SPRINT BIOMECHANICS OF FEMALE NATIONAL COLLEGIATE
ATHLETIC ASSOCIATION DIVISION TRACK AND FIELD
ATHLETE

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF
THE UNIVERSITY OF HAWAI'I
IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE
IN
KINESIOLOGY AND LEISURE SCIENCE

AUGUST 2006

By
Kaori Tamura

Thesis Committee:
Iris Kimura, Chairperson
Ronald Hetzler.
Jan Prins
We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Kinesiology.

THESIS COMMITTEE

[Signatures]

Chairperson

[Signature]
Acknowledgements

Dr. Kimura,
It has been a life lesson. It has been the biggest challenge in my life.
I worked hard and tried my best. At the end, you gave me a biggest present.
   Feeling of Accomplishment.
   You made me step up to the next level.
   Arigatougozaimashita.
Dr. Hetzler, Dr. Prins,
Thank you for being my committee member.
   I truly appreciate your support and encouragement.
Cris,
I could not have done this without your help and guidance.
   Thank you for being patient and supportive. You are the BEST!
Andrea,
You always unconditionally supported EVERYONE in this program, made this program so much better and easier to work with. I am so lucky that I had you in my years.
   Thank you for your endless dedication and unconditional love.
Yukiya,
   You don’t know how much I feel reassured just by having you in this island.
   You are my buddy forever.
Kristen, Ryan, Vanessa, and Kyle,
   We have encountered a lot of things and overcome a lot of things together. Thank you!
Shannon, Kelly, Goose, Arielle, Stephanie, and Bret,
   Every one of you offered to help. Thank you for your support and encouragement.
   It’s your turn now!
Joe, Tomoki,
Thank you for giving me huge encouragement every time I wanted to give up.
   Now I get to write “acknowledgements” and know how this feels like.
   This is why you pushed me to finish it. Everything was worth the effort.
Mom and Dad,
   Thank you for your unconditional LOVE.
   Thank you for my LIFE.
   My life is good.
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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 (Coh et. al., 2001). It has been reported that world class sprinters demonstrate increases in stride length and stride rate, landing angle, thigh acceleration, trunk inclination, and decreases in components such as thigh angle and ground contact time (Kunz and Kaufmann, 1981). 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 shorter contact phases and longer flight phases than less successful sprinters (Coh et. al., 2001). Reaction time, technique, electromyographic (EMG) activity, force production, neural factors, and musculoskeletal structures are other biomechanical factors that can influence sprint performance (Mero et. al., 1992). Hypothetically, successful sprinters must have the ability to exert large ground-reaction forces (GRF) in shorter time periods than a less successful sprinters (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 (contact phase). The contact phase can be divided into braking and propulsion phases according to the vertical movement of whole body center of gravity (CG) or the negative and positive horizontal reaction forces during foot
contact (Luhtanen & Komi, 1978). The braking phase starts from initial foot contact to
the lowest position of CG, during which the extensor muscles of the stance leg work
eccentrically (Luhtanen & Komi, 1978; Miller, 1983). The velocity of the CG decreases
following initial foot impact then the velocity increases during the subsequent propulsion
phase (Cavanagh, 1980). It has been reported that the angle between the horizontal
running surface and the line from CG to initial foot contact point (landing angle) can
affect contact times and CG velocity during the braking phase. In order to minimize
decreases in velocity during the braking phase it is crucial to keep the CG close to the
point of initial foot contact at touchdown resulting in large landing angles. (Deshon &

Payne (1983) reported that the type of foot contact influenced the braking force.
He found that running with no heel contact demonstrated the absence of the first vertical
force peak and smoother force/time patterns. This type of foot contact was mainly seen
in 400 to 800 m specialists and should be considered mechanically more efficient than
foot contacts causing high impact forces where the CG was behind the contact foot
(Payne, 1983). Nett (1964) studied type of foot contact during sprinting and reported that
running speed influenced ground contact. He reported that initial foot contact occurred
on the lateral aspect of the 5th metatarsophalangeal joint, high on the ball of the foot. 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 m run, where the initial foot contact point
shifts back toward the heel and foot plant is somewhat flatter. In distances greater than
1500 m, the initial foot contact 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 contact 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 not” touch the ground throughout the sprint, and that initial ground contact was dependent on gait speed. Consequently, as speed increased initial contact changed from the hind-foot to the forefoot. This issue remains unclear because only five studies have involved examination of type of foot contact during sprinting and its effect on the biomechanics of sprint performance (Nett, 1964; Mann, 1980; Payne, 1983; Novacheck, 1995; Novacheck, 1998)

Differences between levels of elite sprinters have been observed biomechanically (Alexander, 1989; Kunz & Kaufman, 1981; Luhtanen & Komi, 1978; Mann, 1981; Mann and Herman, 1985). However, present kinematic research generally does not extend to the influence of type of foot contact during the ground contact phase of the sprint gait cycle. Although two main biomechanical factors – stride length and stride rate – have been widely accepted by researchers as key factors in sprint performance, foot contact type during the contact phase is unclear and controversial. Therefore, the purpose of this research study was to investigate type of foot contact during the contact phase and its effect on the biomechanics of the 200 m sprint.

Statement of the Problem

The purpose of this study was to investigate selected kinematic variables and initial foot contact types during the ground contact phase of the sprint and their effect on
sprint performance of female National Collegiate Athletic Association Division I track
and field athletes.

Research Questions

(1) How does ground contact time affect 200 m sprint time?

(2) How does touchdown distance (TDD) affect contact time?

(3) How does TDD affect 200 m sprint time?

(4) How does vertical displacement (VD) affect contact time?

(5) How does VD affect 200 m sprint time?

(6) How does initial foot contact type: Heel and ball-of-foot landing, Flat, Ball-of-
foot/Flat landing, and Ball-of-foot-only landing, affect kinematic variables during the
200 m sprint?

(7) How do kinematic variables of sprinting found in elite athletes compare to those
found in collegiate sprinters.
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 consisted of four sprinters, four middle distance runners, three field events athletes, one heptathlete, and one long distance runner. Prior to participation, subjects were screened for musculoskeletal and medical pathologies via medical history, PAR-Q, and a physical examination. Consent forms approved by the University of Hawai‘i, Committee on Human Studies were signed by all subjects.

200 meter Sprint Trials

All 200 m sprint trials were performed on a Mondo track (Mondo USA, Lynnwood, WA). Sprint performance protocol included a 5 m warm up, 5 m rest and stretching period, followed by the sprint trial. 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 m distance. The sprint trials involved a standard track gun 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 m 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 200 m sprint trials, separated by a 20 m rest period. Track competition footwear (e.g. spikes) were worn by all subjects during both 200 m trials.
Data Reduction and Film Analysis

Film data were collected in the sagittal plane with two high speed analog video cameras (Vicon/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 positioned with their optical axes centered on the plane of motion of the runner (center of lane 3) at a distance of 5.7 m, and a height of 80 cm (field of view sufficient to record the foot placement of the right leg of the subjects) on tripods (Model 3221, Bogen Photo Corp., Ramsey, NJ, USA). Horizontal scale length (2.0 m) and vertical scale length (1.0 m) were adopted for calibration by using a custom made calibration frame (2.0 × 1.0 m). Semi-hemisphere reflectors (Peak Performance Technologies, Inc., Centennial, Colorado, USA) were placed on subjects’ hip (greater trochanter), knee (lateral epicondyle of femur), ankle (lateral maleolus), forefoot (head of 5th metatarsal), and heel (calcaneus) by the same Board of Certification, certified athletic trainer.

The kinematic data (Table 1) were reduced from the video and analyzed via the Peak Motus motion measurement system Version 8.0 (Vicon/Peak Performance Technologies, Inc., Centennial, Colorado, USA). The segmental center of gravity locations and the segmental weight from Clauser (1969) was used for the calculation of the whole body center of gravity. 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. The cubic spline filter was used to smooth the raw data. Output data rate (Hz) of the scaled data were set at 60 Hz.
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](image_url)

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

**Table 1** Kinematic variables of sprint performance

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial contact</td>
<td>The part of the ground contact phase during which any portion of the foot contacts the ground.</td>
</tr>
<tr>
<td>Mid-stance</td>
<td>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.</td>
</tr>
<tr>
<td>Push-off</td>
<td>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)</td>
</tr>
<tr>
<td>Ground contact</td>
<td>Also known as the support phase or stance phase.</td>
</tr>
<tr>
<td>Contact time</td>
<td>The total time that the foot contacts the ground.</td>
</tr>
<tr>
<td>Total vertical displacement</td>
<td>The total amount of vertical displacement during the ground contact.</td>
</tr>
<tr>
<td>HBF (Heel and Ball-of-foot)</td>
<td>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.</td>
</tr>
<tr>
<td>BFF (Ball-of-foot/Flat)</td>
<td>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.</td>
</tr>
<tr>
<td>BFO (Ball-of-foot-Only)</td>
<td>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.</td>
</tr>
<tr>
<td>FLAT</td>
<td>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.</td>
</tr>
<tr>
<td>TDD (Touch down distance)</td>
<td>The horizontal distance between the initial foot contact point and the body Center of Gravity at Initial contact.</td>
</tr>
<tr>
<td>MSD (Mid-stance distance)</td>
<td>The horizontal distance between the foot contact point and the body Center of Gravity at Mid-stance.</td>
</tr>
<tr>
<td>POD (Push-off distance)</td>
<td>The horizontal distance between the foot contact point and the body Center of Gravity at Push-off.</td>
</tr>
</tbody>
</table>
Statistical Analyses

Statistical computer software Statistical Analysis System Version 9.0 English Software Package (SAS Institute Inc. Cary, North Carolina, USZ) was used to analyze the data. One-way ANOVA was used to determine differences in each variable between 200 m sprint trials 1 and 2. Pearson product moment correlations were used to examine the relationship between each variable. Regression analysis was used for further examination on the variables that were significantly correlated. The alpha level was set at p<0.05.
Results

Averaged 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 2. Averaged contact phase lower body kinematic data for all of the subjects during the 200 m sprint are presented in Table 3.

Table 2: Averaged descriptive data of subjects (mean ± SD)

<table>
<thead>
<tr>
<th>Event</th>
<th>Subjects (n)</th>
<th>Age (yr)</th>
<th>Heights (cm)</th>
<th>Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinter</td>
<td>4</td>
<td>21.0 ± 1.8</td>
<td>165.52 ± 5.29</td>
<td>65.17 ± 2.08</td>
</tr>
<tr>
<td>Middle distance runner</td>
<td>4</td>
<td>20.0 ± 0.0</td>
<td>171.61 ± 7.48</td>
<td>67.56 ± 2.95</td>
</tr>
<tr>
<td>Field event</td>
<td>3</td>
<td>20.0 ± 1.0</td>
<td>175.47 ± 5.76</td>
<td>69.08 ± 2.27</td>
</tr>
<tr>
<td>Heptathlete</td>
<td>1</td>
<td>19</td>
<td>177.29</td>
<td>69.8</td>
</tr>
<tr>
<td>Long distance runner</td>
<td>1</td>
<td>19</td>
<td>156.21</td>
<td>61.5</td>
</tr>
<tr>
<td>Total (averaged)</td>
<td>13</td>
<td>20.2 ± 1.2</td>
<td>170.2 ± 7.9</td>
<td>65.2 ± 14.9</td>
</tr>
</tbody>
</table>

Table 3. Selected trial-to-trial means and standard deviations of 200 m trials at 30 m and 45 m

<table>
<thead>
<tr>
<th>Variables</th>
<th>30m</th>
<th>45m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of foot contact</td>
<td>BFF (n=7), Flat (n=4)</td>
<td>BFF (n=5), Flat (n=5)</td>
</tr>
<tr>
<td>200m time vs Contact time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200m time (sec)</td>
<td>29.46 ± 2.61</td>
<td>29.84 ± 2.70</td>
</tr>
<tr>
<td>Contact time (sec)</td>
<td>0.11 ± 0.02</td>
<td>0.10 ± 0.02</td>
</tr>
<tr>
<td>Contact time vs TDD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact time (sec)</td>
<td>0.11 ± 0.02</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>TDD (m)</td>
<td>0.30 ± 0.04</td>
<td>0.28 ± 0.04</td>
</tr>
<tr>
<td>Contact time vs MSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact time (sec)</td>
<td>0.11 ± 0.02</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>MSD (m)</td>
<td>0.11 ± 0.07</td>
<td>0.08 ± 0.07</td>
</tr>
<tr>
<td>Contact time vs TVD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact time (sec)</td>
<td>0.12 ± 0.02</td>
<td>0.10 ± 0.01</td>
</tr>
<tr>
<td>TVD (m)</td>
<td>0.02 ± 0.02</td>
<td>0.020 ± 0.01</td>
</tr>
</tbody>
</table>

Analysis of Variance results indicated no significant differences in each dependent variables between trials 1 and 2 at 30 m and 45 m. Therefore, the trial (1 or 2) that had fewer missing data points was selected for each subject at 30 m and 45 m for data analyses. Significantly high correlations were found between contact time at 30 m
and 200 m time (r=.79, p=.0065), and contact time at 45 m and 200 m time (r=.85, p=.0018). A significant negative correlation was found (r=-.7, p=.03) between mid-stance distance (MSD) and contact time at the 45 m point. The relationship between touchdown distance (TDD) and contact time at 30 m (r=.62, p=.09 at 30 m) and 45 m (r=.13, p=.57 at 45 m) was not significant. Vertical displacement (VD) and contact time was moderately correlated but was not significant (r=.60, p=.051) when the data from 30 m and 45 m were combined. Type of foot contact did not correlate with any of the other variables.
Discussion

A thorough understanding of the biomechanical factors involved in sprinting is necessary for optimizing performance in a variety of sport activities. Mero et al (1992) conducted an extensive review of factors affecting sprint performance of elite (world-class) sprinters and found that they shared common biomechanical sprinting characteristics. It included long stride lengths; high stride rates; short contact times, vertical peak-to-peak CG displacements, and touchdown distances. Other factors that influenced sprint performance were reaction time, technique, electromyographic activity, force production, neural factors, musculoskeletal structures, height and leg length. Similar relationships were found, in our study, between performance success and biomechanical characteristics of 13 National Collegiate Athletic Association (NCAA) Division I female track and field athletes.

The highest correlation revealed in the present study was between 200 m sprint times and contact times, 30 m ($r = .79, \ p = .007$) and 45 m ($r = .85, \ p = .002$). Luhtanen and Komi (1978), Kunz and Kaufmann (1981), and Mann and Herman (1985), all found that contact time decreased as running speed increased in world-class sprinters. Our findings strongly agreed with the aforementioned studies. Successful sprinters have the ability to exert large ground-reaction forces (GRF) in short time periods, which results in long stride lengths and fast sprint times (Kunz and Kaufmann, 1981; Luhtanen and Komi, 1980).
Figure 2 Relationship between contact time and 200 m sprinting time in second at 30 m.
\( r = .79, p = .007 \)

Figure 3 Relationship between contact time and 200 m sprinting time in second at 45 m
\( r = .85, p = .002 \)
Contact times and touch down distance (TDD) in the present study showed a moderate, but not statistically significant relationship ($r = .62$, $p = .09$). Touch down distance (TDD) has been identified as the primary reason for decreases in running velocity during the contact phase of running (Mero, 1992). Since TDD represents the horizontal distance between the initial foot contact point and the CG of the body decreases in running velocity may be attributed to the opposing horizontal forces the ground exerts on the foot (GRF) (Hay, 1993). Consequently, placement of the foot as closely as possible beneath the CG at initial foot contact decreases the amount of negative acceleration seen during the contact phase (Deshon and Nelson, 1964). Mann and Herman (1985) noted that Olympic Gold medalists demonstrated small TDDs. Similar findings were documented by Kunz and Kaufmann (1981) who reported world-class sprinters demonstrated larger landing angles than decathletes. These authors stated that large landing angles represented small TDDs. Furthermore, Alexander (1989) found that TDD was one of the best predictors of sprint speed ($r^2 = .86$, $p = .0001$) of male sprinters. He suggested that slight differences in male and female sprinters affected the kinematic variables of running however, these differences were not clear. The non-significant correlation in the present study may have been due to our utilization of females.
Figure 4 Relationship between Touchdown distance (Horizontal distance between foot and CG at initial contact) in meter and contact time in second at 30 m. ($r= .62, p=.10$)

Figure 5 Relationship between Touchdown distance (Horizontal distance between foot and CG at initial contact) in meter and Contact time in second at 45 m. ($r= .57, p= .14$)
Contact times and vertical displacement (VD) in the present study also showed a moderate, but not statistically significant relationship \((r = .51, p = .60)\). Our findings were consistent with those of Mero (1983), and Luhtanen and Komi (1980). These authors found that the contact time was short when the vertical displacement of CG was small. Mero further noted that contact time increases were due to large inferior displacements of CG during the braking phase. Luhtanen and Komi (1980) reported that when vertical displacement was small and contact time was short, the spring constant (the combined elasticity of muscles, tendons and bones) was large. The authors suggested that successful sprinters may utilize extensor muscle elasticity more efficiently, allowing larger GRFs in short contact times, resulting in a smaller fall of CG during the contact phase (braking phase).

![Vertical Displacement vs Contact Time](image)

**Figure 6** Relationship between vertical displacement in meter and contact time in second at 30 m and 45 m combined. \((r = .71, p = .18)\)
The most interesting finding of the present study was the significant correlation between contact time and mid stance distance (MSD) ($r = -0.70$, $p = 0.03$) at 45 m, suggesting that when foot placement was further in front of COG at Mid-stance, contact time was shorter. Conversely, finding of our study and previous studies (Mero, 1992) indicated that smaller TDDs closely correlated to short contact times, thus a similar relationship at mid-stance was expected. This disagreement in findings may be attributed to our definition of "mid-stance". Slocum (1968) stated mid-stance or mid-support “starts once the foot is fixed and continues until the heel starts to rise from the ground”. Since this definition describes the range of the movement and not one finite point of the movement, for digitizing and data reduction purposes, we defined mid-stance as “the point in the ground contact phase during which the patella of one knee overlaps the patella of the opposite knee in the sagittal view”. Consequently, findings of the present study indicated that subjects with CGs further behind the plant foot when both knees overlapped, in the sagittal view, presented shorter contact times. However, after careful video examination it appeared that the time period between initial contact and mid-stance was shorter in subjects who demonstrated shorter contact times and faster $200 \text{ m times}$ than slower subjects. In other words, successful sprinters appeared to reach a greater degree of hip flexion in the stance leg with the patellae nearing overlap prior to initial contact of the swing leg. Less-successful sprinters tended to demonstrate prolonged hip extension times resulting in greater distances between the patellae at initial foot contact of the swing leg. Kunz and Kaufmann (1981) reported that world-class sprinters demonstrated smaller angles between both thighs (thigh angle) at the moment of first surface contact, indicating that their legs were closer together at initial foot contact. This
smaller thigh angle would result in reaching the "mid-stance" sooner after the initial foot contact. In the present study, it appeared that since initial contact and mid-stance were so close to each other in more successful sprinters, very little horizontal translation of CG occurred between these two points. As a result, the placement of CG at mid-stance was further behind the contact foot in successful sprinters than in less-successful sprinters whose increased time period between initial contact and mid-stance allowed for greater horizontal translation.

Kunz and Kaufmann (1981) stated that a smaller thigh angle helped to increase the stride landing angle and also to decrease the contact time and increase the sprint speed. Further video examination in our study also revealed a common characteristic of the swing leg in successful sprinters which would contribute to decreased thigh angle at initial contact. Novacheck (1995) defined swing phase reversal as the instantaneous event in which hip flexion occurring during the initial swing phase changes to progressive hip extension during the terminal swing phase prior to initial contact. This definition suggests overall movement of the foot that is in the same horizontal direction relative to CG prior to swing phase reversal and in the opposite horizontal direction relative to CG after. In the present study, successful sprinters appeared to reach swing phase reversal earlier than less-successful sprinters whose swing phase reversal occurred closer in time or not at all before initial contact. Hay (1993) described the ability to sustain forward momentum during the support phase based on the horizontal ground-reaction forces at initial contact relative to the direction of foot movement. He asserted that a foot moving forward at the moment of initial contact will exert a backward
horizontal ground-reaction force and serve to decrease momentum while a foot moving backward at first contact will exert a forward ground-reaction force creating increased momentum. In this way, the early swing phase reversal demonstrated in our study by successful sprinters should contribute to horizontal ground reaction forces at initial contact that are not only in the proper direction to increase momentum, but are greater in magnitude than those exerted by those runners whose swing phase reversal came later or not at all prior to initial contact. These horizontal ground reaction forces occurring opposite the horizontal direction of CG and the magnitude of these forces should serve to decrease contact time and increase overall sprint speed.
Figure 7 Relationship between mid-stance distance (Horizontal distance between foot and CG at mid-stance) in meter and contact time in second at 30 m. (r= -0.32, p= 0.44)

Figure 8 Relationship between mid-stance distance (Horizontal distance between foot and CG at mid-distance) in meter and contact time in meter at 45 m. (r= -0.75, p= 0.03)
In the present study, two initial foot contact types were observed, ball of foot/flat and flat. All subjects demonstrated heel contact at 30 m and 45 m marks in the 200 m sprint. Since, only 4 of our 13 subjects were sprinters, it was 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. The present study failed to detect any significant correlations between foot contact type and other variables such as contact time and 200 m sprint time.

Figure 9 Type of foot contact (Ball of Foot/Flat and Flat) and 200 m sprinting time. (averaged within group)
Type of foot contact vs Contact time

Finally, it should be noted that the results presented in this paper were specific to 30 m and 45 m points of a 200 m sprint trial. Mero et al (1992) reported that world-class elite sprinters reached their maximal velocity between 50 m and 60 m distances during a 100 m sprint. Since the subjects of the present study were collegiate athletes, and not elite athletes we hypothesized that they would reach maximal velocity sooner than the elite athletes. Therefore, 30 m and 45 m points were chosen as maximal velocity observation points during 200 m sprint trials. No significant differences were found in our study between the 30 m and 45 m observation points in all dependent variables, however, kinematic characteristics associated with maximal velocity were likely to change with fatigue development. Chapman (1982) and Nummela (1994) reported that the development of fatigue decreased stride length and stride rate and increased contact time. Therefore further research is needed to investigate how fatigue changes these kinematic variables.
In conclusion, contact time was significantly related to 200 m sprint time. Contact time was also moderately correlated with TDD and VD. These findings agreed with previous studies conducted on elite athletes. Results of the present study suggest that kinematic characteristics predictive of success in non-elite collegiate athletes are similar to those previously identified in elite sprinters. In addition, the present study revealed a significant negative correlation between MSD and contact time. This finding may be due to a shorter time period between initial foot contact and mid-stance suggesting successful sprinters appeared to begin knee flexion and hip extension in the swing leg in preparation for the contact phase prior to initial foot contact, in order to keep the CG behind or above foot contact. This faster preparation for contact phase may result in an increased stride landing angle and also decreased contact time leading to increased sprinting speed (Kunz and Kaufmann, 1981). However, further research is needed to investigate the relationship of MSD to the kinematic characteristics of sprinting.
Part II
Review of Literature

Effect of lower leg Kinematics on sprinting

Deshon and Nelson (1964) investigated the relationship between running velocity and kinematic variables. Subjects were 19 college varsity athletes, ten sprinters and nine baseball players who all performed an all-out 40 yd sprint. The first 25 yd was used to attain maximum velocity and the last 15 yd was filmed with a 16mm Bolex Camera at 64 frames per sec. The camera was placed 155 ft from the perpendicular to the center of the 15 ft filming zone. The films were analyzed with a Bell and Howell motion analysis projector. Kinematic variables included: runner velocity over 100 frames of the film, cycle velocity, cycle length, leg lift angle, and touchdown leg angle. Leg lift angle was defined as “the angle between a line drawn along the top edge of the thigh and the horizontal”. Touchdown leg angle was defined as “the angle made by a parallel line with the ground through the lateral malleolus and a line through the approximate location of the center of gravity to the lateral malleolus”. Intercorrelations between all variables indicated that all correlations were statistically significant with the exception of the relationship between mean leg lift angle and mean touchdown leg angle. Mean cycle length and the mean touchdown leg angle were significantly related to cycle velocity. The author concluded that the results of the study supported the concept that efficient running is characterized by a high knee lift, long running stride, and placement of the foot as closely as possible beneath the center of gravity of the runner. He further noted that encouraging a performer to lengthen his stride or raise the knees higher would be advisable since these movements might be the result of the propulsive force of the rear
leg. He also noted the conflict between stride length and touchdown angle since
lengthening ones stride would increase speed but the reduction touchdown angle would
decrease speed.

Luhtanen and Komi (1978) studied one-step cycle and the relationship between
running speed and various kinematic parameters. Six national level track and field
athletes (two sprinters, two jumpers, one decathlonist, and one thrower) were asked to run
at 40, 60, 80, and 100% of maximum speed on an indoor track. Film data were collected
at 100 frames/sec with a Locam 51-0003 camera. Results indicated that both stride
length and stride rate increased as running speed increased, however, stride length leveled
off at higher speeds while stride rate increased. Peak to peak vertical oscillation of the
center of gravity was highest at the lowest speed and lowest at the highest speed. Step
cycle, total contact time, and flight time decreased as running speed increased from 40%
to maximum. Flight time was first shorter than total contact time at the lowest speed, but
was reversed as speed increased. When total contact time was divided into a negative
phase (from the beginning of the first contact to the lowest position of center of gravity,
when extensor muscles of the contact leg worked eccentrically) and a positive phase
(portion of contact time that extensor muscles of the contact leg were contracting
concentrically), both decreased with increased running speed but the relative proportions
of contact time did not change. The author concluded that stride length seemed to be a
limiting factor for increases in velocity, in that the compensatory mechanism to increase
running speed at higher velocities would be to increase stride frequency at a greater rate
than that of stride length.
Kunz and Kaufmann (1981) conducted a kinematic analysis of two groups of 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 distinguished world class performance in the 100m. Results indicated that American sprinters produced longer strides, higher stride rates, shorter support phases, larger landing angles, smaller upper leg angles, greater upper leg accelerations, larger trunk inclinations, and greater trunk/thigh angles than the Swiss decathletes. The larger landing angle of the world class sprinters indicated that their foot touch-down was closer to their centers of gravity than the Swiss decathletes. Stride length and stride rate are primary kinematic variables that influence running speed and since both variables are interdependent of each other, a delicate balance of both factors should be maintained.

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 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 of the recovery leg activity prior to toe-off was seen in the less skilled sprinters.
Mann and Herman (1985) kinematically analysed the men's 200 m sprint 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 indicated that the gold medalist had the fastest horizontal velocity and that there was a significant difference in stride rate between the Gold and Silver medalist. Furthermore, ground contact or support phase (time) was shorter in the Gold medalist than in the Silver medalist. The results indicated that the skilled sprinters are capable of ending ground contact early and also begin leg recovery more quickly. All three sprinters were able to successfully produce the same degree of full leg extension followed by high knee positions, which enabled those sprinters to initiate upper leg velocity during ground contact. Leg speed during the support phase dictated the success of the race secondary to reduced 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 contact leg range of motion, and that all of these 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. Maximal sprint performances of the subjects were video-recorded in the sagittal plane.
The position of the camera was set 50m from the start line where the subjects were expected to 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 of the plant foot to the CG were determined with the film analysis. Torque, power and range of motion of the major muscle groups of the lower body required for sprinting were measured with a Kinetic Communicator isokinetic dynamometer. 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 sprint speed and five kinematic variables (stride length, thigh displacement, peak angular velocity of lower leg, recovery time, and upper arm maximum displacement) of the female sprinters. Male sprinter results revealed multiple correlations \( R^2 = 0.98 \) between the sprint speed and 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 sprint kinematic variables produced by the stepwise multiple regression analysis for the female and male were similar.

Kyröläinen et al. (2001) investigated intra-individual differences in running economy of 17 middle-distance runners. Subjects performed nine submaximal run trials and four maximal sprints on an indoor track. Kinematic data, 3-D ground reaction forces (GRF), and EMG recordings of selected leg muscles were recorded during the
performances. Results indicated that contact times shortened as the running speed increased. Other kinematic variables such as stride rate and length also increased with running speed. Ankle and knee joint angular displacements decreased during the contact phase as running speed increased while hip angle increased. Ankle, knee, and hip peak and average angular velocities increased only during the push-off phase. The EMG activity of the biceps femoris muscle was correlated with the energy expenditure ($r = 0.48, P < 0.05$). Biceps femoris EMG activity was highest in the swing and contact phases during maximal running. Gastrocnemius muscle activity increased in the late swinging and braking phases. Minor angular displacements in the ankle and knee joint in the braking phase were associated with shortened contact times and increased stride rate, which indicated an increased functional contribution of the stretch reflexes. Tendon-muscular elasticity around the ankle and knee joints in the braking phase contributed to force production in the push-off phase, which appeared to indicate that proper coactivation of agonist and antagonist muscles around these joints were required to increase the joint stiffness to meet the requirements of increased running speed.

In summary, step length and the step rate increased and contact time decreased as running speed increased (Luhtanen & Komi, 1978; Kunz & Kaufmann, 1981; Mann & Herman, 1985; Kyrolainen, 2002). Elite sprinters produced larger hip extensor and knee flexor impulses to minimize the horizontal braking forces (Mann, 1981) and placed their contact feet as close as possible beneath their center of gravity (Deshon & Nelson, 1964; Kunz & Kaufmann, 1981). Researchers noted that stride length and stride rates were the two main kinematic variables that dictated running speed, and since both variables were
interdependent of each other, a delicate balance of both factors should be maintained (Kunz and Kaufmann, 1981). Stride length and peak angular velocity of the shank were found to be the best predictors of sprint speed for both female and male sprinters (Alexander, 1989). Kyröläinen et al. (2001) found that the angular displacements in the ankle and knee joints during the contact phase decreased as running speed increased while the hip joint angle increased. Increased peak and average angular velocities of the ankle, knee, and hip joints were observed only during the push-off phase.

**Initial foot contact type**

Nett (1964) compared foot plant of elite 100 m sprinter to marathoners who were competing at the highest level of track meets in Germany. Subjects were filmed with a high speed camera at 64 frames per second that was placed at a height 20-30 cm above the ground. Nett determined that the initial ground contact foot placement of all runners at all distances was made on the outside edge of the plant foot. Ground contact of the foot was dependent on the speed and distance of the run. Thus, initial foot contact in the 100 m and 200 m runs was made on the outside edge of the sole, high on the ball of the foot and as run speed decreased, foot contact point shifted more posterior, toward the heel. In the 400 m run, foot contact shifted back toward the heel and foot plant was somewhat flatter. In running distances greater than 1500 m initial foot contact was made on the “outside edge at the arch between the heel and the metatarsus”. Nett further noted that during the load-phase of foot contact, the heel contacted the ground, even in the case of sprinters; especially when the sprinters were fatigued.
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). Various components of the gait cycle in walking, running, and sprinting were recorded in the sagittal plane via high-speed film data collection. Results indicated that step length, step rate, and horizontal velocity increased as gait shifted from walking to running, and from running to sprinting. Film analysis also revealed increases in hip and knee flexion and ankle dorsiflexion range of motion as gait speed increased, thereby, lowering the body’s center of gravity. Ankle joint biomechanics were 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 with the toes and continuous dorsiflexion occurred during the stance phase followed by rapid planter flexion and no heel contact.

Payne (1983) investigated ground contact forces of 18 elite runners of various distances. The double force platform system developed by the investigator was set into the field at ground level and speed of running was measured with photoelectric beam timers. The subjects were also filmed with 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 with the Hulcher sequence camera during international competitions. Ground contact methods (type) utilized by the subjects were divided into four categories: heel and ball-of-foot; flat; ball-of-foot/flat; and ball-of-foot-only. Results indicated that
sprinters and middle distance runners frequently used the ball-of-foot/flat method. While 400m and 800m specialists often used the ball-of-foot-only method. Smoother force-time curve patterns were observed among the subjects who ran mainly on the ball of the foot. Payne noted that the ball-of-foot method of initial contact was physiologically more demanding especially for endurance runners and required a high skill level 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 made on the outside edge of the foot. He noted that the point of foot contact (type/method) depended on the speed and distance of the run. 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. In contrast, Mann and Hagy (1980) reported that initial ground contact during sprinting was made on the toes and continuous dorsiflexion occurred during the stance phase followed by rapid plantar flexion and no heel contact. Payne (1983) noted that sprinters and middle distance runners frequently used the ball-of-foot/flat method. He also stated that running with the ball-of-foot method was physiologically more demanding especially for endurance runners and required a high level of skill for sprinters.

Influence of fatigue on sprinting performance

Chapman et al (1982) investigated kinematic and temporal changes induced by fatigue in five female provincial caliber sprinters. Small circular adhesive markers were placed on the greater trochanter, lateral epicondyle, head of fibula, lateral malleolus, head of the fifth metatarsal, and heel of the sole of the track shoe of the subjects' left leg.
Subjects performed three maximal effort 400 m runs on three separated days. Kinematic film data were collected at 100 m (initial) and 380 m (final) points in the run. Results indicated significant decreases in mean velocity and mean stride length from the initial to the final phase. Significant increases in mean contact time, mean time of stance (sum of absorption and driving phase) and mean time of driving phase were also revealed. A decrease in thigh and knee range motion was seen with fatigue that contributed to a decrease in step length. The author noted that different hierarchical patterns in temporal and kinematic variables were observed among subjects in response to fatigue.

Nummela et al (1994) investigated EMG activity and ground reaction forces during fatigued and non-fatigued running. Subjects were ten male 400m runners and hurdlers (age: 25 ± 3 yr, height: 1.83 ± 0.06 m, weight: 73 ± 6 kg) who performed 3-5 maximal 20 m speed trials with a flying start over 40 m and a maximal 400 m time trial on the first day, and 3-5 submaximal 20 m runs with a flying start at average speed of the first 100 m during the 400 m run on the next day. Stride length was measured and stride rate was calculated from average speed and stride length. Electronic photocell timers were used to time 400 m and 20 m runs, additionally a video camera was used for interval timing during 400 m run. In order to obtain EMG activity during each run, surface electrodes were placed on the right: medial head of the gastrocnemius(GA), vastus lateralis (VL), biceps femoris (BF), and rectus femoris (RF) , and the EMG transmitter was attached to the subject’s waist. The 4 m long force plate was located on the last 6-10 m before the end of each distance and the force plate and EMG data were recorded simultaneously. Horizontal and vertical force components were separated into braking
and propulsion phases by using the horizontal force-time record. Results indicated that peak and resultant ground reaction forces decreased more at the end of the 400 m run than during maximal and submaximal 20 m runs in the braking and propulsion phases. Significant decreases in stride rate and stride length, and significant increases in contact time, braking phase, and propulsion phase with the constant ratio of braking to propulsion phase were also revealed. Decreased stride length was significantly related to decreased ground reaction forces. Ground reaction forces decreased remarkably during the braking phase, which indicated possible failure of eccentric muscle tension thus reducing the ability to store elastic energy during the braking phase. Significant increases in RF averaged EMG (AEMG) from the submaximal 20 m to the end of the 400 m in the braking phase, and significant increases in the GA and the BF AEMG from the maximal 20 m to the end of the 400 m run in the propulsion phase. These findings indicated that the RF had an important role in tolerating impact loads in running while BF and GA primarily functioned in the propulsion phase of sprint running. A significant positive relationship between increases in preactivity (AEMG 50 ms prior to ground phase) and decreases in resultant ground reaction forces in the braking phase during the 400 m run, indicated that pre-activation had an important role in maintaining force production during the 400 m run. The author concluded that the increased neural activation was used to compensate for muscular fatigue.

Derrick et al (2002) investigated the kinematic adjustments that runners made during an exhaustive run and their effects on shock and shock attenuation. Ten recreational runners (age: 25.8 ± 7.0, mass: 70.8 ± 10.1 kg) performed an exhaustive run
on the treadmill. The subjects were fitted with two 1.8 g piezoelectric accelerometers on
the distal anteromedial aspect of right tibia and frontal bone of skull, a custom-built knee
electrogoniometer, and custom-built rearfoot electrogoniometer then subjects ran on the
treadmill until volitional exhaustion at a velocity equal to their average 3200 m run
velocity. Data were collected every 30 sec for an interval of 8 sec and divided into three
conditions: start (the first two intervals), middle (the middle two intervals), and end (the
last two intervals). Results indicated a significant increase in peak impact at the leg,
maximum knee flexion, knee flexion at heel contact, maximum knee flexion velocity,
inversion, maximum rearfoot angle, and maximum rearfoot velocity from the start to the
end. The increased shock attenuation was indicated by the increased impacts at the leg
and stable head accelerations. The altered kinematics may also have affected metabolic
costs during the latter stages of the exhaustive run. The author noted that it was unknown
whether these changes in kinematics were a shift to optimize criteria of the system for
injury prevention or a failure of the system to maintain optimal behavior.

Weist et al (2004) investigated the influence of fatigue on the muscle activity and
the plantar loading patterns during fatiguing treadmill running. Subjects were 30
triathletes (22 male and 8 females) with mean age, body mass, and height of 34.5 ± 8.7
years, 69.6 ± 8.9 kg, and 177.9 ± 8.2 cm, respectively. Individual anaerobic threshold
was predetermined with maximal running tests on a treadmill and individual base-level
lactate plus 2 mmol/L was used to determine the level of effort and running speed during
the exhausting treadmill run. Self-adhesive electrodes were placed on tibialis anterior,
medial and lateral gastrocnemius, soleus, peroneus longus, biceps femoris,
semitendinosus, rectus femoris, vastus medialis, and lateralis, adductor, tensor fascia lateae, gluteus maximus, and gluteus medius of subjects' left leg to record EMG muscle activity. Plantar pressure measurements were assessed with a sensor insole that was placed in the runners left shoe between foot/sock and sock liner. Muscular impulses were synchronized with the EMG measurements, and used for the determination of step cycle durations. The subjects performed an exhausting run on the treadmill at the predetermined speed until they had to terminate the run because of fatigue. At least 20 steps of EMG and pressure distribution were recorded intermittently every 2 min during the exhausting run. The first measurement after the initial 2 min of running and the last measurement before the termination of the run were used as the non-fatigue and fatigue phase, respectively. Results indicated significant increases in peak pressures, maximal force and impulses under the second and third metatarsal head and under the medial midfoot toward the end of exhausting run. The contact area became larger only under the first metatarsal, and the contact time in the midfoot and forefoot did not change. The author noted that the contact time and the impulse in the medial heel significantly increased with fatigue. The EMG activity of lower leg and biceps femoris muscles significantly decreased with fatigue. The step length and frequency remained constant because of the constant treadmill speed. The author concluded that the runners changed their landing technique as a compensatory strategy in the fatigue stage.

In summary, the stride length and stride rate decreased and contact time increased with the development of fatigue during the 400m run trials (Chapman, 1982; Nummela, 1994). However, no changes in stride length and stride rate were detected when a
treadmill was used to induce fatigue at slower speeds (Derrick, 2002; Weist, 2004). Derrik (2002) found increases in knee and ankle range of motion and joint velocity. In contrast, Chapman (1982) found decreases thigh and knee range of motion, which accounted for decreased stride length. Development of fatigue also influenced EMG activity and ground reaction forces. The EMG activities of rectus femoris during the braking phase and gastrocnemius and biceps femoris during the propulsion phase increased whereas the GRF decreased in both braking and propulsion phase (Nummela, 1994). Weist (2004) found that the EMG activity of the calf and hamstrings muscles decreased during ground contact and that peak pressure, maximal force, and impulse increased under the second and third metatarsal heads and medial midfoot with fatigue development (Weist, 2004). It is unclear whether the different protocols and running speeds used to induce fatigue contributed to the contrasting findings, however, it is clear that fatigue does change the kinetics and kinematics of running.
References


Appendix A
Figures

Figure: 11 Relationship between Touchdown distance and 200m sprinting time at 30m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of Touchdown distance indicates foot behind the CG.

Figure: 12 Relationship between Touchdown distance and 200m sprinting time at 45m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of Touchdown distance indicates foot behind the CG.
Figure: 13 Relationship between Mid-stance distance and 200m sprinting time at 30m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of Touchdown distance indicates foot behind the CG.

Figure: 14 Relationship between Mid-stance distance and 200m sprinting time at 45m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of Touchdown distance indicates foot behind the CG.
Figure: 15 Relationship between Push-off distance and 200m sprinting time at 30m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of
Touchdown distance indicates foot behind the CG.

Figure: 16 Relationship between Push-off distance and 200m sprinting time at 45m
Positive number of Touchdown distance indicates foot in front of the CG. Negative number of
Touchdown distance indicates foot behind the CG.
Figure: 17 Relationship between Total vertical displacement and 200m sprinting time at 30m

Figure: 18 Relationship between Total vertical displacement and 200m sprinting time at 45m
Figure: 19 Relationship between Push-off distance and Contact time at 30m

Figure: 20 Relationship between Push-off distance and Contact time at 45m
Appendix B
INFORMED CONSENT
To Participate in a Research Study

I. INVESTIGATORS

Principal Investigators:  Supervising Professor:
Joseph H. Smith, ATC, CSCS  Iris F. Kimura, PhD, ATC, PT
Tomoki Kanaoka, ATC

Department of Kinesiology and Leisure Science
University of Hawai‘i at Manoa
1337 Lower Campus Road, PE/A Complex RM231, Honolulu, HI 96822
Phone: 1-808-956-7606  Fax: 1-808-956-7976

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$_{\text{Max}}$) 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$_{\text{Max}}$ 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.

<table>
<thead>
<tr>
<th>Schedule A</th>
<th>Exercise Bicycle Test</th>
<th>Sprint Field Tests (SFT&lt;sub&gt;Max&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WAnT</td>
<td>200 meter sprint</td>
</tr>
<tr>
<td>Week 1</td>
<td>1 trial</td>
<td>—</td>
</tr>
<tr>
<td>Week 2</td>
<td>1 trial</td>
<td>—</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Schedule B</th>
<th>Exercise Bicycle Test</th>
<th>Sprint Field Tests (SFT&lt;sub&gt;Max&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WAnT</td>
<td>200 meter sprint</td>
</tr>
<tr>
<td>Week 1</td>
<td>—</td>
<td>1 trial</td>
</tr>
<tr>
<td>Week 2</td>
<td>1 trial</td>
<td>—</td>
</tr>
</tbody>
</table>

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<sub>Max</sub> 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
200 Meter Sprint Trial Kinematic Data

### Trial 1 (<30m Mark>)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Type of Foot Contact</th>
<th>200M Time (sec)</th>
<th>Distance b/w CG and Foot (meter)</th>
<th>Contact Time (sec)</th>
<th>Vertical Displacement of CG (m)</th>
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<tbody>
<tr>
<td>1</td>
<td>BFF</td>
<td>28.17</td>
<td>Initial 0.279, Mid 0.155, Push-off -0.452</td>
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<td>2</td>
<td>FLAT</td>
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<td>3</td>
<td>FLAT</td>
<td>33.15</td>
<td>Initial 0.282, Mid 0.155, Push-off -0.575</td>
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### Trial 1 (<45m Mark>)

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<th>Distance b/w CG and Foot (meter)</th>
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**Trial 2 <45m Mark>**

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<th>Contact Time (sec)</th>
<th>Vertical Displacement of CG (m)</th>
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