	0.590	0.662			
Angular velocities of hip, knee, and ankle	0.851	0.701	5.692	0.094			
Angular accelerations of hip, knee, and ankle	0.630	0.260	1.704	0.336			
Contact time of heel and forefoot	0.248	-0.053	0.825	0.490			

Table: 18 Multiple regression analysis of the models predicting 200m sprint performance during push-off of the 200m sprint in Trial 2

Model Predicting 200m Sprint performance	R^2	*Adjusted* R^2	*F*	Sig.		*B*	Sig.
Horizontal and Vertical velocities of the body	0.125	-0.225	0.358	0.716			
Angles of hip, knee, and ankle	0.396	0.056	0.876	0.524			
Angular velocities of hip, knee, and ankle	0.907	0.837	13.018	0.016	Angular velocity of ankle	-0.006	0.026
Angular accelerations of hip, knee, and ankle	0.359	-0.282	0.560	0.677			
Contact time of heel and forefoot	0.248	-0.053	0.825	0.490			

Discussion

The most important finding of our study was that two types of initial foot contact were observed and that all runners demonstrated heel contact on the ground at 30m and 45m marks of the 200 m sprinting. Only four of the 13 subjects in our study were sprinters; therefore, it is difficult to compare our results to those of Nett (1964), Payne (1983), and Mann (1980) who studied elite sprinters. However, our results appear to coincide with Nett's observation that the heel contacts the ground during sprinting.

Nett (1964) claimed that the distance or the pace of the race dictated the type of the foot-plant. He divided type of foot placement in three categories. The first category included the 100 and 200 meter runs, where initial ground contact was made with the outside edge of the sole, high on the ball of the foot. In the second category, the initial ground contact point was made back toward the heel; and the foot plant was somewhat flat and "the position of the foot is almost completely flat." The third category included distances greater than 1500m, up to the marathon, where initial ground contact was made with the outside edge at the arch of the foot between the heel and the metatarsus.

Payne (1983) selected four categories of foot/ground contact in runners: heel and ball-of-foot, flat, ball-of-foot/flat, and ball-of-foot-only for various running distances.

In his study, 56% of elite runners (n = 18) demonstrated the ball-of-foot/flat contact, 11% revealed the flat contact, and only 6% of the elite runners utilized the ball-of-foot-only contact for sprints up to 200 meters. Results of our study indicated that 46% of the subjects demonstrated Ball-of-foot/flat or BFF initial ground contact while 38% of the subjects demonstrated a FLAT initial contact. The fact that Nett and Payne observed international level elite athletes leads us to question whether the level of performance and the elite caliber of athletes affected differences between the aforementioned studies and the present study in which the subjects were NCAA Division I female track and field event athletes.

Converse to the results of our study and the aforementioned authors, Mann (1980) and Novacheck (1998) stated that the heel of the sprinters did not or "may never" touch the ground throughout the sprint and that initial ground contact is dependent on gait speed, consequently, as speed increases initial contact changes from the hind-foot to the forefoot. Novacheck (1995) noted that initial ground contact can distinguish running from sprinting. Results of these authors is questionable as neither stated clearly whether film or video data were collected to quantify these statements relative to the entire distance of the run/sprints analyzed.

Another important finding of our study was that initial ground contact (heel and forefoot contact time) was revealed via multiple regression analysis as a predictor of the 200-meter time ($p < 0.05$). Consequently, an increase in heel contact on the ground by 1/100 sec can predict a 0.938 sec increase in 200-meter time. Logistic analyses of the same model to predict the type of foot placement also revealed significant results. Kunz and Kaufmann (1981) reported that world-class sprinters (n = 3) demonstrated significantly shorter ground contact times than decathletes (n = 16) during maximal sprinting.

In the present study, multiple regression analyses results indicated that "Horizontal and Vertical velocities of the body" were significant predictors of 200m sprint times. Mann (1981) concluded that the plantar flexors played a significant role in halting negative (downward) vertical velocity of the body through eccentric contraction during the initial ground contact phase. Movement of the body into the impending non-support phase occurred by concentric contraction of the plantar flexors to generate positive (upward) vertical and horizontal (forward) velocities. Conversely, Herman and Mann (1985) reported that elite sprinters' maximum vertical velocity (Max = 0.67 m/s) was produced late in the ground contact phase.

Finally, all runners in our study reached peak horizontal velocity and peak velocity at or near the 30m and 45m distances. Results of the present study revealed a high correlation between peak velocity and 200-meter sprint time ($r = -0.95$) and indicated that average peak velocity 7.83 ± 0.72was attained between 4.23 - 8.86 seconds, corresponding to a distance of 25-50 meters. Similar findings were documented by Volkov (1979), and Berthoin et al. (2001) who found correlations of $r = -0.855$ and $r = -0.90$, respectively between peak velocity and 100 meter sprint performance (total time) of sprinters. These authors also found that peak velocity was attained within 4-5.6 seconds, corresponding to a distance of 30-50 meters. Peak velocity appears to be a more sensitive indicator of sprint time as distance increases from 100 to 200 meters.

Part II

Review of Literature

Biomechanics of sprint performance has been extensively studied both qualitatively and quantitatively (Mann, 1981). Biomechanical analyses of sprinting indicate that stride length tends to decrease with development of fatigue while stride rate or frequency is likely to increase (Elliott and Roberts, 1980). Similarly, results of other research studies reveal that stance or support phase increases with development of fatigue while double float or non-support phases decrease. Other researchers noted in the literature that the development of fatigue is observable by quantifying the changes in kinematic pattern during sprint performance (Chapman, 1982).

Effects of Lower Extremity Kinematics on Sprint Performance

Mann and Hagy (1980) biomechanically and electromyographically investigated walking, running, and sprinting. Subjects included: two male sprinters, five experienced joggers (2 females and 3 males), and six elite long-distance runners (3 females and 3 males). Sagittal plane motion of the lower limbs was video-recorded via the high-speed film data collection of various components of the gait cycle in walking, running, and sprinting. Results indicated that the step length, step rate, and horizontal velocity increased as gait shifted from walking to running, and from running to sprinting. Analysis also revealed an increase in the hip and knee flexion and ankle dorsiflexion range of motion as gait speed increased, thereby, lowering the body's center of gravity. Overall range of motion of the hip increased as the speed of gait increased during sprinting; however, while most of magnified motion was found in flexion, the degree of extension was slightly decreased when compared to running. Increased knee flexion was found as gait speed increased, but the degree of extension was decreased. Approximately 10° of the knee flexion was observed during walking and 35° during running after the ground contact followed by the knee extension. During sprinting, however, a second period of knee extension was not observed and continuous knee flexion was revealed. EMG data revealed quadriceps activity for the first 80% of the stance phase and the last 50 to 60% of the swing phase, these findings were significantly different from quadriceps activities seen in walking and running. The biomechanics of the motion at the ankle joint was also significantly different in walking, running, and sprinting. Plantar flexion occurred at initial ground contact followed by progressive dorsiflexion during walking gait. During running, dorsiflexion took place at initial ground contact followed by progressive planter flexion. During sprinting, the initial ground contact was made via toes and continuous dorsiflexion occurred during the stance phase followed by rapid planter flexion and no heel contact.

Mann (1981) conducted a kinetic analysis of sprint performance via investigation of the muscle activity about the hip, knee, ankle, shoulder, and elbow. Fifteen elite sprinters were filmed in the sagittal plane during a maximal effort sprint. A force platform was also used to record the vertical and horizontal components to determine the non-body ground forces on the body. Results indicated that elite sprinters produced larger hip extensor and knee flexor impulses to minimize the horizontal braking force. Sprinters who best succeeded in generating productive moments of propulsive ground reaction force (GRF) utilized the entire ground contact phase. Conversely premature termination of propulsive GRF or the recovery leg activity prior to toe-off was seen in the less skilled sprinters.

Kunz and Kaufmann (1981) conducted a kinematic analysis of the two groups of the elite athletes: Sixteen Swiss national decathletes and three world class American sprinters. Video-recorded data were used to compare the selected kinematic variables to determine what kinematic parameters distinguish world class performance in the 100 m. Results indicated that American sprinters produced longer strides, higher stride rates, shorter support phases, smaller landing and upper leg angles, greater upper leg accelerations, larger trunk inclinations, and greater trunk/thigh angles than the Swiss decathletes. Stride length and stride rate are primary kinematic variables that influence running speed, and since both variables are interdependent to each other, a delicate balance of both factors should be maintained. Other factors such as standing height, leg length, crural index (ratio between calf length and thigh length), explosiveness of muscular contractions, and speed of movement of the lower limbs may influence the optimal relationship between these factors.

Mann and Herman (1985) conducted kinematic analyses of the men's 200 meters sprint events at the 1984 Summer Olympic Games. Cinematographic records of the first (Gold), second (Silver), and eighth-place finishers were utilized to quantitatively analyze selected kinematic variables. The results of the analyses revealed that the fastest horizontal velocity was observed in the Gold medalist and there was a significant difference in stride rate between the Gold and Silver medalist. Furthermore, ground contact or support phase (time) was smaller in the Gold than Silver medalist. The results indicated that the skilled sprinters are capable of ending the ground contact early and also begin leg recovery quickly. All three sprinters were able to successfully produce the same amount of degree of full leg extension followed by high knee positions, which enabled those sprinters to initiate the production of the upper leg velocity into and during ground contact. Leg speed during the support phase dictated the success of the race secondary to reduce ground contact time. Higher lower leg velocity at landing decreased the initial horizontal braking force during ground contact. The authors concluded that shortened ground contact time, increased stride rate, and high horizontal velocity were primary factors that lead to the overall efficiency of the ground mechanics permitting a shortened ground leg range of motion, which all of those factors produced the winning edge.

The major kinematic variables of sprinting such as joint movement and joint position observed in elite sprinters have been reported in the literature; however, almost no attention has been paid to the relationship between these variables and muscle strength. Alexander (1989) investigated the relationship between lower limb muscle strength and selected kinematic variables of 23 (9 females and 14 males) elite sprinters. The maximal sprinting of the subjects was video-recorded in the sagittal plane. The position of the camera was set at 50 m from the start line where the subjects would reach their maximum speeds. Kinematic variables such as stride length, stride rate, horizontal and vertical velocity of the body's center of the gravity (CG), support time, non-support time, angular kinematics (position, displacement, and velocity) of the lower limb segments and trunk, and the touchdown distance from the foot to the CG were determined by the film analysis. Strength of the major muscle groups of the lower body required for sprinting was measured by a Kin/Com isokinetic dynamometer. Torque and power over the range of motion were determined by the dynamometer. Means and standard deviations of measured muscle strength and kinematic variables were calculated by SAS (Statistical Analysis System) program. The Pearson product-moment correlations were determined between the kinematic variables and the sprinting speed. Alexander noted that this technique has frequently been applied to sports biomechanics research to investigate the relationships between independent variables and the final outcome of the event. Stepwise multiple regression analysis was used to determine the best group of strength variables, and sprinting kinematic variables which predicted sprinting speed. The results of the correlations between peak torque values and sprinting speed indicated that those correlations were statistically significant. The results of the stepwise multiple linear regression procedures indicated that there was a multiple correlation ($R^2 = 0.99$) between the sprinting speed and the five kinematic variables (stride length, thigh displacement, peak angular velocity of lower let, recovery time, and upper arm maximum displacement) of the female sprinters. For the male sprinters, there was a multiple correlation (R^2 = 0.98) between the spring speed and the six kinematic variables (stride length, upper arm displacement, touchdown distance to center of gravity, lower leg displacement, peak angular velocity of lower leg, and peak thigh velocity in push-off). The researcher concluded that sprinting kinematic variables produced by the stepwise multiple regression analysis for the female and male were similar.

Kyröläinen et al. (2001) investigated intraindividual differences in running economy by biomechanical factors such as joint kinematics, kinetics, and muscle electromyographic (EMG) activity at different running speed. A total of 17 middle-distance runners were recruited as subjects for the research study. The subjects performed nine submaximal running bouts and four maximal sprints on an indoor track. Kinematic data, 3-D ground reaction forces (GRF), and EMG recordings of the selected leg muscles were recorded during the performance. Results indicated that contact times shortened as the running speed increased. Other kinematic variables such as stride rate and length were also increased together with the speed of running. The angular displacements in the ankle and knee joints during the contact phase decreased as the speed of running increased while the hip extended with a larger range. Increased peak and average angular velocities of the ankle, knee, and hip joints were observed only during the push-off phase. The EMG activity of the biceps femoris muscle was correlated with the energy expenditure ($r = 0.48$, $P < 0.05$). Its activity was highest both in the swing and contact phases during the maximal running. Activity of the gastrocnemius muscle increased in the pre- and braking phases. Minor angular displacements in the ankle and knee joint in the braking phase associated with the shortening of contact times and increased stride rate, which suggested there was increased functional contribution of stretch reflexes. Tendon-muscular elasticity of the muscles around the ankle and knee joint in the braking phase contributed to force production in the push-off phase, which could indicate that proper coactivation of agonist and antagonist muscles around these joints were required to increase the joint stiffness to meet the requirement for increase in running speed.

In summary, the step length, step rate, and horizontal velocity increased as gait shifted from walking to running, and from running to sprinting. Overall range of motion of the hip was increased as the speed of gait increased during sprinting; however, while the most of magnified motion was found in flexion, the degree of extension was slightly decreased when compared to running (Mann and Hagy, 1980). Elite sprinters produced a larger hip extensor and knee flexor impulses to minimize the horizontal braking force (Mann, 1981). Researchers noted that stride length and stride rates are the two main kinematic variables dictate the running speed, and since both variables are interdependent to each other, a delicate balance of both factors should be maintained (Kunz and Kaufmann, 1981). Another study indicated that stride length and peak angular velocity of the shank were found to be the best predictor for sprinting speed for both female and male sprinters (Alexander, 1989). The contact times shortened as the running speed increased. Kyröläinen et al. (2001) found that stride rate and length were increased together with the speed of running. The angular displacements in the ankle and knee joints during the contact phase decreased as the speed of running increased while the hip extended with a larger range. Increased peak and average angular velocities of the ankle, knee, and hip joints were observed only during the push-off phase.

Biomechanics of Lower Extremity during the Support Phase of Running

Nett (1964) investigated foot plant in running. Elite runners who were competing at the highest level of track meets in Germany were filmed by a high speed camera (64 pictures per second) that was set 20-30 cm high from the ground. A various types of runners, from the 100-m sprinters to marathoners, were video-recorded. Nett discovered that the initial foot placement or ground contact of the foot of all runners at all distances was the outside edge. The point of the ground contact of the foot was depending on the speed of running and distance of the race. For instance, the initial ground contact of the foot in the 100 and 200 meters run was "the outside edge of the sole, high on the ball (joints of the little toe)." As the running speed decreased, the contact point shifted more posterior or toward the heel. In the 400 meter run, the ground contact shifted further back toward the heel and foot plant was somewhat flatter. In the distance of beyond 1500 meter run, the initial ground contact of the foot was on the "outside edge at the arch between the heel and the metatarsus". Nett further noted that during the load-phase of the ground contact of the foot, the heel contacted the ground, even in the case of sprinters; especially when the sprinters were fatigued.

Payne (1983) investigated foot to ground contact forces of elite runners. A total of 18 athletes of various running events took a part in this study as subjects. The double force platform system developed by the investigator had been set into the field at ground level and speed of running was measured by photoelectric beam timers. The subjects were also filmed by a Hulcher 35 mm sequence camera at 45 frames per second with each exposure at 1/650 sec or less. A total of 90 other athletes were filmed by the Hulcher sequence camera during international competitions in order to assess the investigation of the study. Ground contact methods utilized by the subjects were divided into four categories: heel and ball-of-foot; flat; ball-of-foot/flat; and ball-of-foot-only. According to results of the study, sprinters and middle distance runners frequently used the ball-of-foot/flat method. The 400-m and 800 meter specialists often used the ball-of-foot-only method. Smoother force-time curve patterns were observed among the subjects who were running with mainly on the ball of the foot. Payne noted that running with the ball-of-foot method is physiologically more demanding especially for endurance runners and may require the high level of skill for sprinters.

In summary, Nett (1964) reported that the initial foot placement or ground contact of the foot of all runners at all distances was the outside edge. He points out that the point of the ground contact of the foot was depending on the speed of running and distance of the race. He further noted that during the load-phase of the ground contact of the foot, the heel contacted the ground, even in the case of sprinters; especially when the sprinters were fatigued. Another study reports that sprinters and middle distance runners frequently used the ball-of-foot/flat method. For instance, the 400-m and 800 meter specialists often used the ball-of-foot-only method (Payne, 1983). In addition, Payne noted that running with the ball-of-foot method is physiologically more demanding especially for endurance runners and may require the high level of skill for sprinters.

Appendices

Appendix A

Glossary

Terminology	Definition
Initial contact	The part of the ground contact phase during which any portion of the foot contacts the ground.
Mid-stance	The part of the ground contact phase during which the patella of one knee overlaps the patella of the opposite knee in the sagittal view.
Push-off	The part of the ground contact phase during which the forefoot leaves the ground. (for the purposes of this analysis, the point at which the head of 5th metatarsal completely leaves the ground)
Ground contact	Also known as the support phase or stance phase.
Ground contact time	The total time that the foot contacts the ground.
Horizontal velocity of the body	The linear velocity of the iliac crest in a horizontal direction.
Vertical velocity of the body	The linear velocity of the iliac crest in a vertical direction. A positive value indicates an upward direction. A negative value indicates a downward direction.
Hip angle	The angle between the iliac crest and the lateral epicondyle with the apex at greater trochanter. A positive value indicates flexion. A negative value indicates extension.
Knee angle	The angle between the greater trochanter and the lateral maleolus with the apex at lateral epicondyle. A positive value indicates flexion. A negative value indicates extension.
Ankle angle	The angle between the line segment of the lateral epicondyle to the lateral maleolus and the line segment of the calcanues to the head of the 5th metatarsal. A positive value indicates plantar flexion. A negative value indicates dorsiflexion.
HBF (Heel and Ball-of-foot)	A type of foot landing in which initial contact of the foot on the ground is made with the heel followed by the ball-of-foot.
BFF (Ball-of-foot/Flat)	A type of foot landing in which initial contact of the foot on the ground is made with the ball-of-foot followed by the heel.
BFO (Ball-of-foot-Only)	A type of foot landing in which initial contact of the foot on the ground is made with the ball-of-foot and the heel never touches the ground.
FLAT	A type of foot landing in which initial contact of the foot on the ground is made with the mid portion or plantar surface of the foot.

Appendix B
INFORMED CONSENT
To Participate in a Research Study

I. INVESTIGATORS

Principal Investigators:
Joseph H. Smith, ATC, CSCS
Tomoki Kanaoka, ATC

Supervising Professor:
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II. TITLE

Determination of Anaerobic Performance Via a Maximal Sprint Field Test

III. INTRODUCTION

This study is part of two master's degree theses by University of Hawai'i graduate students. Because you are in good physical condition and participate regularly in some form of physical activity, you are being asked to take part in this research study. The purpose of this study is to examine sprint field tests (SFT_{Max}) of 200 and the Wingatge anaerobic test (WAnT) to assess your anaerobic performance (a type of physical ability which enables one to perform high-intensity exercise in a relatively short period of time). During the SFT_{Max} test you will be video-recorded with high speed cameras for biomechanical analyses.

The reason for giving you the following information is to help you decide if you would like to participate in this study. This consent form may contain words that are unfamiliar to you. Please discuss any questions you have about this study with the research staff members. Your participation in this research is voluntary, and you will not be paid. Be assured that all information collected about you will be kept confidential. You and the researchers will be the only ones to know the individual results of your tests.

IV. DESCRIPTION OF PROCEDURES

You will be asked to report to the University of Hawai'i at Manoa Human Performance Laboratory to engage in standard measurements of height, body mass and lower limb lengths (hip-knee length, lower leg length, and foot length). You will also be asked to refrain from exercising, eating or drinking (except water) 4 hours prior to reporting to the laboratory so that you are well rested and well hydrated upon arrival.

Test Schedule

You will be asked to perform two different tests, which will be spaced at least one week apart for a total of 2-3 weeks. Your scheduled may appear like that depicted in the tables (Schedule A, B) below.

Schedule A	Exercise Bicycle Test	Sprint Field Tests (SFT_{Max})
	WAnT	200 meter sprint
Week 1	1trial	—
Week 2	—	1 trial

Schedule B	Exercise Bicycle Test	Sprint Field Tests (SFT_{Max})
	WAnT	200 meter sprint
Week 1	—	1 trial
Week 2	1 trial	—

Wingate Anaerobic Test

A maximum bicycle sprint will be performed using the cycle ergometer (exercise bicycle). You will start with a 5-15 minute warm up on the cycle ergometer, a 15-second mock familiarization trial of the WAnT, followed by a 5-minute resting and stretching period. You will then participate in the 30-second WAnT protocol. **Finger prick (#6)** (blood drawing) will then be performed during a passive recovery within 5 minutes of completion of the test. **Finger prick** will be taken from your fingertip using a sterile lancet. **Your blood sample will be used to measure blood lactate level in order to determine your anaerobic capacity, which is your ability to sustain high-intensity exercise in a relatively short period of time (#7).** The blood sample will be labeled using your identification numbers in order to ensure confidentiality. The total time of the test will be approximately 15-25 minutes.

Maximal 200 meter Sprint Field Test

The maximal 200 meter sprint test will be performed at the University of Hawai'i Cooke Field track. You will be asked to wear proper running shoes for the test. Before the tests, you will participate in a 5-15 minute warm up period, followed by a 5-minute resting and stretching period. You will then participate in a 200 meter SFT_{Max} test. Sprint times will be recorded using photoelectric cells and will be used to measure velocity and acceleration. You will also be video-recorded with high speed cameras for biomechanical analyses. **Finger prick** (blood drawing) will then be performed during recovery within 5 minutes of completion of the test. **The procedure and purpose of finger prick will be the same as previously described in the Wingate anaerobic test (#7).** The total time of the test will be approximately 20 to 30 minutes.

V. RISKS

Due to the high intensity of the activity involved (maximal anaerobic performance), you may feel distress, nausea, fatigue, muscle pain, soreness, or discomfort. A very remote possibility of cardiac arrest exists. Temporary pain or discomfort may be felt during **finger prick** (blood drawing). Excessive bleeding or infection may occur, and bruising at the site is a common side effect. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. The **principal investigators are nationally recognized health care providers: National Athletic Trainers Association, Board of Certification (NATA/BOC) certified athletic trainers**; First Aid/CPR certified and trained to use the portable automated external defibrillator (AED) on site. You should understand that if you are injured in the course of this research procedure that you alone may be responsible for the costs of treating your injuries.

VI. BENEFITS

You may not directly benefit from this study although you will gain the experience of being part of a scientific experiment. You will obtain information concerning your anaerobic fitness levels and sprint running abilities. Knowledge gained from this experiment will help individuals and coaches to more specifically create training programs to enhance performance.

VII. CONFIDENTIALITY

Your research records will be confidential to the extent permitted by law. You will not be personally identified in any publication about this study. **However, the University of Hawai'i at Manoa Committee on Human Studies may review your records (#8).** A code, which will be known only to study personnel and you, will be used instead of your name on laboratory records of this study. Personal information about your test results will not be given to anyone without your written permission. In addition, all data (including video recordings) and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science Human Performance Laboratory. These materials and the video recordings will be permanently disposed of in a period not longer than 5 years.

VIII. CERTIFICATION

I certify that I have read and that I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent and to discontinue participation in the project or activity at any time without prejudice.

I herewith give my consent to participate in this project with the understanding that such consent does not waive any of my legal rights, nor does it release the principal investigator or institution or any employee or agent thereof from liability for negligence.

If you have any questions related to this research study, please contact principal investigators, Joseph Smith and Tomoki Kanaoka at 956-3804 or you may also contact Iris F. Kimura at 956-3800 at any time.

____ ____________________

Signature of individual participant Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 1 <30m Mark>

	DV 1	DV 2	Distance b/w Body and Foot (meter)			Hip Angles			Knee Angles			Ankle Angles		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1	FLAT	28.17	0.30	0.05		28.6			25.6			9.8		
2	FLAT	31.92				30.1			27.0					
3	FLAT	33.15	0.29	0.17	-0.56	24.9	27.7	-1.0	25.9	32.9	30.4	7.7	-2.6	24.6
4	FLAT	28.30	0.29	-0.14	-0.56	31.3	26.2	-6.8	28.7	48.7	20.7	11.5	-15.3	27.6
5	BFF	30.82	0.40	0.06	-0.50	33.5	34.8	-0.9	26.7	45.1	22.9	9.4	-12.7	14.3
6		27.28												
7	BFF	28.15			-0.52			-7.0			12.0		2.4	38.9
8		26.57												
9	BFF	33.44	0.43	0.13	-0.66	27.1	18.3	-7.1	21.0	36.8	11.6	17.6	-14.4	29.9
10	BFF	29.64	0.35	0.12	-0.53	22.3	18.1	-11.2	25.1	38.1	9.6	-1.3	-18.5	20.2
11	BFF	30.88	0.32	0.00	-0.42	23.6	17.1	1.6	14.1	39.8	17.4	20.1	-14.1	20.7
12	BFF	25.21	0.28	0.15		33.9	17.3		29.0	37.9		7.5	-12.0	
13		26.87												

Trial 1 <45m Mark>

1		28.17												
2	FLAT	31.92	0.31	-0.04		37.6	42.1		29.2	53.7		6.4	-22.3	10.7
3	FLAT	33.15	0.35	0.12	-0.51	25.1	22.4	0.6	25.8	39.2	32.9	10.1	-9.4	20.2
4	FLAT	28.30	0.28	0.02	-0.55	42.4	28.4	-10.3	30.3	47.1	22.3	14.0	-10.7	24.0
5	BFF	30.82	0.35	0.23	-0.45	37.1	35.9	-4.6	32.1	38.6	21.8	12.6	-3.9	11.2
6		27.28												
7		28.15												
8		26.57												
9	BFF	33.44		0.11	-0.44									
10	BFF	29.64	0.21	0.09		29.0	28.2		26.4	36.0		-5.6	-18.9	
11	BFF	30.88	0.35	0.15	-0.41	33.0	24.6	0.4	15.2	27.4	16.3	20.1	-2.0	28.3
12	BFF	25.21	0.36	0.23	-0.50	36.7	25.3	3.0	16.1	20.5	13.2	21.5	9.8	28.1
13	FLAT	26.87	0.32	0.19	-0.49	29.4	32.2	4.3	28.1	32.3	21.5	2.5	-10.1	26.7

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 1 <30m Mark>

	DV 1	DV 2	Contact Time (sec)			Horizontal Velocity of COB			Vertical Velocity of COB			Angular Velocity of Hip		
Subject	Type of Foot Contact	200M Time	5th Metatarsal (Forefoot)	Calcaneus	% Heel contact	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1	FLAT	28.17	0.084	0.05	59.5	7.83			-0.54			26.9		
2	FLAT	31.92	0.050		0.0	7.13			-0.35					
3	FLAT	33.15	0.117	0.033	28.6	7.40	6.89	8.91	-0.52	-1.39	0.10	-86.4	197.7	-306.5
4	FLAT	28.30	0.100	0.017	16.7	8.73	8.28	10.96	-0.71	-0.38	-0.27	-53.8	-372.0	-207.7
5	BFF	30.82	0.117	0.017	14.3	6.62	7.38	9.95	-1.20	-0.37	0.11	-152.4	-389.6	-387.8
6		27.28												
7	BFF	28.15	0.117	0.033	28.6			9.80			-0.39			250.6
8		26.57												
9	BFF	33.44	0.167	0.084	50.0	6.63	5.6	7.2	-0.2	-0.4	0.3	-356.2	-228.9	-121.2
10	BFF	29.64	0.117	0.067	57.1	6.63	7.4		-0.5	-0.7		-47.0	35.1	
11	BFF	30.88	0.117	0.050	42.9	6.48	6.48	8.29	-0.20	-0.04	0.12	-174.9	-139.1	1.9
12	BFF	25.21	0.084	0.017	20.0	7.8	8.0		-0.9	-0.2		-699.5		
13		26.87												

Trial 1 <45m Mark>

1		28.17												
2	FLAT	31.92	0.117	0.067	57.1	6.98	6.42		-0.56	-0.57		12.6	76.4	
3	FLAT	33.15	0.117	0.067	57.1	6.93	7.09	9.17	-1.49	-0.86	0.92	-421.8	478.0	-453.9
4	FLAT	28.30	0.100	0.050	50.0	8.07	7.81	10.91	0.10	-0.85	-0.02	21.1	-531.0	-309.5
5	BFF	30.82	0.100	0.017	16.7	6.85	7.58	9.49	-1.17	-1.79	-0.03	152.4	-23.9	-568.0
6		27.28												
7		28.15												
8		26.57												
9	BFF	33.44	0.134	0.033	25.0		5.7	8.5		-0.7	0.1		286.6	-503.6
10	BFF	29.64	0.100	0.033	33.3	6.86	6.43		-0.71	-0.08		-4.3	-144.7	
11	BFF	30.88	0.117	0.033	28.6	6.55	6.85	8.33	-0.71	-0.23	-0.21	-114.9	62.5	-375.2
12	BFF	25.21	0.100	0.033	33.3	8.39	7.84	10.91	-0.36	-0.84	-0.02	18.5	-328.7	-249.4
13	FLAT	26.87	0.100	0.033	33.3	7.25	7.82	10.26	-0.38	-0.21	-0.29	-260.5	131.1	-218.2

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 1 <30m Mark>

	DV 1	DV 2	Angular Velocity of Knee			Angular Velocity of Ankle			Angular Acceleration of Hip		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1	FLAT	28.17	307.8			-553.2					
2	FLAT	31.92									
3	FLAT	33.15	248.0	654.1	-408.2	-346.7	-577.6	705.1	10578.8	7271.7	14812.1
4	FLAT	28.30	415.7	-12.7	-765.6	-487.9	17.5	1018.7	-6991.2	-14125.6	25723.1
5	BFF	30.82	358.1	127.9	-540.6	75.2	-107.1	942.6	3472.2	-17809.3	23458.7
6		27.28									
7	BFF	28.15			-633.9		-344.0	1030.4			-9991.1
8		26.57									
9	BFF	33.44	17.2	364.9	460.5	-216.7	-488.6	182.6	-4120.7	-13960.7	3545.0
10	BFF	29.64	226.5	295.6		234.9	-962.0	1243.0	-2394.9	-4297.2	
11	BFF	30.88	404.1	109.0	-464.4	-400.5	-118.2	1101.6	2790.7	2797.9	9736.2
12	BFF	25.21	217.3			-758.6					
13		26.87									

Trial 1 <45m Mark>

1		28.17									
2	FLAT	31.92	431.6	339.8		-344.9	-305.8	1218.4	-6564.7	-18972.6	
3	FLAT	33.15	132.8	720.1	-630.4	-204.5	-421.9	957.1	2606.3	849.2	7389.8
4	FLAT	28.30	277.5	379.7	-904.0	-246.3	-455.2	1198.9	-9507.5	2719.9	37572.7
5	BFF	30.82	536.5	308.5	-615.3	-472.5	-740.5	1017.9	-1428.2	-13162.2	23270.2
6		27.28									
7		28.15									
8		26.57									
9	BFF	33.44		435.3	-691.6	-276.6	-353.2	1080.9			13099.3
10	BFF	29.64	419.0	379.2		-367.9	-718.8		-4536.7		
11	BFF	30.88	372.0	548.8	-658.6	-309.0	-613.8	1083.8	-5043.9	7238.5	8252.8
12	BFF	25.21	229.9	546.5	-629.0	-438.8	-966.3	1400.3	-8634.2	-1204.8	13930.3
13	FLAT	26.87	174.0	379.3	-515.0	-357.2	-642.7	1219.5	15088.2	5101.1	21507.8

Appendix C
The 200 Meter Sprinting Test Kinematic Data

Trial 1 <30m Mark>

	DV 1	DV 2	Angular Acceleration of Knee			Angular Acceleration of Ankle		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off
1	FLAT	28.17						
2	FLAT	31.92						
3	FLAT	33.15	17662.9	11504.7	19019.5	-19250.4	-307.7	-10641.0
4	FLAT	28.30	8889.3	-18952.5	28861.0	-24440.8	27844.0	-31230.5
5	BFF	30.82	3986.9	-13012.9	16757.9	-19555.0	19231.3	-6948.4
6		27.28						
7	BFF	28.15			18887.2			-30824.8
8		26.57						
9	BFF	33.44	3986.3	-13296.2	25795.8	-24009.4	10559.6	-23777.9
10	BFF	29.64	10077.6	-10608.9		-16943.1	805.1	-32576.8
11	BFF	30.88	9164.5	-20737.0	12471.3	-26258.3	25935.8	-7850.3
12	BFF	25.21						
13		26.87						

Trial 1 <45m Mark>

1		28.17						
2	FLAT	31.92	5150.9	-20501.3		-17559.9	17844.5	
3	FLAT	33.15	7943.8	-467.3	7599.3	-21816.3	18639.3	-5084.5
4	FLAT	28.30	12420.0	-13506.9	23086.0	-28683.5	20366.1	-26125.4
5	BFF	30.82	-5786.6	-10301.7	19413.6	-23919.2	2462.9	1401.8
6		27.28						
7		28.15						
8		26.57						
9	BFF	33.44			21913.5		-5377.0	-2245.0
10	BFF	29.64	4090.4			-20385.2	-4655.1	
11	BFF	30.88	6623.7	2846.9	19213.3	-21888.5	9131.4	-26318.0
12	BFF	25.21	19881.7	9161.9	33214.2	-29788.8	-10345.1	-26054.4
13	FLAT	26.87	8139.5	8376.7	27277.1	-22616.7	225.6	-29311.4

Appendix C
The 200 Meter Sprinting Test Kinematic Data

Trial 2 <30m Mark>

	DV 1	DV 2	Distance b/w Body and Foot (meter)			Hip Angles			Knee Angles			Ankle Angles		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1		28.77												
2		32.38												
3		34.00												
4	FLAT	26.80	0.36	0.01	-0.58	25.5	15.5	-8.9	24.2	52.6	16.8	7.0	-21.6	19.9
5	BFF	28.76	0.41	0.17	-0.47	25.0	38.9	-13.9	20.5	36.7	15.8	14.6	-7.7	13.2
6		28.07												
7	BFF	28.78			-0.47			3.4			15.5		3.5	29.5
8		27.22												
9	BFF	33.22	0.39	0.19	-0.54	13.5	9.7	-6.6	17.1	28.3	12.3	21.5	-9.0	23.0
10	BFF	30.48	0.31	0.09	-0.42	22.9	22.7	-13.6	20.7	35.6	15.0	14.8	-10.1	7.4
11	BFF	30.79	0.34	0.14	-0.32	27.8	22.1	8.6	10.3	28.0	26.1	18.9	-5.6	5.7
12	BFF	25.49	0.32	0.20		27.7	22.2		23.2	28.4		5.6	-6.9	12.0
13	BFF	26.73	0.31	0.22	-0.13	28.3	22.9	9.1	25.9	27.1	27.2	1.3	-5.5	24.5

Trial 2 <45m Mark>

1		28.77												
2		32.38												
3		34.00												
4		26.80												
5		28.76												
6		28.07												
7		28.78												
8		27.22												
9	BFF	33.22	0.43	0.24	-0.44	11.5	8.6	-14.2	12.5	22.4	13.6	18.2	-3.7	14.6
10	BFF	30.48	0.36	0.15		26.3	23.2		18.2	27.7	9.8	12.9	-2.1	20.9
11	FLAT	30.79	0.34	0.01		21.6	13.3		22.3	44.3		7.2	-22.4	
12	BFF	25.49	0.35	0.22	-0.35	25.7	30.3	4.5	12.4	23.8	23.2	25.0	5.1	7.9
13	FLAT	26.73	0.31	0.20	-0.48	31.9	28.6	8.3	26.8	32.0	21.6	6.3	-9.5	30.7

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 2 <30m Mark>

	DV 1	DV 2	Contact Time (sec)			Horizontal Velocity of COB			Vertical Velocity of COB			Angular Velocity of Hip		
Subject	Type of Foot Contact	200M Time	5th Metatarsal (Forefoot)	Calcaneus	% Heel contact	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1		28.77												
2		32.38												
3		34.00												
4	FLAT	26.80	0.117	0.017	14.3	7.09	7.68	9.19	0.29	-0.71	-0.05	21.6	-346.4	-780.8
5	BFF	28.76	0.117	0.033	28.6	7.07	7.99	8.44	-1.20	-0.38	-0.05	-14.4	115.4	-585.5
6		28.07												
7	BFF	28.78	0.117	0.017	14.3			9.64			-0.55			-383.1
8		27.22												
9	BFF	33.22	0.134	0.033	25.0	6.33	6.02	8.14	-0.37	-1.03	-0.05	-594.0	-232.5	162.6
10	BFF	30.48	0.100	0.050	50.0	6.48	6.93	8.90	-0.20	-0.37	0.12	-135.7	-48.6	-97.7
11	BFF	30.79	0.100	0.033	33.3	6.78	6.78	8.14	-0.54	-0.20	-0.05	-236.2	-3.6	-109.3
12	BFF	25.49	0.100	0.033	33.3	7.80	7.48		-0.54	-0.43		-159.5	-247.3	
13	BFF	26.73	0.100	0.033	33.3	7.38	7.38	-0.55	0.00	-0.51	-0.02	-190.6	-196.0	-31.7

Trial 2 <45m Mark>

1		28.77												
2		32.38												
3		34.00												
4		26.80												
5		28.76												
6		28.07												
7		28.78												
8		27.22												
9	BFF	33.22	0.134	0.067	50.0		6.24	8.06		-1.02	0.11		232.0	-238.7
10	BFF	30.48	0.117	0.033	28.6	6.96	7.13		-0.39	-1.18		-124.5	17.6	
11	FLAT	30.79	0.100	0.033	33.3	6.63			-0.81			-207.6		
12	BFF	25.49	0.084	0.033	40.0	7.82	7.68	10.27	-0.53	-0.53	-0.18	484.4	39.9	-585.8
13	FLAT	26.73	1.002	0.334	33.3	5.98	7.51	9.71	0.57	-0.38	-0.19		-63.3	-327.3

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 2 <30m Mark>

	DV 1	DV 2	Angular Velocity of Knee			Angular Velocity of Ankle			Angular Acceleration of Hip		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off	Initial	Mid	Push-off
1		28.77									
2		32.38									
3		34.00									
4	FLAT	26.80	381.7	83.8	-884.8	-178.0	-161.3	1244.6	-6813.0	4015.4	
5	BFF	28.76	504.0	247.6	-577.2	-340.9	-389.7	1150.1	18332.8	-29622.4	35336.3
6		28.07									
7	BFF	28.78			-748.8		-260.9	962.2			25459.2
8		27.22									
9	BFF	33.22	64.5	446.2	-219.5	-559.4	-464.4	1054.4	16556.6	-2107.0	12536.9
10	BFF	30.48	288.9	313.9	-599.9	-297.8	-586.6	1323.6	7005.7	-5258.3	32822.6
11	BFF	30.79	397.7	543.5	-550.0	-175.2	-735.1	973.9	-1368.0	3726.6	10392.8
12	BFF	25.49	240.0	461.7		-438.4	-934.2		-610.8	-3948.3	
13	BFF	26.73	68.9	364.3	-809.8	-85.5	-699.6	2218.5	-4686.9	1852.1	4937.4

Trial 2 <45m Mark>

1		28.77									
2		32.38									
3		34.00									
4		26.80									
5		28.76									
6		28.07									
7		28.78									
8		27.22									
9	BFF	33.22		544.1	-452.9	-224.2	-585.0	1055.1		4191.6	31248.8
10	BFF	30.48	156.1	411.7		-48.8	-585.2	1117.3	1064.3	-2903.6	
11	FLAT	30.79	432.7			-438.0			1446.4		
12	BFF	25.49	611.4	658.8	-685.9	-599.9	-1026.8	1416.0	17973.5	-20078.8	13677.2
13	FLAT	26.73		364.1	-422.1	-412.9	-784.2	1075.2			18809.0

Appendix C

The 200 Meter Sprinting Test Kinematic Data

Trial 2 <30m Mark>

	DV 1	DV 2	Angular Acceleration of Knee			Angular Acceleration of Ankle		
Subject	Type of Foot Contact	200M Time	Initial	Mid	Push-off	Initial	Mid	Push-off
1		28.77						
2		32.38						
3		34.00						
4	FLAT	26.80	17522.4	-18722.5	34997.5	-18416.5	22336.5	-28208.7
5	BFF	28.76	6343.0	-10313.7	17842.9	-24503.5	7400.1	-4926.0
6		28.07						
7	BFF	28.78			12998.2			-10047.0
8		27.22						
9	BFF	33.22	9867.4	-796.6	33043.1	-30936.4	14174.6	-24383.5
10	BFF	30.48	10940.4	-12912.2	13022.0	-24653.1	14366.6	4499.7
11	BFF	30.79	12857.8	-5785.3	-7049.0	-32353.5	12368.7	10905.3
12	BFF	25.49	13462.2	4220.2		-19367.5	-5452.1	
13	BFF	26.73	5735.9	12517.3	-16371.5	-25623.3	-16815.8	-139998.8

Trial 2 <45m Mark>

Subject	Type of Foot Contact	200M Time	Knee Initial	Knee Mid	Knee Push-off	Ankle Initial	Ankle Mid	Ankle Push-off
1		28.77						
2		32.38						
3		34.00						
4		26.80						
5		28.76						
6		28.07						
7		28.78						
8		27.22						
9	BFF	33.22		4875.7	28789.1	-23893.8	5143.8	-10340.7
10	BFF	30.48	5682.4	520.0		-19190.9	-1355.2	-18624.8
11	FLAT	30.79	9654.9			-25634.2		
12	BFF	25.49	18946.8	-7503.7	2211.5	-30314.3	1722.2	11018.6
13	FLAT	26.73			29376.9	-27371.0	839.2	-32487.5

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