HOW RELATIVE TIMING OF HAMSTRING MUSCLE ACTIVITY AFFECTS GROUND-CONTACT KINEMATICS IN COLLEGE-AGE DISTANCE RUNNERS

A thesis by

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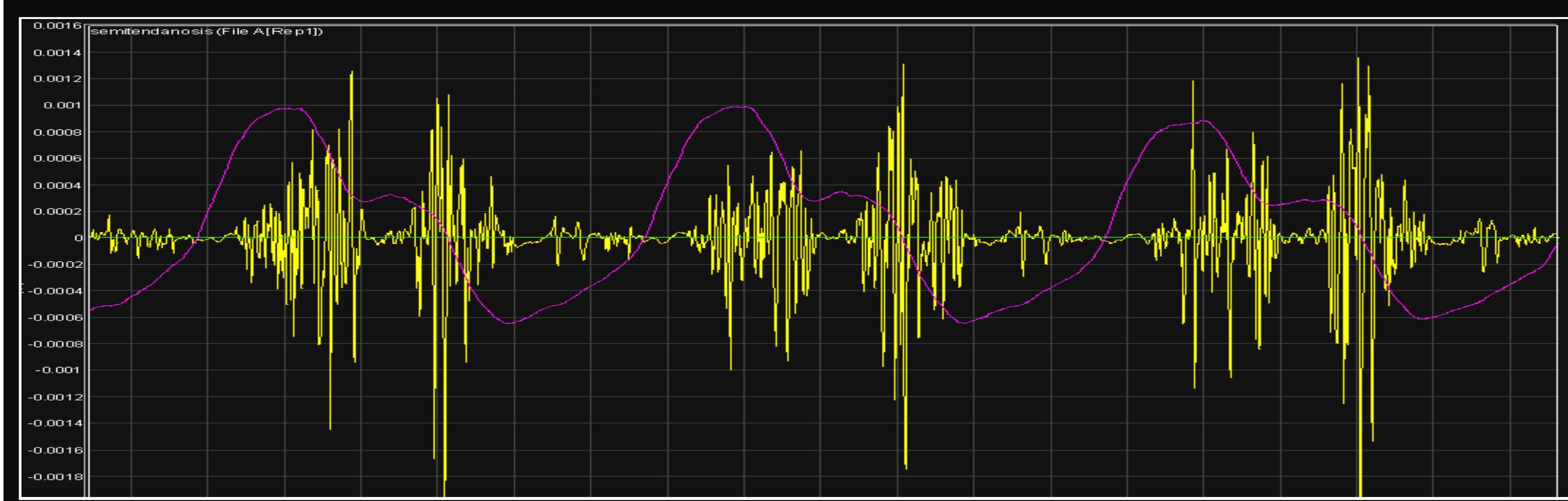

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DEDICATION

This work is dedicated to my loving parents, John and Mary Nunan, along with my brother and sisters, John, Stacy and Gail who have always supported me, and to Marcy whose prayers I greatly appreciate.

A saying of King Solomon (950 BC):

חֲנֹךְ לַנַּעַר עַל־פִּי דַרְכּוֹ גַּם כִּי־יַזְקִין לֹא־יָסוּר מִמֶּנָּה׃

(Hebrew Old Testament)

“Train up a child in the way he should go: and when he is old, he will not depart from it.” (Proverbs 22:6, KJV).

ABSTRACT

The purpose of this study was to examine the relationship shared by the relative timing of onset, peak and termination of contraction in hamstrings Biceps femoris (BF) and Semitendinosus (ST) with the kinematic indicants of mechanical efficiency, *height-adjusted angle of foot-strike* (HFS°) and relative ground contact time (*ground speed*, GS) in 34 college-age distance runners performing at constant pace (5.7m/s for men, 4.8m/s for women) and constant stride frequency (97 rpm). Delsys telemetric electromyographic system measured neural timing; kinematic variables were measured with Dartfish video analysis software. Pearson correlations of men’s mean timing of BF with HFS° (r = .75, p = .001) and with GS (r = .62, p = .007) indicated a link between neuromuscular timing and mechanical efficiency; significant relationships were also observed in ST. The women’s results yielded insignificant correlations; this was largely caused by variance in relative net hamstring force produced during pre ground-contact hip extension.

CHAPTER ONE
INTRODUCTION

Running performance is a common denominator of many sports; Dr. Jack Daniels (2007), observed among teenage distance runners, “…about 50% took up running either to get in shape for another sport or because they got cut from a sport they truly wanted to participate in” (p. 8). Basketball training advisor Lindsay (2007) stated, “It's estimated that a starting high school player will run a total of 3 to 5 miles in a 32-minute game”. With the advent of using miniature global positioning monitors worn on the bodies of players, it is possible to break down the running component of team play which has become an object of focus in sports. “Soccer doctor”, Kirkendall (2001), stated that pro soccer players will average from 5 miles (for women) to more than six miles (for men) per 90 minute competition; he specified, “The most physically intense part of the game is while in control of the ball”, and yet he also pointed out that roughly 98% of the time running is spent chasing down or responding to the movement of the ball by other players. The higher intensity in basketball play, with increased possession time of the individual player, should warrant different running training strategies and yet it is accepted that most of the competitive advantages gained during play in either soccer or basketball are affected by the collective running abilities of a team’s players to efficiently and repeatedly achieve offensive and defensive team positions at a minimal cost.

It is not surprising that the disciplines of track and field have offered practical models for illustrating the running component of team sport strategy; the efficient execution of what former Stanford University track and field coach, Brooks Johnson (personal communication, January, 1989), called the “fluff miles” (often the first three quarters of a middle-distance or long-distance running race) is necessary in achieving position for an effective “end-race kick” or “critical zone”. Formally applying Johnson’s concept to team sport strategy puts the creative emphasis on defining “when” and “how” to apply the critical zone intensity and hopefully scoring as a result of the opponent’s inability to respond. In a middle distance and distance running competition, a race may have multiple critical zones within a competition period (i.e. surges); team sports also would likely prepare for multiple critical zones as a strategy for distributing the timing of peak team efforts throughout a single competition.

It would be expected that the track and field community would also be the authority on assessing and teaching running mechanical efficiency; although it has offered considerable support for endurance and strength training issues for benefiting both track runners and team-sport players, there is no single template for running efficiency assessment and intervention. Instead, event-specific critical-zone skills are continually reinforced leaving the matter of efficiency up to interpretation by the athlete. Although most coaches will admit the importance of athletic efficiency, few coaches attempt to directly modify inefficient running motor behaviors.

In youth fitness assessment tests and in professional athletic coaching, the stopwatch has always been the most relied upon tool for assessing running performance and, according to Bundle, Hoyt and Weyand (2003), the stopwatch is now the primary tool used as an “…alternative to existing tests of anaerobic power and capacity” (p. 1955). Although a coach may lean on some form of taxonomy assessment of general motor abilities and specific skills for selecting a starting lineup, athletes of any age who perform well under the clock in both speed and endurance will commonly be selected simply because they can be relied upon for being in the opponent’s face, most of the time. The problem with using timed running tests as the sole predictor of athletic ability is that running performance often does not serve to predict athletic performance potential in developing athletes.

Besides the use of the stopwatch, other indicants that are sometimes used by competent coaches for assessing physiological components of running ability include the heart rate monitor and, for those who can afford it, equipment for measuring *maximum oxygen uptake capacity* (VO_2max). Maughan (2000), however, warns of some important limitations of physiological assessments: "…although a high capacity for oxidative metabolism is necessary for success in distance running, it does not, in itself, distinguish the elite performer" (p. 16). Track coaches are all too aware that there will always be runners of similar performance levels who vary considerably in physiological attributes (cardio/pulmonary performance), as well as there will always be runners with similar physiological attributes who vary substantially in timed running performance. Simply, the commonly used running assessment methods fail as tools for assessing other important factors that contribute to running performance, such as motivation and biomechanical efficiency.

One of the reasons it is hard to find advice on coaching the efficiency factor of running in sports is because, "neural-level" motor analysis, which is critical to understanding kinetic and kinematic aspect of motor abilities, is commonly set apart from behavioural motor-analysis and is not regarded by many textbooks on *motor learning* as pertaining to the domain of physical education.

With major emphasis placed on behavioural motor analysis, Magill (2001) lists two theoretical supports for the science of motor learning: (a) the general "*motor program* theory" and (b) the "*dynamic pattern* theory". Many who subscribe to the program theory cite from (Schmidt, 1991) with regard to certain fundamental components of physical activities such as *running gait* as being "invariant". According to Magill (2001), Schmidt's *invariant features* theory holds that *relative time* and *relative force* of specific groups of skills or *class of actions* (e.g. the running phases) remain constant. "The term *relative* in the relative time and relative force indicates that what is invariant are the percentages, or proportions, of overall force and timing of the components of a skill" (p.48). Schmidt's theory is also in harmony with the common acceptance of the definition of *abilities*. Schmidt (1991) himself noted; "…abilities themselves do not change because abilities are by definition genetically defined and not modifiable with practice" (p. 145).

Magill (2001) described an alternative theory residing within the behavioural approach, the *dynamic pattern theory*: "The basis for this theoretical viewpoint is a multidisciplinary perspective involving physics, biology, chemistry, and mathematics" (p. 53). It proposes that motor-patterns are not all generated from programs stored in memory; instead, it allows for individual trial and error in determining "preferred" or "attractor" behaviors which best suit the individual. The dynamic pattern theory also calls on concepts, such as *nonlinear behavior* (which is shown in the transition from walking gait to running gait as a function of the increased velocity) to account for variations in "invariant" patterns such as *relative timing* patterns in an individual's running gait. Because both the motor program and the dynamic pattern theories are behaviourally interpreted by most motor-learning texts, there is little consideration for changing an individual's running form outside of changes generated from an intrinsic *interpretation of* and *response to* "environmental" factors.

How these theories have affected the last thirty years' praxis in the general teaching of running can be summed up in the comments of renowned road racer/distance runner, Bill Rodgers (1980), "You can't plug yourself into a particular coaching system. What you do is try to study and learn about different coaches, different concepts, and different ways to improve. You experiment. Try a little bit of one, a little bit of another" (p. 282). From a runner's perspective, Rodgers appeared to reflect on some appealing qualities of the sport of distance running; he was certainly reflecting (less fondly) on established coaching methodologies.

Partly due to the state of motor learning theory, coaches have been let "off-the-hook" as far as being responsible for teaching efficient running form. Among distance running coaches, high mileage training programs have become a catch-all method for addressing the development of running form, along with other various essential factors (i.e. VO_2max development, strength and stamina development) that contribute to running performance. There is always a hope that high-mileage training can be effective for promoting running efficiency if runners are afforded the opportunity to shadow runners who have already acquired efficient running mechanics; this strategy would be particularly advantageous to university sports programs that are able to draw the accomplished athletes who already display superior running behaviors.

There remains, however, impetus to directly address the issues of biomechanical efficiency in running, even among distance running programs that use high mileage training. Many debilitating injuries are directly related to overuse and poor running mechanics; this fact is pointed out by Messier, Edwards, Martin, et al. (1995) who suggest high mileage training has direct links to *iliotibial band friction syndrome*. Excessive heel-strikers, according to Laughton, Davis and Hamill (2003), often suffer overuse injuries; they recommend, "…runners, with shock related injuries such as stress fractures, might benefit from switching to an FFS (*forefoot-strike pattern*)" (p. 154).

There has been a growing community of coaches who have echoed dissonance to the idea of relying solely on "chance" as the teacher of running skill; one such voice is former Humboldt State cross country & track coach, Jim Hunt, who issued this warning to any coach who would neglect the important undertaking of directly addressing the neuromuscular development of young runners: "Beginning runners left to their own means and interpretations of the kinetics of running, almost without exception, will develop a pattern of over striding, with a slow on-and-off the running surface foot action" (Hunt, 2004, p. 1).

Two *attractor* behaviors, over striding and long ground-contact times (relative ground-contact time is regarded as an "invariant feature") were identified in Hunt's statement; he implied that if these two behaviors were not improved upon, a runner may never be able to translate inherent or acquired physical and psychological attributes, such as anaerobic power, increased VO_2max and motivation, into fast race times. It was inferred by the investigator of the present study that there exists a variety of methods for developing a runner's performance potential through specific neural motor-behavioural intervention. This question was posed: Which specific neuromuscular activation patterns produce the kinematics and biomechanical events associated with efficient running? In simpler terms, how do the muscles of efficient runners behave?

Research Purpose

In the pursuit of identifying the neuromuscular patterns which are linked with the specific kinematics associated with efficient running, the main purpose of this study was to observe college-age distance runners performing at constant velocity and cadence, and with the use of electromyography (EMG) and video analysis, determine if the relative timing of onset, peak, and termination of hamstring muscle activation was related to the kinematic characteristics of ground-contact which describe attractor behaviors, “over striding” and “slow on-and-off the running surface foot action” (Hunt, 2004, p. 1).

In order to achieve this purpose, it was also a necessary objective to designate two kinematic variables that could best quantify the degrees of variance of the two aforementioned kinematic behaviors (identified by Hunt); these variables, called *angle of foot-strike* (HFS°) and *ground-speed* (GS) would also serve as indicants of mechanical efficiency within a task analysis system, consisting of six components, called the Kinematic Running Assessment Method (KRAM, see Appendix B). How these components, including the two variables relevant to the present study, qualified to be used in these capacities is theoretically justified in chapter two. HFS° and GS are operationally defined in chapter 3.

Definitions

Angle of Foot-strike: An angle with a vertex at the virtual static center of mass and the sides that intersect points, marked by the Lateral Malleolus of the stance limb at moment of foot contact with the running surface, and by a point on running surface directly beneath the virtual center of mass.

Attractor: “The stable behavioral steady state of systems. In terms of human coordinated movement, attractors characterize preferred behavioral states…” (Magill, 2001, p. 349)

Body Core: Region of the body referred as the “powerhouse” of athletic function (Siler, 2000). The core boundaries extend from the pelvic region, including Glutaeus maximus, to the diaphragm (Kibler, Press and Sciascia, 2006).

Cardinal Plane: This qualifies a frontal, sagittal, or transverse plane as the one passing through the center of mass; any plane, among an infinite number of planes, referred to as “the” frontal, transverse or sagittal plane signifies the one that is cardinal (Hamilton & Luttgens, 2002, p. 373).

Center of Mass: The point of balance, pertaining to a body or an object, upon which the field of external gravitational forces work (Beiser, 1972).

Degrees of Freedom: The number of independent elements or components in a control system and the number of ways a component can act (Magill, 2001, p. 350).

Degrees of Freedom Problem: A theory of Nicolai Bernstein which describes the task performed by the neuromuscular aspect to establish an organized control system, consisting of one or more components with multiple degrees of freedom, in such a way as to limit motor-behavior in order to achieve a desired objective, e.g. kicking a ball (Magill, 2001).

Electromyography: "EMG is the study of muscle function through inquiry of the electrical signal the muscles emanate." (Konrad, 2002, p. 4).

Foot-switch: A pressure detector pad circuit (that is electronically connected to an EMG recorder) placed between the foot and shoe at a location of investigation (heel, toe or 5th metatarsal). Pressure created when the body makes contact with the ground closes the circuit allowing full voltage to be passed, detecting and recording the chronological event of foot contact with the ground.

Ground-speed: “The speed with which the foot can get on-and-off the surface” (Hunt, 2004); It is the ratio of combined ground contact times of both feet to the time period of one full revolution. To this study, ground-speed is defined as the ratio of ground-contact time of the investigated foot to its combined mid and late-swing-phase period, occurring immediately prior to the investigated ground contact.

Height-adjusted Angle of Foot-strike:: Represents the angle of foot-strike adjusted for runner height variance (see Appendix A).

Invariant Features: "A unique set of characteristics that defines a general motor program and does not vary from one performance of an action to another" (Magill, 2001, p. 47).

Kinematics: Analysis of moving bodies with attention to geometric (directional and angular) qualities expressed as quantities of displacement, velocity, acceleration and momentum (Hamilton and Luttgens, 2002).

Onset of Muscle Activation: Recorded moment in time of initiation of concentric contraction of the investigated hip extensor.

Peak Muscle Activation: Recorded moment in time of maximum relative muscle power of the investigated hip extensor during concentric contraction.

Preactivation: A neuromuscular behavior of maximizing the benefits gained from the functional stretch reflex property in muscles by stiffening a muscle before it encounters resistance, as occurs in the lower limb before ground contact during running. (described in Paavolainen, Nummela, Rusko, and Hăkkinen, 1999).

Root Mean Squared : "…reflects the mean power of the EMG signal and is the preferred recommendation for smoothing" (Konrad, 2005, p. 27).

Running Phases:

1. ***Early Swing Phase***: The early swing phase occurs from the moment the foot of the investigated limb leaves the ground until the moment the foot of the opposing limb touches the ground.
2. ***Late-swing Phase***: The late-swing phase begins when the foot of the opposing limb leaves the ground and is completed when the foot of the investigated limb comes in contact with the ground.
3. ***Mid-swing Phase***: When the foot of the opposing limb is in contact with the ground the investigated limb is in the mid-swing phase.
4. ***Support Phase***: The support or *stance* phase of the running cycle occurs when the foot of the investigated limb is in contact with the ground.

Static Center of Mass: In standing posture, "It is generally accepted that in the transverse plane in females the center of gravity (mass) is located approximately 55% of the standing height, and whereas in males…57% of standing height" (Hamilton & Luttgens, 2002, p. 373).

Stride Frequency: is tantamount to "running cadence"; the meaning of the term stride frequency (measured in revolutions per minute) does not reflect the distinction between the definition of *stride* and *revolution*.

Relative Time: "The proportion of the total amount of time required by each of the various components of a skill during the performance of that skill" (Magill, 2001, p. 49).

Revolution: A revolution is one complete running cycle, usually marked by two consecutive foot-strikes of the same limb.

Stride Length: The distance between two consecutive foot-strikes of opposing limbs. .

Stride Period: The time separating two consecutive foot-strikes of opposing limbs.

Telemetry (telemetric): Telemetry is a method of sending electronic information using wireless means (radio frequency transmission).

Termination of Contraction: Recorded moment in time of cessation of concentric contraction of the investigated hip extensor.

Virtual Static Center of Mass: The estimated graphic representation of static center of mass of a subject observed in the dynamic state.

Assumptions

It was assumed college athletes who train regularly (more than 20 miles per week) do so with the intention of maintaining fitness and improving performance. The sample of athletes selected for this study had recently participated in some form of training regimen which included paced interval workouts designed to increase speed and endurance. It was also assumed that the participants would exhibit a broad range of advanced running behaviors which were of interest to this study.

Running shoe weight, design, and sole thickness were expected to vary. With attention directed toward possible exceptions, running-shoe attributes were not expected to significantly affect neuromuscular and kinematic relationships of collegiate competitive runners during fast *sub-maximal* paces (less than 7 meters per second).

Limitations and Delimitations

The design of the present study focused on examining the isolated, single, stride of one limb, rather than drawing an average from a multitude of strides. Various considerations were addressed for the purpose of understanding how isolated neuromuscular behaviors affect the kinematic behaviors of distance runners.

Limitations

Due to the limitations of the EMG and Video equipment compounded by the limited available volunteer resources, only one single limb could be investigated for EMG activity per testing session. This condition presented the problem of the possible occurrence of asymmetrical mechanical behavior caused by either injury, constraints of the EMG system apparatus on the participants, or by *dominant limb behaviors*. Considerable effort was made to screen participants with regard to any injury that could affect motor behavior; in addition, testing site set-up and EMG apparatus configuration was alternated between right-limb and left-limb investigation for each successive session. Nevertheless, there remained an unavoidable possibility of dominant limb behavior or unreported injury that could affect the symmetry of motor behavior which, in turn, could affect the ratios of the intrinsic and extrinsic variable values. The research design (see chapter 3) of the present study accommodated for this possibility (particularly through the isolation of the investigated stride) in order to limit the impact that asymmetrical behavior by any participant might have on the results of the investigation.

Delimitations

The Running Conditions

The present study observed runners performing in *overground running* conditions, only. It is well known that *treadmill running* at paces greater than 5 m/s have affected muscle behaviors when compared to overground running (Williams, 1985); this may be caused by the absorption of mechanical energy from treadmill motor by the body.

Investigated Muscles

Because research by Montgomery, Pink & Perry (1994) showed that Biceps femoris (BF) and Semimembranosus (which mimics Semitendinosus, ST) were significantly active during the mid-swing and late-swing running phases, BF and ST were selected for the present study (BF and ST were also accessible using surface electromyography). Hamstring activity during these running phases was believed to significantly contribute to observed running kinematic behavior; supportive reasoning is cited in chapter two.

Sagittal Plane Analysis

Although the importance of frontal and transverse plane components in analyzing running mechanics was well recognized, for the purpose of studying hamstring muscle effects on forward running progress, only movement observed within the sagittal planes proximal to the cardinal sagittal plane were measured. Although the features of the investigated limb used for identifying kinematic markers did not reside directly on the cardinal sagittal plane, because of the relative proximity in relationship to the camera (error < 00.5%) they were regarded as references to the cardinal plane.

Target Test Pace

Variance in pace is commonly known to influence running kinematics; in order to avoid the possibility that across-the-sample pace-variance might overshadow the detection of neural/kinematic relationships, a constant target pace was used. Using the maximum 400 meter times reported by the participants on the questionnaire, a $V_{\mathbf{400max}}$ coefficient (supplied by Hunt, personal communication, 2003) was applied to calculate the common testing-pace that is both fast (simulated 5,000 meter race pace) and easily achievable by all of the runners over a 60 meter distance. The $V_{\mathbf{400max}}$ coefficient values for various race distances, along with a sample application, are included in Appendix A.

Target Stride Frequency

There was concern that variance in stride frequency would impact the relationship between neural indicants (relative muscle timing) and the angle of foot-strike. A target stride frequency of 97 revolutions per minute was prompted with the use of a metronome placed in the “start zone” of the runner approach runaway. Additional filtering (see chapter 3) was applied to eliminate excessive extremes in stride frequency. The use of 97 rpm as a constant was determined through general observations by the investigators, conducted at the 2006 NCAA Division 1 men’s and women’s track and field championship finals in races of distances 1500m through 10,000 meters.

The Hypothesis

Expected Outcomes

It was expected that at target (sub-maximal) running pace and at target stride frequency, the *relative timing* of hamstring muscle activation would be a dominant factor (over *relative force*) in determining kinematic position of the foot at ground-contact, relative to the body core (the measure of variance of "over striding" behavior). It was also believed, because of the relationship between shank angle and ground contact time (observed by Cavanagh and Williams, 1987) that relative timing of hamstring muscles would also share a covariant relationship with the relative ground contact time of the investigated foot to the investigated stride (the measure of variance of "on-and-off the running surface foot action", Hunt, 2004, p. 1).

The null hypothesis "H_0" asserted that there was no significant evidence to support the existence of a relationship between relative timing of neural events and the two kinematic variables, one that measured angular measured position of foot-placement and the other that measured relative ground contact time. The variables are defined later in this chapter and the procedures for testing the hypothesis are described in chapter three.

Theoretical Support

It is commonly held by many coaches that the position of the foot in relation to the body core at the moment of initial ground contact in running is determined by the work performed by the hamstrings muscles during the mid-swing and late-swing running phases. According to Hamilton and Luttgens (2002) the leg becomes a "class three" lever during hip extension with an effort arm (the hamstring muscles) and resistance arm (the leg). Given a limited linear displacement of the foot (pace) and limited time period to perform the work (stride frequency) the position of the foot at ground contact should be a function of (a) length of the resistance arm (the leg) and a combination of either (b) variance of relative timing of work initiation (muscle activation) or (c) variance in muscle force (affected by muscle fiber recruitment). It was postulated that at a controlled stride frequency, controlled pace and a common relative level of fitness of the participants, variances in the relative timing of muscle activation would be a major determinant of angular displacement of the lower limbs. It was recognized, based on discussions by Rusko (2003), that experienced runners have a different "set point" which determines muscle fiber recruitment and that at "…maximum oxygen uptake, only a fraction (15 – 30 percent) of muscle fibers and motor units is recruited" (p. 13). At the designated target pace, it was expected that percentage of muscle fiber recruitment would be similar, across the sample; this would increase the influence of relative timing as a determinant of angular displacement of the hip.

Variables

Two sets of variable were used to test the relationship between neural timing of hip extensors and the ground contact kinematics, (a) *Intrinsic variables*, representing EMG measured relative timing of hamstring activation and (b) *Extrinsic variables*, representing angular kinematic values and relative ground contact times.

All variables were calculated from data elements which were directly observed values through the use of EMG testing apparatus and analyzed video recording. Figure 1 illustrates the time components, marking mid-swing, late-swing and support-phase of the investigated limb. All of the variables used in testing the hypotheses were, in part, determined by these time element values. The elements were (a) *opposite limb foot-strike* (OFS), (b) *opposite limb toe-off* (OTO), (c) *investigated limb foot-strike* (IFS), and (d*) investigated limb toe-off* (ITO).

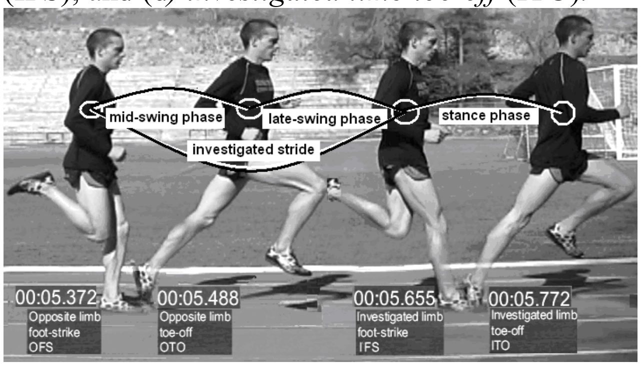


Figure 1. **Chronological elements marking the running phases (Dartfish enhanced image).**

Intrinsic Variables

In the same way the ignition timing of a sparkplug (in relation to the piston stroke) can be associated with certain engine performance characteristics, it was suspected that the variance of neuromuscular timing of hip extensors, relative to the running phases, would impact running kinematics in a predictable way. In the present study, the intrinsic variables described the relative timing of hamstring activity (*onset of contraction*, *peak relative power* and *termination of contraction*). These (EMG acquired) events were compared to the chronological occurrence of the investigated stride or the combined mid and late swing phases. Figure 2 consists of (a) the chronologically marked stride period (times not shown) and (b) the chronologically marked neuromuscular events (the figure shows only when these muscle activities would likely occur). The figure illustrates the relationship between the aforementioned neuromuscular events and the investigated stride.

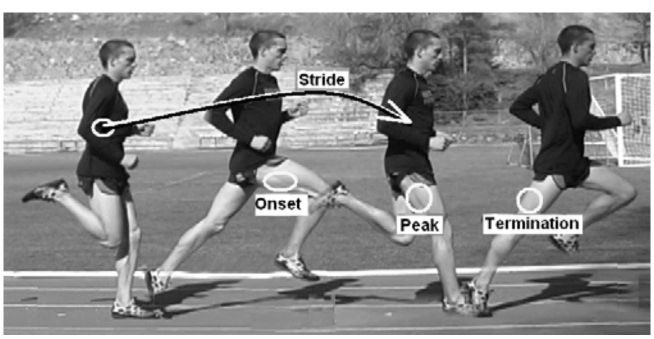


Figure 2. **Elements which were used to calculate the intrinsic variables.**

Chapter 2 provides theoretical background to the current study's application of surface EMG method; Chapter 3 describes the procedures by which the EMG elements were operationally acquired and how the data was applied to test the hypotheses.

Extrinsic Variables

The activity of high jumping reveals attributes that contribute to athletic performance. Figure 3 kinematically quantifies body lean at the moment of foot-plant (3a) and trajectory at take-off (3b) which affects conservation and translation of horizontal, vertical and rotational characteristics. In a similar way, kinematic analyses of pace, stride frequency and specific characteristics associated with ground-contact provide critical indications of running efficiency which can affect running performance.

a. b. c.

Figure 3. **Kinematic components of a high jump foot-plant and take-off (Dartfish enhanced photo).**

In the present study, the extrinsic variables, measuring variance of Hunt's two behaviors ("over striding" and "slow" ground contact times), are respectively, angle of foot-strike (FS°) and ground-speed (GS); these were determined using three time elements: beginning of the mid-swing phase (OFS), the beginning of the stance phase (IFS), and the completion of the stance phase (ITO) of the investigated limb. Angle of foot-strike was measured at the moment of IFS. Ground-speed (GS) was the ratio of the investigated ground-contact (stance) phase to the investigated stride period (combined durations of the mid and late-swing phases). Figure 4 shows the ground contact component, angle of foot-strike with the elements for calculating GS, the ground contact (stance) phase (i.e. ITO – IFS) and the investigated stride (i.e. IFS – OFS). The relevance of the components GS and FS° to running efficiency is explained in chapter two; the procedures used to extract the component values are described in chapter three.

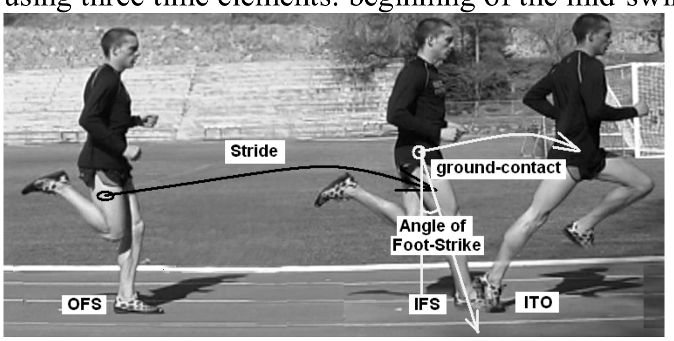


Figure 4. **Ground contact components, angle of foot-strike and ground-speed (determined from elements ITO, IFS and OFS).**

Research Justification

With specific relevance to the administration and management of physical education and sport, Krotee and Bucher (2007) identified fundamental objectives that are common to these domains; these include (a) *physical fitness development*, (b) *motor skill development*, (c) *cognitive development* and (d) *affect development*. The authors also identified similar objectives as "benefits" toward collegiate athletes who seek to enhance their professional, health, social and individual development as adults; Not least among these objectives is "skill development".

According to Snowman and Biehler (2003) most children begin to develop fine motor skills during the fourth grade; these skills will likely become a foundation which may determine the level of efficacy experienced when participating in sport and recreation activities. The American Association of Health, Physical Education and Dance (AAHPERD) has submitted a call to researchers who might provide empirical evidence that shows "the relationship between physical competence (motor skills), learned in school physical education classes, and physical activity participation throughout the lifespan" (AAHPERD, 2006).

The present study served as a step toward responding to AAHPERD's call by examining the neuromuscular timing patterns associated with two kinematic indicants (angle of foot-strike and ground-speed) which are believed to be linked to skill specific indicants of running efficiency. These indicants are being examined for their role as part of broader system of running assessment called the Kinematic Running Assessment Method (KRAM); this system would focus on specific kinematic indicators of running efficiency as well as focus on anaerobic attributes specific to running mechanics (A description and analysis of the KRAM components are found in Appendix B).

Justification for the present study is predicated on the assertion that efficient running motor skills (which may enhance genetically acquired motor abilities) are best learned in childhood. Furthermore, it is also suspected that the acquisition of these skills at an early age may significantly determine the extent of participation (during youth and adulthood) in many forms of sport and recreation, especially those that involve running.

CHAPTER TWO
LITERATURE REVIEW

The main purpose of this study was to observe college-age distance runners performing at constant velocity and cadence, and with the use of electromyography (EMG) and video analysis, determine if the relative timing of onset, peak, and termination of hamstring muscle activation was related to the kinematic characteristics of ground-contact which describe attractor behaviors, "over striding" and "slow on-and-off the running surface foot action" (Hunt, 2004, p. 1).These behaviors were assessed by measuring the variance of angle foot-strike (FS°) and ground-speed (GS), both were components of the Kinematic Running Assessment Method (KRAM) found in Appendix B.

The present study examined runners without initial regard to performance level of the individual participants. It is believed by the investigators that mechanical efficiency of runners can be a major determinant of running performance; it is not, however, the only important factor. The current investigation focused on manifold attributes affecting *running efficiency*; its acquisition and practice is believed by the investigator to significantly contribute to the advancement of the novice runner as well as set apart the elite runner from advanced runners. Terms such as "high-caliber" and "highly-trained", among other terms that describe both degrees of neuromuscular efficiency as well as degrees of performance ability, are cited and defined in context.

This chapter contains (a) reviews of *running efficiency* studies relevant to the present investigation, (b) specific methods used in electromyographic research, (c) review of a study using a research design similar to the present investigation and (d) a description of the extrinsic variables and their relevance as assessment indicants.

Running Efficiency

Running efficiency is a highly investigated topic in running research. Hamilton and Luttgens (2002) have stated, "…whether the run is an easy jog or a full speed sprint, economy of effort is a highly desirable objective" (p. 482). There are multiple factors which can contribute to running efficiency; Williams and Cavanagh (1987) make the point, " …there is no single 'template' that can be applied to all individuals to produce an economical running style….it might be more fruitful to concentrate on the identification of uneconomical aspects of running mechanics of the individual" (p. 1244). This wisdom concurs with the statement of Bill Rodgers (in chapter one) who advocated searching out one's own best advice. Despite conventional wisdom, Hunt specifically identified, across the running population, certain dominant inefficient neuromuscular "patterns" which should be addressed as an issue of competency in the learning of fundamental running skills.

Energy Expenditure

Many methods have been developed by researchers to assess energy expenditure in athletes. Mechanical analysis and various physiological indicators are some of the most commonly used methods. Although energy measurement was not of primary interest to this study, it is important to recognize similarities and differences in the findings of different investigations that measured energy consumption.

Research by Kyrolainen, Belli & Komi (2001), showed a uniform increase in energy expenditure across a sample of runners with increase in running speed. It was noted that the disparity of energy expenditure between efficient runners and runners showing "poor" mechanics also widened with increasing running speed. The "poor" technique was attributed to "…unusually high braking and mediolateral forces, which may be caused by limited action of the hamstring muscles (abstract)"

Energy costs between novice runners and highly trained marathon runners were examined by Slawinski and Billat (2004). It was shown that both untrained and well trained runners used the same amount of energy as well as produced equivalent amounts of lactic acid. Where the two groups differed was revealed in comparing mechanical energy distribution; lesser trained runners spent energy in "vertical displacement" of center of mass whereas highly trained runners distributed mechanical energy to limb movement around center of mass (CM). It was also noted that high stride frequency was characteristic of highly trained runner; they yielded significantly smaller vertical oscillation of CM. From these two studies addressing energy of running, it should be apparent that in considering either "poor" mechanics, "braking forces", hamstring activity, faster stride turnover, or limb movement around the center of mass, that the assessment of energy efficiency in running is directly linked to the neuromuscular component of running behavior.

Passive Energy

It is a common misconception that the primary function of hamstrings in running is performing the task of propulsion during the running stance phase. An investigation by Kyrolainen, Avela, and Komi (2005) into hamstring activity in running showed that peak EMG amplitude in Biceps femoris during running was greater than peak amplitudes produced by maximum voluntary contraction (MVC). In fact, the greatest dynamic hamstring EMG activity occurred before the investigated limb made contact with the ground. The authors concluded, "…increased pre-contact EMG potentiates the functional role of stretch reflexes, which subsequently increases tendomuscular stiffness" (p. 1101). This is like stiffening a spring mechanism which allows for quicker recoil speed of the limb. The present study focused, in part, on the muscle activation (onset and peak) timing of Biceps femoris and Semitendinosus during the pre-contact leg swing phases.

Finnish researchers, Paavolainen, Nummela, and Rusko (1999) directly addressed the topic of passive energy, "Effective storage and release of elastic energy during stretch-shortening cycle of exercises plays an important role in force production contributing also to mechanical efficiency. This ability to use stored elastic energy is influenced by the level of pre-activation and increased muscle stiffness, velocity and magnitude of stretch…" (p. 516). In a later work, Rusko (2003) expanded on the merits of preactivation in running:

> This preactivation has been shown to be greater in high caliber compared to low caliber runners with similar VO_2max, when running at the same velocity. As a result, total ground contact time as well as the braking and propulsion phases during contact is shorter even though the relative muscle IEMG activation during the propulsion phase of the contact is lower in high caliber runners compared to low caliber runners having similar aerobic power characteristics. Also, the shorter the ground contact time the better the distance running performance. (p. 13)

Rusko makes a direct correlation between short ground contact time and high distance running performance. Because he also qualifies both "high caliber" and "low caliber" categories as having the same aerobic characteristics; the term "high caliber" may be inferred as runners who perform well by exhibiting neuromuscular efficiency. In addition, the early relative timing hip extension should not be confused with preactivation; preactivation serves to stiffen the muscle before ground contact whereas early hip extension was observed (in the present study) for its role in accelerating the foot in a backward direction before ground contact. Accomplishing this end has kinematic mechanical advantages (described in this chapter) which may also determine the role of preactivation in the muscles of the knee, as well as in the hip, ankle and foot.

Kinematic/Kinetic Relationships

Kinetics and Kinematics of human movement can be compared to the "tracking" of orbiting satellites in space: According to Vazquez (2006), ten Keplerian orbital elements describe a satellite's orbit characteristics; these include orbit-size; *eccentricity*, inclination, *right ascension*, *argument of perigee*, and others. "Once these elements are known for a *specific time*, the satellite's position in space can be predicted using complex mathematical calculations". These data may be compared to kinematic measurement of human motion which can serve to predict (using the understanding of the physical, geometrical and mathematical sciences) certain performance outcomes based on the quantifiable attributes of bodily motion

The description of energy (force) of the rocket that put the satellite into orbit can be compared to the kinetic analysis of the human physical activity. The present study examined the effect relative timing of muscle activation had on the positioning of the leg at ground contact, and its consequent period of ground contact, on runners performing at competitive 5 – 10k pace; this could be compared to examining the interval (in relation to the orbit period) of booster thrust timing of the space shuttle in order to compensate for drag caused by the earth's upper atmosphere and maintain a low but stable orbit pattern that would otherwise "degrade". What was of interest to the present study was not the magnitude of force (kinetics) applied by the muscles but the relative timing of muscle contractions and the resultant direction of resistance (angle of foot-strike) at initial ground contact. Kinematic analysis can be helpful in qualifying the kinetic nature of body movement if it is accompanied with the understanding of the neuromuscular patterns which produced that movement.

There are a variety of interpretations of how hamstring muscles function during running. Besides the basic roles which include thigh extension, knee flexion, and lateral (BF) or medial (ST) rotation (Marieb, 2001), there is also an important role of placing the foot in the right place, in the right direction and at the right time. Athletics coach, Hunt (2006) described this skill: "Landing on the mid foot with paw back action allows the foot lever to perform the action which nature has designed it" (p.3). Sports training author, Nirenstein (2000), used an analogy of the Cheetah which reaches forward with the front limbs and paws backward before ground contact. Both descriptions illustrate the mechanical kinematic result of unimpeded hip extension; it can be reasoned that if the foot achieves zero velocity in relationship to the ground at foot-strike, the kinetic characteristics are likely to have a more pronounced vertical (versus horizontal) aspect.

Deficient hamstring function adversely affects ground-contact components. In the motion picture, "Chariots of Fire" (1977), a world renowned trainer (Sam Mussabini) teased his new client and Olympic hopeful, Harold Abrahams, for his over striding running form: "…it knocks you back". This effect, as the old coach described, is commonly referred to as "braking force" which is a *ground reaction force* (GRF) brought about in part by the kinematic relationship between the center of mass and point of ground contact.

The measurement of GRF is accomplished with the use of a force plate system mounted flush with the running surface. These plates measure the vertical and horizontal forces generated from ground contact by the foot as it makes contact with the plate. A study conducted by Paavolainen, Nummela, Rusko, and Hặkkinen (1999) used a forceplate to observe variations in ground reaction force patterns among "High Caliber" and "Low Caliber" 10k runners. At controlled pace during various stages of a long distance effort, each runner passed (making contact) over the plate and was measured for vertical and horizontal forces during contact. The investigators found elite level runners produced substantially less horizontal (braking and propulsion) forces and higher vertical forces compared to the lesser performers.

A publication on running biomechanics by Lafortune, Valiant and McLean (2000), who discussed GRF, added to the findings in Paavolainen et al. (1999) that elite runners, performing at race pace, exhibited less body deceleration resulting from foot-strike than non-elite athletes.

Cavanagh (1990) described two important interactive attributes that affect GRF values in runners: *(a) Effective Mass* is “that part of the mass of the human body that has an effect on the forces that are developed passively within the knee joint during the impact phase” (p. 239) and (b) *Vertical Compliance* is what attenuates vertical GRF and absorbs the shock of foot-strike; increased knee flexion accounts for most increases in vertical compliance and shock absorption at “…an increase of about 25 percent in the oxygen cost of running for each 5-degree increase in mid-stance knee angle” (p. 242).

Increased knee flexion during ground contact also increases ground contact times; this fact was important to the present study because it could conceivably be a factor directly affecting the results. A Study observing knee-stiffness (Riemann, DeMont, Ryu, and Lephart, 2001) showed that a straight knee was less compliant (resisted bending) than a bent knee. Although Knee-flexion can help explain the characteristics of the extrinsic variables, it was not a measured value in the present study.

Another determinant that affects GRF is the runner *foot-strike pattern* (not a measured value in the present study); foot-strike patterns in distance runners commonly occur as Heel-striking (heel to toe sequence during foot contact with the ground) and as midfoot-striking. With the midfoot-striker, the foot makes initial contact on the lateral midfoot and then everts or *pronates*, flattening the arch and allowing the heel to make contact. Various studies with large sample groups, such as in (Williams, 1985), have shown that 70 - 80% of distance runners exhibit heel striking behavior whereas “…faster runners tend to be midfoot-strikers” (p. 401).

An examination of foot-strike behavior in (Scholten et al. 2002) entitled, “Foot-strike patterns after obstacle clearance during running.” utilized risers (mini-hurdles) of increasing height for modifying foot-strike behavior. When the hurdle height reached 15% of the individual runner’s stance height there was a 100% change across the sample of heel strikers from a heel initial contact to a midfoot/forefoot initial contact pattern. The investigators suggested that this was possibly a protective mechanism from the shock of landing. Research by Laughton, Davis, and Hamill (2003) showed higher attenuation of shock in runners showing higher vertical to horizontal GRF ratios. There are two likely reasons for this: (a) the horizontal vector is nullified by the “paw-back” action of the hamstrings and (b) vertical GRF may indicate the likelihood of midfoot strike pattern which is also associated with lower shock loading rates than the heel-strike pattern (according to Laughton et al).

Hunt (Personal communication October 31, 2006) commented on the “height of the foot” of the *recovery-leg*, observed among elite distance and cross country runners: “The elite runners exhibit a significantly higher foot as it swings past the support leg than do most runners”. Occurring together, increased foot swing-height and midfoot-strike behavior may promote higher utilization of passive energy through muscle preactivation. Figure 5 illustrates the use of mini-hurdles for promoting these behaviors (recovery-leg swing-height was also not measured in the present study).

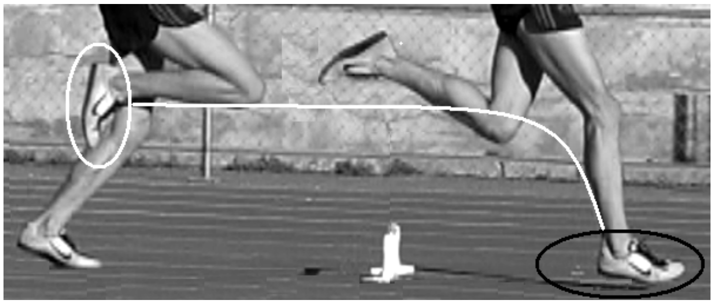


Figure 5. **Using mini-hurdles to promote ankle above the knee recovery-leg swing height and midfoot-strike.**

The measurement of the recovery-leg swing-height as it crossed frontal midline (as shown in Figure 5.) was not an investigated value but was included as a proposed component of the Kinematic Running Assessment Method (KRAM) found in Appendix B.

Investigating the Intrinsic Component of Running

Surface electromyography (sEMG) is the most commonly used method of assessing neuromuscular activity. Shultz and Perrin (1999) describe some of its specific capabilities, "sEMG can assist the clinician or researcher in determining when a muscle is activated, the timing of that activation in relation to a stimulus or *event*, and its sequential firing with other muscles" (p. 166). The present study examined hamstring muscle activity in individual athletes in relation to the "event" of their investigated running stride cycle (combined mid and late-swing phases of the investigated limb), occurring between the events of foot-strike of opposite and investigated limbs. Because neural events (such as muscle onset) can be regarded as a component of the neural skill of effective hip extension, this relationship of onset to stride period can be referred to as relative time, according to (Magill, 2001, p. 49). Relative timing of neural events would likely be characterized by Schmidt (1991) as "invariant".

The relative timing of muscle activation (relative to the occurrence of stride) was believed to share covariance with the degrees of freedom of two different kinematic components of ground-contact, angle of foot-strike (FS°) and ground-speed (GS). Because ground-speed is the time of the stance phase component of a running stride, it is also considered proportionally "invariant", according to the general motor program theory.

The event that usually indicates the time of muscle activation is called *onset* time. Shultz and Perrin (1999) describe the requirements in determining onset, "To accurately determine the onset of muscle activity, the clinician or researcher must be able to confidently identify when EMG activity begins or significantly deviates from static or baseline activity.….One subjective method is to use the raw signal along with visual recognition, using subjective criteria to determine when muscle activation occurs or to mark the point at which EMG activity begins or changes abruptly from baseline activity" (p. 170). This subjective method was given as an alternative to using computer-assisted program that processes the raw signal. Although the computer method is more reliable in consistency, it is "….unable to confirm the validity of the measure or event" (p. 170). Because it was important to the present study to distinguish between *hip extension* from other hamstring functions such as *knee flexion*, visual assessment of the raw signal was the chosen method in determining onset. To reduce the level of subjectivity and increase reliability, onset times were confirmed by visual recognition, based on criteria given in chapter three, and with video confirmation of visible thigh movement (the termination of muscle contraction was determined in the same way).

Computer assisted programs are necessary for identifying relative power; the measurement of relative time of peak power was determined by a computer program which processed the raw EMG signal (using a root mean square formula), and smoothed the EMG signal. The criteria for determining relative time of peak muscle activation are found in chapter three; the formula for "root mean square" is shown in Appendix A.

Synthesis of Intrinsic and Extrinsic Detection Methods in Research

The design of the present study followed a concept used by Montgomery, Pink and Perry (1994) that differed by its methodology in using fine-wire telemetric EMG, instead of surface sensors. The investigators did, however, combine EMG inquiry with video to examine muscle activation timing of 11 different muscles. Integrated power was used to evaluate the relative muscle activity during the "running phases" defined in chapter one of the present study. Although most of the analysis in the discussion referred to anterior muscle groups, especially with hip flexors and knee extensors, it was evident that hip extensors, BF and Semimembranosus, which mocks Semitendinosus (ST), exhibited significant activity during the mid-swing and late-swing phases. This cited study was instrumental in selecting the two hip extensors, BF and ST, which were investigated in the present study (Semimembranosus was not selected because of its inaccessibility by surface sensor EMG.

The accuracy in using a sagittal (*orthographic*) video camera orientation depends on the distance of the camera from the plane of view; the perfect scenario would be to have the camera placed at an infinite distance in order to capture parallel light rays that are perfectly perpendicular to the subject's sagittal plane. The closer the camera is to the subject, the more *gnomonic* (distorted) are the distributions of the graphic data (Encarta, 2007). Although the characteristics of video camera optics differ from 35mm optics, a zoom lens limited to a 19 degree horizontal field of view, in either application, is commonly categorized as a "*telephoto"* lens which has less graphic distortion than a standard or a wide-angle lens.

Extrinsic Variables

Angle of Foot-strike

Measuring the foot-strike position during running is not a new idea: one method, used by Williams and Cavanagh (1987), reported a measurement called "shank angle" or SANG which described a shin angle deviation from vertical orientation. In runners, this angle correlated with ground contact times ($r = 0.66$); this was not surprising because it reasoned that the greater SANG deviated from vertical at the moment of foot-strike, the more likelihood that maximum knee flexion at mid-stance would also increase (maximum knee flexion at mid-stance increases ground contact times). Variables such as SANG, however are inadequate for describing foot plant in relation to the center of mass. More appropriate would be a variable which included the relationship between center of mass, hip angle, knee angle and the point of ground contact; it should be descriptive to the purpose of defining a kinematic ground component indicator that has a natural association with hip extension.

An article by Kibler, Press and Sciascia (2006) discussed the importance of the condition and position of the body core in producing "… proximal stability for distal mobility and function of the limbs" (p. 190). The core boundaries extend from the pelvic region, including the Glutaeus Maximus, to the Diaphragm. Athletic function is regarded as a "chain" of muscular events emanating from a stable body core. The authors regarded core stability as "pivotal" in assessing biomechanical advantages in force production for running as well as reducing joint stresses and protecting the back muscles from injury (Core assessment and rehabilitation is also essential to rehabilitation of many extremity injuries).

Numerous disciplines of physical training associate the function of the body core with successful physical performance. *Pilates* trainer and author, Siler (2000) described the body center or "powerhouse" as comprising of the hips, buttocks, lumbar region, and abdomen. The energy source for Pilates movements originates from this center or "foundation". Pilates is one of numerous physical body disciplines identifying this concept as essential to successful performance. Running technique author, Dreyer (2004) uses the "Chi" concept to integrate awareness of many factors which contribute to balance in running. One factor mentioned by the author referred to the forward position of the body core (lower trunk) for achieving the correct lean for maximizing running economy.

A bodily reference that is associated with the core is the static (natural standing) estimate of center of mass (SCM). According to Hamilton and Luttgens (2001), center of mass in adults (in standing position) is centered in the transverse plane at approximately 57% of height of males and 55% of height of females. Although true center of mass deviates significantly from SCM during dynamic physical activity, it is a fair reference point to the body core center, "…level with the first sacral segment" (p. 374).

For the present study, SCM was elected as the reference point used in defining angle of foot-strike for three reasons: (a) SCM falls within the region of the body described by physical educators and researchers as the heart of the body core, the foundational base from which distal mobility of the lower limbs is executed, (b) variances, resulting from body type or pathologies (associated with anterior pelvic tilt and limited hip extension), yield minimal deviation of SCM relative to the proximity of the *ischial tuberosity* which is the origin of the investigated hip extensors, and (c) SCM can be graphically located on individual video frames and represented as virtual SCM (VSCM) in a dynamic state (i.e. at moment of foot-strike). The angle of foot-strike is a component of the Kinematic Running Assessment Method (KRAM) found in Appendix B.

Ground-speed

It has been pointed out in this chapter that ground-contact time shares significant association with running efficiency. Ground-speed (GS) is defined as the relative amount of time both feet are in contact with the ground during a full revolution. According to Idaho State University head track and field coach, Dave Nielsen (personal communication January 12, 2007), individual sprinters can exhibit considerable variance in GS within the span of a 100 meter dash. Upon leaving the starting blocks, sprinters can show as high as 0.60 GS index during the first 20 meters (employing *back-side* or propulsive mechanics). During the last 80 meters the index drops substantially to near 0.40 as the sprinter achieves maximum constant velocity (where *front-side mechanics* are exhibited; this is described and illustrated earlier in this chapter by Hunt and Nirenstein as efficient hamstring behavior).

The relationship between relative ground contact time and the horizontal ground reaction forces, resulting from individual distance runner kinematics, is generally accepted. A major objective of the present study was to determine how variance in distance runners' relative timing of hip extensors affected their GS characteristics, while running at constant velocity. It was also an objective to establish a method for efficient, in training, measurement of GS, using on-site video analysis. Ground-speed is also a component of KRAM (found in Appendix B).

Summary

For the purpose of identifying important factors impacting efficiency in running, the main points from the review of the literature are reiterated: (a) Neuromuscular behavior of hamstring muscles plays a critical role in maximizing utilization of passive energy in running (kyrolainen, Avela and Komi, 2005), (b) a high ratio of vertical to horizontal GRF is found among high caliber runners (Paavolainen, Nummela, Rusko, and Hặkkinen, 1999), (c) core stability is essential to achieving the efficient use of limbs in athletic function (Kibler, Press and Sciascia, 2006), (d) ground-speed is an indicant of efficient biomechanics as well as a determinant of running performance (Cavanagh. 1990), and angle of foot-strike, in comparison to shank angle in (Williams and Cavanagh, 1987), and Ground-speed are correlated by virtue of compliant knee behavior (Cavanagh, 1990).

CHAPTER THREE: METHODS AND PROCEDURES

The main purpose of this study was to observe college-age distance runners performing at constant velocity and cadence, and with the use of electromyography (EMG) and video analysis, determine if the relative timing of onset, peak, and termination of hamstring muscle activation was related to the kinematic characteristics of ground-contact which describe attractor behaviors, "over striding" and "slow on-and-off the running surface foot action" (Hunt, 2004, p. 1).These behaviors were assessed by measuring the variance of angle foot-strike (FS°) and ground-speed (GS), both were components of the Kinematic Running Assessment Method (KRAM) found in Appendix B.

Participants

Twenty-eight male and eleven female distance runners applied to participate in the study; the target participant age was 18 – 24 years. Most were university student athletes from Idaho State University (Pocatello), William Jessup University (Rocklin CA), University of California (Berkeley) and American River College (Sacramento) who were either currently competing as distance runners or had recently competed in age-level competitions. The desired participant qualities were (a) runners who would likely exhibit consistent motor patterns (b) runners with adequate motor control of pace and stride frequency in order to meet the conditions for testing the hypotheses. Without these criteria being met, the response variables would be contaminated by variance of pace and stride frequency resulting in the weakening of the argument to either assert or negate any association between muscle activation timing and the consequent extrinsic behaviors.

Approximately two-thirds of the participants were currently training in intercollegiate athletes. Although this caliber of runner more than exceeded the requirements for obtaining consistent performance during the testing sessions, the runners were categorized for later reference on a case by case basis. These categories had no bearing on the outcome of the hypotheses of the present study but served for general interest in result analysis and future studies; the category descriptions are found in Appendix A.

Facility and Research Apparatus

Apparatus consisted of equipment to facilitate: (a) the running activity, (b) collection and analysis of electromyographic (EMG) data, (c) collection and analysis of video data, and (d) analysis and reporting of results including hardware, and software based scientific and statistical tools.

Facilities and Equipment

The study was conducted at track and field training sites of Idaho State University and William Jessup University with permission from the respective cross country team program directors. Modern all-weather surfaces were used (with the exception of compacted hard-pan/crushed granite dirt in one setting) for the testing of participants. Locations were chosen based on availability of space for placing of camera equipment (15 meters minimum at closest pass) and availability of power to operate the laboratory tools (video, EMG equipment and computers). At least 60 meters of unobstructed approach to the observation zone which was 4.88 meters (16 feet) was also a determining factor in choosing the best locations. Lighting conditions and time of day were also factors in choosing a location.

Orange cones and marking tape were used to guide runners on the correct line of approach. Tape or 18” pieces of ½” PVC (plastic pipe) were laid down (spaced at the target stride length; men used 1.77 meters and women used 1.52 meters) on a starting zone of 10 – 12 meters before the 60 meter approach zone. An audible metronome was set at 97 beats per minute and was used to aid runners in achieving the target stride frequency in the starting zone and into the early part of the approach zone.

EMG Data Collection and Analysis Tools

The Myomonitor III Telemetric EMG system, of Delsys Inc., used wireless (D-Link) communication to the laptop computer (Fujitsu Life Book C series) dedicated to EMG measurement. The supplied software (EMGworks 3.1) was used to translate raw signals from the transmitter (sampling rate of 1.0 KHz). The software featured two modules: a Data Recording module (enabling the computer to convert the transmitted signals from the Myomonitor into recorded raw data files) and a Data Analysis module (for displaying and analyzing recorded data for research purposes).

The Myomonitor III unit (2 lbs.) was carried in a lumbar pack with shoulder strap. The unit received data from an 8 channel input module (clipped to the lumbar pack) via an input module cable. In this study the input module accommodated multiple detectors including: two differential surface EMG electrodes (which were attached to the skin at the hamstring muscle sites); four foot-switches, a fiber-optic multi-use goniometer (measuring hip flexion and extension), and a ground wire which was attached to the skin with a high-conductivity surface pad covering the knee of the participant’s investigated limb.

An initiation switch was specially constructed by Delsys Engineers for the purpose of synchronizing the Myomonitor with the video camera. The switch (held by the participant) initiated the EMG recording process while activating an LED light which the camera could detect and record, establishing a video synchronization point for each test.

Additional apparatus used in preparing EMG equipment included a Norelco electric razor / trimmer, rubbing alcohol and cotton swabs for preparing the skin surface sites. A trainer's table or a stable, elevated and padded surface was used to facilitate this process and provide reasonable comfort to the participant. Athletic training tape, pre-wrap and Velcro strapping material were used for securing wires to the body.

Video Data Collection and Analysis Tools

The present study used two cameras meeting the specification of the National Television System Committee (NTSC): A Sony DCR-TRV140 Digital 8 as the main unit for recording running performance and a Canon XL1 for synchronization, event verification and documentation purposes. Each camera was supported on a tripod that had either built-in leveling capabilities or required leveling by hand using a carpenter's level and a carpenter's plumb tool. Both cameras used Firewire cables as a link to a Fujitsu N6410 laptop computer.

The Fujitsu computer was used to record video data and to operate the video analysis software. Both processes of capturing video and analyzing recorded video were accomplished using Dartfish Pro Suite Video Analysis software updated 4.08 edition. The program's "In The Action" module supported live feeds from the two video cameras. The testing sessions were also taped in case there was failure in the video capturing process.

Statistical Tools

Microsoft Excel was used for recording and sorting observed data (e.g. moments and angles of foot contact and for calculating values (Ground-speed, Pace, Stride Frequency and relative timing of muscle activation) using observed elemental data.

Minitab statistical software was used for generating standard statistical values of observed and calculated data as well as for performing covariant analysis to test the hypothesis.

Test Session Procedures

Preparation of the Research Site, Processing and Preparation of Participants, Testing Procedures, Data Processing Procedures and Statistical Procedures are included in this section.

Preparation of the Research Site

With help of institution maintenance workers, access to power helped in the selection of the laboratory area, near the track. Training tables and research equipment tables were set up under cover of shade from buildings or from a reusable portable tarp. Direct sunlight was avoided in the laboratory and participant preparation areas.

The main camera was placed 15 meters from a point that was both tangent to the running path and located in the center of the observation zone. Camera height was placed at the adjusted mean height of combined men and women estimated center of mass (98cm). The camera lens was adjusted to a horizontal view-width of approximately 19° to contain, in view, two sets of two small marking cones spaced 4.88 meters apart with the center of the zone oriented 90° to the camera's line of site; this established the "observation zone". Cones were placed on both sides of the running lane, marking four corners of the observation zone, in order to create a virtual perspective used in video analysis. Figure 6 illustrates the configuration of the main camera (after leveling).

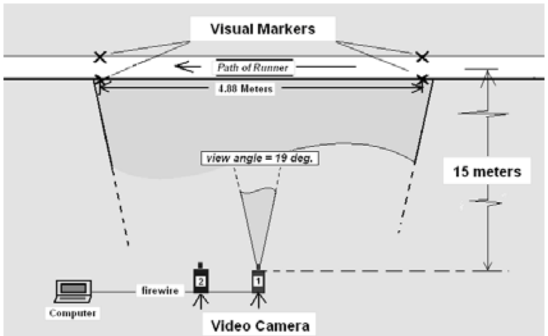


Figure 6. **Positioning of camera 1 and camera 2.**

The second camera was positioned for convenient manual access; it served for time-stamping the moment of EMG test initiation (explained later in this chapter). It was also positioned for panning the runner from the beginning of the approach through the observation zone where it recorded runner activity, simultaneously with the first camera (the first camera was fixed). This process allowed for the synchronization between the EMG system and the video data.

Strips of white tape or ½" white polyvinyl chloride (PVC) tubing cut to 20" lengths were placed to the running surface near the starting zone and spaced at the distance of the target stride length for the purpose of aiding the participants to adjust to individual stride to meet testing criteria.

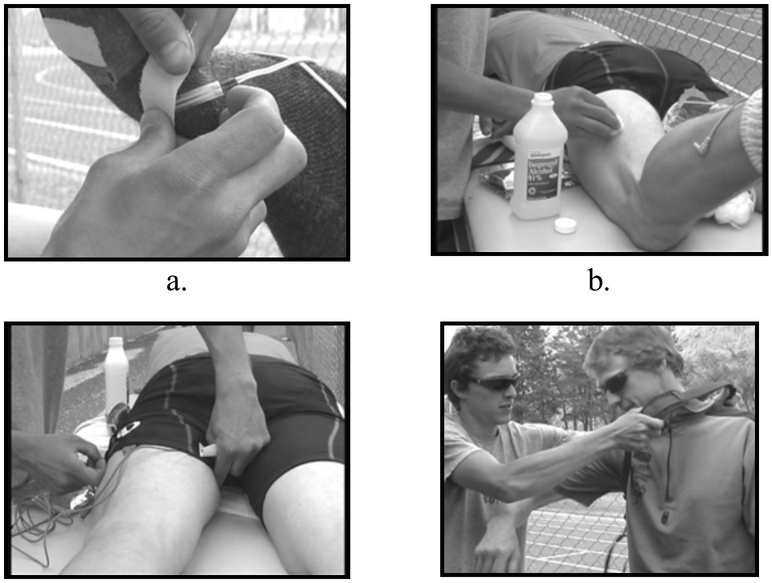
Processing of Participants

Each study participant and volunteer were informed verbally and in writing of the purpose and procedures they would adhere to by agreeing to be subject to the research process. Participants signed a consent form and then were instructed to complete applicable fields of a questionnaire form. The form was designed to assess the current abilities of each runner (current average weekly mileage, best marks in 400 – 10,000 meter race) as well as record height, weight, age, and gender. After completion of the form, the investigator assigned a random participant reference number (known by the researchers, only). The reference served as a substitute for the runner's name on all test data sheets in order to protect anonymity.

Preparation of Participants

The runners were asked to dress in standard running-style or Spandex shorts and close-fitting shirt (tucked-in). In order to aid the analysis process it was made certain that features significant to kinematic measurement (e.g. lateral malleolus) were visible to the camera. In some cases, marking the feature with athletic tape or reflective adhesive tape served to increase visibility. The barefoot height of the participant was measured for the purpose of calculating the static center of mass (SCOM) estimate which is defined as 55% of height for females and 57% for males (not including shoe thickness).

The runner was asked to lay face-down on the trainer's table while the investigator located (through voluntary contraction) the muscle belly of the investigated hamstrings (Semitendinosus and long head of the Biceps femoris). The sites were shaven and rubbed vigorously with isopropyl alcohol applied to a cotton swab (see Figure 7.b).



a. b. c. d.

Figure 7. **Participant preparation procedures.**

EMG bipolar surface sensors were applied using double sided adhesive tape with slots to allow the two metallic sensors to make contact with the skin. The sites were covered, either with Spandex/Lycra style clothing or athletic tape (figure 7c). Other implements linked to the Myomonitor, such as foot switches and Goniometers were attached to the body (figure 7.a). The foot switches were taped to the sock at the fifth metatarsal (for midfoot-strikers) or the center of the pad of the heel (for rear foot-strikers). Each foot also had a foot switch to the center of the plantar surface of the big-toe for detecting termination of ground contact at toe-off.

A thin sock was placed over the runner's sock and the switches. The goniometer was supported by a Velcro strap around the waist and an elastic strap around the upper thigh of the investigated limb with the vertex (center) of the goniometer positioned next to the skin surface near the Greater trochanter of the investigated limb. Combined use of footswitches and goniometer aided in the verification of the moment of foot-strike and toe-off of both limbs.

After securing all wiring to the body with tape (allowing sufficient slack for easy movement) the lumbar pack, containing the Myomonitor unit, was strapped to the waist and over the shoulder (Figure 5.d). A ground wire from the Myomonitor was attached to the knee of the investigated limb using a conductive adhesive patch; this assured unambiguous reception by the Myomonitor of the distinct electrical impulses sent by the EMG surface sensors, the goniometer and the foot-switches.

Finally, while the shod participant stood in a natural posture, measuring from the ground, two marks about 10 cm apart were made by placing visible tape on the hip, one forward of the frontal plane and one aft, both at a height of 57% and 55% (for men and women, respectively) of the participants measured height, plus 2.5 cm as an constant for shoe thickness (video analysis error tolerances were ± 1.5 cm. This process enabled easy reference for identifying VSCM from individual video frames. The two marks allowed for consideration of anterior pelvic tilt and hip rotation when estimating the location of VSCM in the dynamic state (Procedure for estimating VSCM is described later in this chapter).

Testing of Participants

Selection of right or left limb as the investigated limb alternated between testing sessions (1-2 sessions per day, involving 1-4 participants per session). Particular venues limited choice of approach direction due to physical layout of the area or because of visibility issues due to poor lighting conditions. Some conditions forced the choice of limb to be investigated.

Two processes were involved in the testing process: verifying functionality and fully active test repeats. The first process established the functioning of the Myomonitor system for each participant and recorded the maximum voluntary contraction (MVC). It commenced by turning on the internal power and the initiating the recorder (using the hand held switch) of the Myomonitor system, the participant had 30 seconds to again lay face down on the training table and raise the foot of the investigated limb; the participant was asked to attempt to flex the knee, forcing the heel to the buttocks while the investigator resisted this force, pulling the foot back (toward an extended knee position). This event lasted for 2-4 seconds, during which MVC was established. After the 30 second (programmed) duration of the test was completed and if the computer showed evidence of a successful recording, the system was considered operational for conducting full running tests. Although the acquisition of MVC was not essential to the present study, it helped to verify that a clear EMG reading was being obtained.

Tests were conducted with the help of a volunteer who attended to any problems with securing of apparatus to the body of the participant (wires, straps etc.). About half of the participants were tested having EMG recorder initiation triggered at the computer by the investigator. Following an audible queue from the investigator, "test is go", the volunteer tapped a goniometer in view of the Canon video camera; this event was detected by both the video and the EMG systems thereby establishing a video synchronization reference. The latter half of the participants used a trigger switch, which was held by the participant, to initiate the recording process when he or she was ready. The runner pointed a thumb-switch (equipped with an LED light) at the main camera. Both the EMG recorder and the LED light turned on the instant the switch was thrown (see Figure 8). Both methods used for initiating the tests (goniometer and LED thumb-switch) were tested for validity and reliability by conducting mock testing sessions that used both initiation methods in the same test. There was no significant variance in time as both relied on the accuracy of the digital camera which, through interpolation, was within one-hundredth of a second. The Myomonitor sampled at one-thousandth of a second which was beyond the required precision (to the nearest one-hundredth of a second).

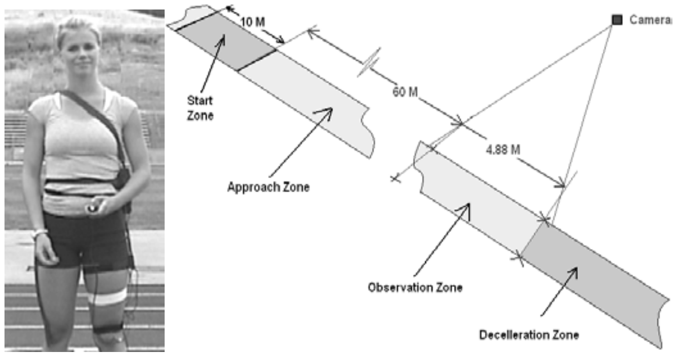


Figure 8. **Test initiation and runner approach.**

Runners were allowed approximately 15 minutes to warm up with the EMG sensors attached and the belt back mounted. Warm-up for testing was determined by the participant. The runners began tests at approximate pace and stride frequency and repeated tests from 3-12 times depending on the individual need of each runner to make fine adjustments in order to approach the target pace and stride frequency.

Figure 8 illustrates the approach path of the participants. The runners accelerated through the starting zone (10-12 meters) and maintained the pace and stride frequency down the approach area (60 meters) and through the observation zone (4.88 meters). A deceleration zone extended 20 meters beyond the observation zone.

Data Analysis

Microsoft excel software was used to create individual “d-line” spreadsheets (one for each participant) to which the elemental data sets (one set for each test), observed from the video and EMG recordings, were manually entered (a sample d-line element set is shown in Appendix A). The term “d-line” described the linear format into which the data elements were entered. The first third of the d-line element set consisted of general information associated with the participant including: ID #, sex, age, height, weight, runner classification. The second third consisted of the participant’s test number followed by the chronologically recorded (critical) events of opposite limb foot-strike, opposite limb toe-off, investigated limb foot-strike (with associated angle), investigated limb toe-off (with associated angle), pace and stride frequency, all calculated from video data using Dartfish Pro Suite 4.09 analysis software (stride frequency was verified by cyclical EMG data). The final third of the d-line contained the chronological events of onset, peak and termination of contraction of both muscles (verified from the raw EMG data), using the Delsys EMGworks 3.1 software. The d-line sheets were void of formulas used for calculating intrinsic or extrinsic variable values and ground-speed values; formula calculations were performed on separate Excel “calc”-sheets.

Angular measurements were made with use of the Dartfish video analysis measuring tools: Virtual Static Center of Mass (VSCM) was used as a reference for angle of foot-strike and angle of toe-off. VSCM was obtained from visual markings that were placed on the body before the testing began in order to represent the height of static center of mass (SCM) in the dynamic state. Figure 9 shows the basic steps of determining VSCM: (a) drawing a line through the SCM marks (VSCM falls on this line), (b) bisecting the torso region (this corrected for any hip rotation, and (c) marking the point on the line that bisects the segment; this point is the imaginary sagittal representation of a point within the body at the Sacral segment which functions as the vertex of FS°.

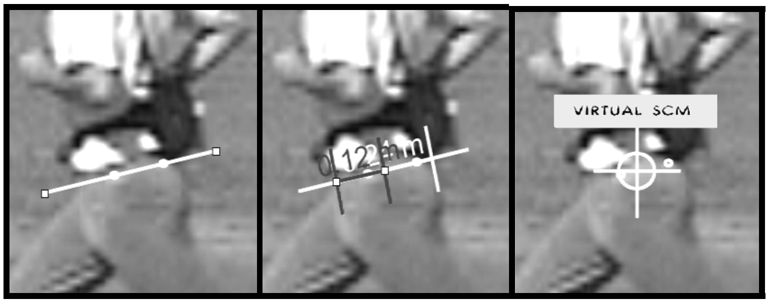


Figure 9. **Establishing VSCM using SCM markings.**

Chronological occurrences of critical kinetic events (opposite and investigated foot-strike and toe-off) were corroborated by use of foot-switch, goniometer and video data and then entered into the d-line (to the nearest hundredth of a second) as moment of time occurring within the duration of the thirty second test (measured by the Myomonitor). The Dartfish program timing-function reports at intervals of one sixtieth of a second (with an accuracy of one thousandth of a second). Angular values associated with an event (i.e. foot-strike) occurring between two reported times were produced through interpolation using angular values associated with the moments of reported values before and after the investigated event. Newton's third law assures that interpolated values are reliable in this context (even though slight change in velocity may have occurred within the investigated interval of one sixtieth of a second). In one instance, a chronological element, the foot-strike of limb opposite to investigated limb (not as critical as foot-strike of investigated limb), occurred outside of video detection; the value (moment of occurrence) was then extrapolated by determining relative event occurrence to EMG data of previous and successive strides. In this case, multiple strides were analyzed to establish an estimate based on the EMG data, producing a likely value with high probability.

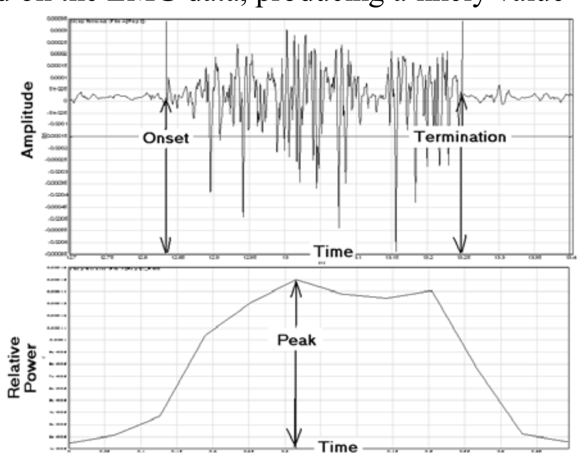


Figure 10. **Raw EMG signal and smoothed RMS signal.**

Delsys EMGworks 3.1 analysis module displayed EMG data. Vertical cursors in Figure 10 shows respective events: onset, termination (top graph), and peak power of contraction (bottom graph). The "*x"* axis represents the chronology of events.

EMG elements

Onset and Termination of Muscle Contraction

The major neuromuscular event which occurred during the period of interest, comprising of mid-swing phase and late-swing (pre-contact of the investigated limb), was the onset or *initiation* of concentric contraction of the investigated hip extensors, Biceps femoris (BF) and Semitendinosus (ST). The onset of hip extensor activation was determined through visual examination of the raw EMG data (see Figure 10). Contractions that were concentric in nature were of primary interest; muscle onset and termination of contraction were both verified by (a) significant change in EMG amplitude readings, (b) visible change in spectral quality of EMG raw data that remained consistent throughout the contraction and (c) associated physical response (video observation) occurring simultaneously or immediately after the time of onset indicated by the EMG data.

Peak Power

Peak power was determined using a root mean squared (RMS) formula (see Appendix A) which averages raw EMG signals observed within an overlapping moving window, revealing the desired portions of the raw EMG signal (see Figure 10). Because this process smoothes the raw data, it was the chosen method for determining the occurrence of peak muscle power. Peak power was expected to occur before, during or after the time of foot-strike of the investigated limb.

Intrinsic (EMG) variables

Intrinsic variables, relative time of onset ($INIT_{BF}$ and $INIT_{ST}$), relative time of peak power ($PEAK_{BF}$ and $PEAK_{ST}$), and termination of contraction ($TERM_{BF}$ and $TERM_{ST}$) for Biceps femoris and Semitendinosus, respectively, were calculated using the chronological values of both EMG elemental data and critical events in Figure 1. The mathematical relationship between the critical events and the intrinsic variables are explained in Appendix A.

Extrinsic (kinematic) variables

Three methods were used to triangulate the events: 1. Footswitch detection. 2. Joint compliancy detection (with goniometer). 3. Video recognition. Footswitches were most reliable for obtaining ground contact in runners showing midfoot-strike patterns and relatively smaller angle of foot-strike; even though vertical compliance (observed in knee flexion) was less it could be assumed that effective mass was achieved upon the closing of the footswitch circuit. Runners exhibiting heel-strike patterns were more likely to have a larger angle of foot-strike; knee and hip compliance were strong indicators of effective mass being achieved, in these cases. A goniometer that measured hip extension and flexion, supplied by Delsys, was used for verifying the achievement of effective mass for the foot-strike events; the goniometer was also occasionally used in eliminating ambiguities observed in EMG data during hamstring muscle onset.

Height Adjusted Angle of Foot-strike HFS°

The observed angle of foot-strike, FS°, required special attention because variance in runner height directly affected angular displacement when stride length and pace were controlled. The virtual static center of mass (VSCM), essential for calculation of angle of foot-strike, was also determined by the height of the participant. It was reasoned that taller runners would produce less angular displacement, in order to achieve equal running surface displacement (distance), than shorter runners. For this reason, the sine trigonometric function was applied with the mean VSCM of the men's and the women's groups to adjust for runner height variance. According to the formula in Appendix A, runners who were taller than the mean height (according to gender) were assigned slightly larger angles than their respective observed angles. Runners who were shorter than the mean height were assigned slightly smaller angles; this was because the delimitation of pace and stride frequency demanded different responses from runners of varying heights. This assigned angle (HFS°), called the height-adjusted angle of foot-strike, was applied in the calculation of all neural-kinematic correlations. In effect, this eliminated any influence participant height had on angular kinematic correlations (comparisons between HFS° and FS° correlations with height are shown in chapter four).

Ground-speed (GS)

Ground-speed (GS) typically describes the ratio of time the feet are on the ground in relation to the time they are off the ground during one full revolution (ground time of left and right limbs are both measured). In the present study, GS is operationally defined as the ground-contact time of the investigated limb divided by the combined time of the mid-swing and late-swing phases (period of the investigated stride). The GS value was calculated using three recorded events: (a) the moments in time when the foot of the limb opposing the investigated limb (opposite limb) achieved foot-strike, (b) the consequent moment in time when the investigated limb achieved foot-strike, and (c) the moment in time when the investigated foot left the ground; by dividing the ground-contact component (c - b) by the stride component (b - c) yielded a decimal value (GS) that was normally between 0.30 and 0.77.

Research Design and Statistical Methods

The present study, as in (Montgomery, Pink and Perry, 1994) was descriptive in design; it looked at two kinds of behavior, the neuromuscular timing patterns of hamstring activity (Intrinsic) and the kinematic behaviors directly related to ground contact (extrinsic) events in each subject.

The investigative design consisted of three research components (shown in figure 11): (a) the runner, (b) the EMG system and (c) the video system; the synchronization of the technological components provided the means to investigate the relationship between the intrinsic and extrinsic behaviors. The most important intrinsic (neural) value could arguably be the time of peak muscle activity; among extrinsic elements, the time of foot-strike had the strongest influence over the statistical values (the EMG system's footswitches and goniometer were heavily relied upon for determining this value).

Any runner, although failing to run at best form, would yield usable data by achieving close to the target pace and target stride frequency. Because pace has been known to affect foot-strike position as well as ground-contact times, achieving as close as possible to the target-pace and target stride-frequency was essential to the task of eliminating any ambiguities which may reside in the correlation of relative onset, peak and termination of muscle activation to the angle and relative time associated with ground contact.

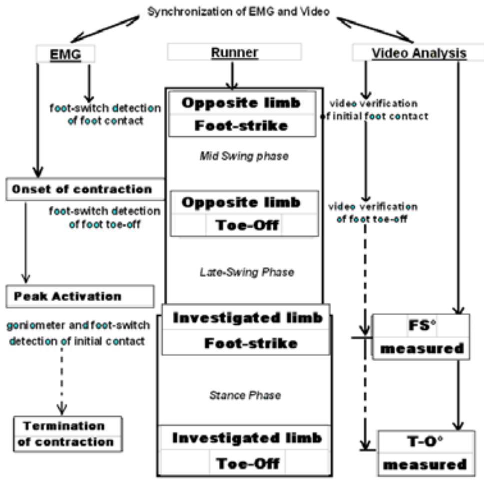


Figure 11. **Schematic integration of the three investigative components: The EMG system, the runner and the video system.**

Figure 11 schematically illustrates (chronologically from top to bottom) a hypothetical coincidence of events, inserting the likely occurrence of the investigated events that were detected by the EMG system on the left side. Onset of muscle contraction was expected to occur well before the foot-strike of the investigated limb (with a value less than 1.00). Peak power was expected to either occur before foot-strike ($PEAK_{BF/ST} < 1.00$), upon ($PEAK_{BF/ST} = 1.00$) or occur after foot-strike ($PEAK_{BF/ST} > 1.00$) of the investigated limb. Termination of contraction ($TERM_{BF/ST}$) was likely to occur after foot-strike of investigated limb thereby producing a value greater than 1.00. Ground-speed (GS) must be less than 1.00 to qualify the activity as running (vs. walking).

Figure 12 shows the output of a runner's elemental and calculated data generated from video and EMG systems. The numeric values represent the kinematic and EMG chronological elements from a specific test of a participant (manually recorded on the d-line spreadsheet that is designated to the specified participant). A sample of a d-line element set, together with detailed application of the formulas used for calculating the intrinsic variables and GS are found in Appendix A.

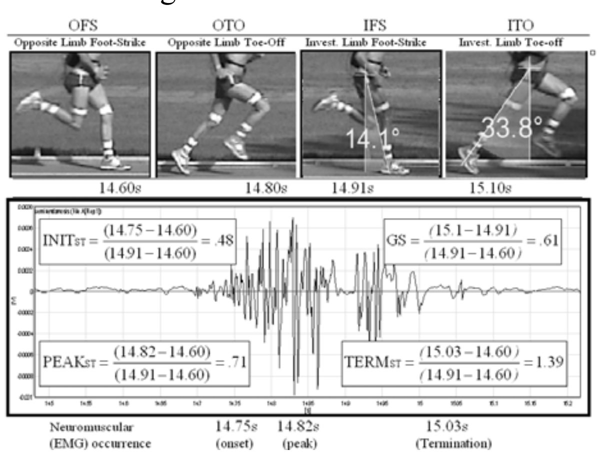


Figure 12. **Data output from video analysis and the EMG signal of Semitendinosus activity.**

The Pearson product moment correlation provided a means to detect relationships between intrinsic and extrinsic behaviors; although there might be theoretical justification to assign the "independent variable" category to the neural events, this classification was not used because multiple (three neural values, onset, peak and termination) values were measured in each category. Instead, the intrinsic and extrinsic variable category allowed for flexibility in the reporting and graphing of correlation values.

Data Filtering

From multiple attempts by each participant to achieve both of the targets in a single test, a single *best test* was selected. The following criteria were applied to determine the best test of each participant: (1) Tests performed by each participant were sorted by pace and then by stride frequency; test(s) closest to target pace were then filtered according to meeting the stride frequency target. (2) For participants who exhibited equal pace and stride frequency values for multiple tests, the last test performed was chosen to be included in the pool (the "general sample") consisting of the best test of each participant.

In order to eliminate excessive variance of pace and stride frequency values within the pool used for testing the hypotheses, a final pool of tests (called the "filtered sample") was selected, for both men and for women, by eliminating tests which showed values outside one standard deviation from the mean of exhibited pace and stride frequency across the pool that consisted of all participants' best test.

All sorting and calculating of specific values were executed using Microsoft Excel. Minitab statistical software was used for statistical calculations and for graphing the data. Relationships between variables were evaluated with Pearson correlation coefficients. Standard statistical methods were used to calculate means and standard deviations. The alpha level was set at $\alpha < 0.05$.

Testing the Hypothesis

The two extrinsic variables, HFS and GS, were tested separately against the set of three intrinsic variables INIT (onset), PEAK and TERM for BF and for ST (a total of four tests per gender). A rejection of the null hypothesis for any one of the four tests would require one of the following conditions: (a) two or more *significant* ($p <$ ** .05) Pearson p-values in any test or (b) any one significant p-value, in combination with two *noted* ($p <$ *0.10) p-values in any test. The rejection would only apply to the individual test in which these conditions were met.

Note: Upon processing the data, another relative timing index was tested (peak-influenced mean of muscle activity, PIMMA, described in chapter four). It was amended to the null-rejection criteria that any significant (p < ** .05) correlation between either extrinsic variable value and either PIMMA index of the hamstring muscles would stand in as an additional p value within a related test for determining a rejection of the null hypothesis.

Summary

It was in the interest of this study to broaden the understanding of how certain isolated neuromuscular events (onset, peak and termination of muscle hamstring activity contribute to kinematically measured (HFS° and GS) running motor behaviors. Although the higher level of runner experience and general level of training by each participant across the sample was expected to reduce variation in individual running behavior, variation in individual stride patterns (other than abnormal change in velocity) did not reduce the relevance of data generated from individuals exhibiting inconsistent motor behavior; the experiment was designed to uncover neuromuscular/kinematic relationships, shown through variant behavior, by isolating (rather than averaging) the investigated stride elements.

CHAPTER FOUR:
RESULTS, DISCUSSION AND CONCLUSIONS

The main purpose of this study was to observe college-age distance runners performing at constant velocity and cadence, and with the use of electromyography (EMG) and video analysis, determine if the relative timing of onset, peak, and termination of hamstring muscle activation was related to the kinematic characteristics of ground-contact which describe attractor behaviors, “over striding” and “slow on-and-off the running surface foot action” (Hunt, 2004, p. 1).These behaviors were assessed by measuring the variance of angle foot-strike (FS°) and ground-speed (GS), both were components of the Kinematic Running Assessment Method (KRAM) found in Appendix B.

Thirty-nine runners, 11 female and 28 male, participated in the study; the data from one female and four males was lost due to technical failures. The remainder produced a total of 85 successful tests; from this pool, the best test was determined for each individual (according to the procedure described in chapter three). In the general sample (N = 34) of successfully tested participants, the mean age was 22 years and about 29 percent were among the high mileage group (also defined in chapter three).

The results are divided into two sections: the general sample (all participants' best test) and the filtered sample (participants from the general sample whose pace and stride frequency values fell within a specified range of deviation from the mean); each section includes a discussion that is relevant to the literature reviewed in chapter two as well as relevant to future research applications. These sections are followed by a summary consisting of major conclusions and recommendations for applying the running assessment method, KRAM, for the purposes of teaching motor-skills of efficient running to people of all ages and designing future studies, including those prompted by AAHPERD, focusing on issues requiring longitudinal investigation.

The General Sample Data

This section examined the data consisting of the best test (explained in the data processing section of chapter 3) from each successfully tested participant (N = 34); descriptive analysis (means and standard deviations) of the intrinsic and extrinsic variables was performed (this included notes on various intra-participant motor-behavioral analyses observed in the data all 85 tests). The tables contain the descriptive statistics and the graphs show the data distribution curves.

Intrinsic Variables

The statistical values in Table I show means and standard deviations of neural event relative timing in decimal form; these values can be interpreted as a percentage of the chronological stride period. Intrinsic variable values less than 1.00 indicate events which occurred while the investigated stride was being performed (before foot-strike of the investigated limb), the value 1.00 marked the moment of foot-strike, values greater than 1.00 identify event occurrence after completion of the investigated stride (after foot-strike).

The mean onset and mean termination of Semitendinosus (ST) show that this muscle was active over a period of time that exceeded the duration of the average investigated stride. Runners who exhibited later termination of hamstring contraction likely indicated that acceleration occurred just before toe-off, which would compensate for lost velocity at initial ground contact. This would be indicative of horizontal ground reaction forces (GRF) mentioned in Paavolainen, Nummela, Rusko et al (1999). Although the present study did not measure GRF, kinematic data could help in descriptively qualifying relative vertical and horizontal forces.

Table I
Descriptive statistics of intrinsic variable values obtained from the general sample

Men (n = 24)	INIT		PEAK		TERM	
	M	SD	M	SD	M	SD
Biceps femoris	0.41	0.10	0.92	0.21	1.47	0.12
Semitendinosus	0.36	0.10	0.80	0.22	1.51	0.16
Women (n = 10)	**INIT**		**PEAK**		**TERM**	
	M	SD	M	SD	M	SD
Biceps femoris	0.40	0.12	0.92	0.29	1.43	0.15
Semitendinosus	0.38	0.09	0.90	0.34	1.40	0.16

Note. "INIT", PEAK", and "TERM" are the respective variable names for the relative timing of "onset", "peak", and "termination" of muscle activity; the values in this table represent the means and standard deviations across the men's and women's *general samples*.

Women's ST was active only slightly longer than the average women's stride duration. The average relative peak time of the women's ST (0.90) occurred closer to foot-strike (1.00); the associated standard deviation (0.34) shows that, even with such a small sample in the present study, more women achieved peak activation of ST during ground contact (weight bearing) than did men. This fact does not disagree with the findings of DeMont and Lephart (2004) that the mean EMG activity in female runners' "medial hamstrings" exceeded mean activity of the males. Probable reasons for this are discussed later in this chapter.

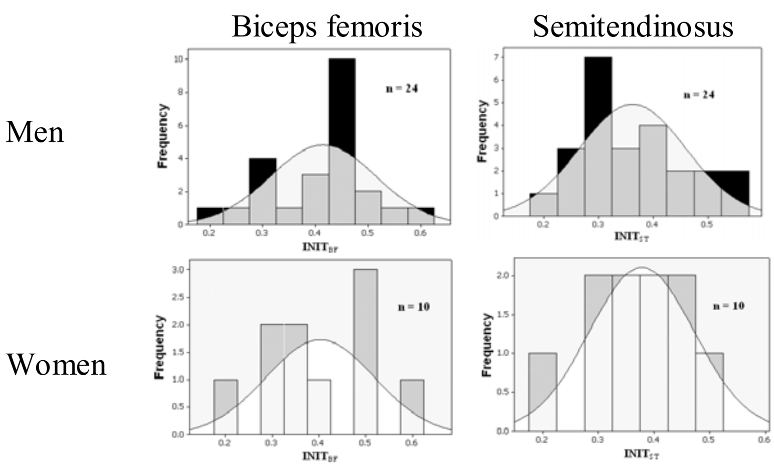


Figure 13. **General sample distributions of onset of hamstring contraction.**

The graphs in figures 13 – 15 show the distribution of intrinsic variable values calculated from the participants' EMG data. Despite the small number of participants, relative timing of onset of either hip extensor appears to vary normally for both the men and the women. If it were found that kinematic behavior occurred in concert with muscle onset timing, it could possibly serve as a neural indicant for assessing running mechanics.

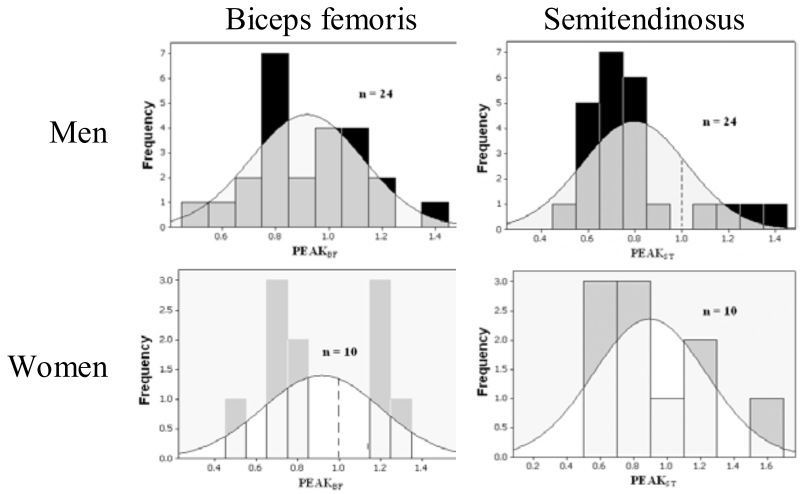


Figure 14. **General sample distributions of peak hamstring activation.**

The data distribution of relative timing of peak hamstring muscle activation is normal in men's BF and women's ST but quite peculiar in men's ST and women's BF (see figure 14). It is interesting that the latter two share a common characteristic; the occurrence of peak activation does not occur at or near the moment of foot-strike (value of 1.00). This agrees with the statistical data from table 1 (indicating a difference between men and women's peak activation in ST); from the combined evidence, it can be inferred that there exists a difference between men and women in the distinction between medial (ST) and lateral (BF) hamstrings. The lack of sample size of female runners limits the certainty of this, however. Nevertheless, using relative timing of peak hamstring values in assessing runners appears to serve better as a two-degree categorical determinant, rather than a variance of a decimal value. Using a *before foot-strike* versus *after foot-strike* occurrence of relative timing of peak activation might prove equally descriptive, if not more descriptive than a set of values on a continuum. In the data containing all of the tests, some runners tested showing peak activation "before foot-strike" on one test and "after foot-strike" on another (e.g. one male runner showed peak BF occurring at 0.83 and at 1.13 in consecutive tests); it is important to realize that the averaging of relative timing of certain neural events can yield values which may never likely occur in actuality. Schmidt (1991) commented on this phenomenon: "…performance fluctuations within a single person tend to be obscured by averaging procedures" (p. 158). A pronounced variance of peak values in the same runner may indicate a shift in attractor running behavior having occurred during the warming up process; this is why the last acceptable test was chosen for the sample of all runners' best test. A possible future application of the KRAM components might consist of investigating the change in neural and kinematic behaviors during the warm-up process.

It should also be pointed out that the intra-participant variance of relative timing of neural events should embolden researchers to look well beyond the perception of any constraint imposed by the "invariant features" theory; extensive exploration of intervention methods for improving the mechanics of runners should be undertaken.

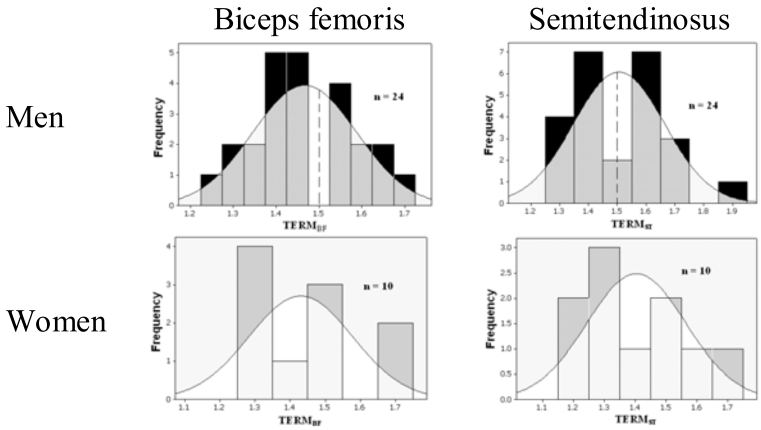


Figure 15. ***General sample* distributions of termination of hamstring activity.**

The relatively low occurrence of termination of hamstring contraction near the relative time value of 1.50 in men (observed in Figure 15), is associated with the event of the foot of the investigated limb leaving the ground (according to video analysis of several runners). A descriptive neural assessment might categorize runner's hamstring behavior as either terminating *before toe-off* or *after toe-off*. It is difficult (due to small sample size) to determine if this categorization is warranted in the case of females.

Extrinsic Variables

The general sample descriptive statistics of the two extrinsic variables, height-adjusted angle of foot-strike (HFS°) and ground-speed (GS) are shown in table II; figure 16 shows their data distributions. These variables were part of the proposed six-component kinematic running assessment method (KRAM).

Table II

Means and standard deviations in men's and women's extrinsic variable values.

	HFS°		GS	
	M	*SD*	*M*	*SD*
Men (n = 24)	14.7[a]	2.3	0.54[b]	0.06
Women (n = 10)	15.0	2.5	0.57	0.08

[a]HFS° values are expressed in degrees (i.e. 14.7°).
[b]GS values are interpreted as percentages of one stride period (i.e. 0.54 = 54%)

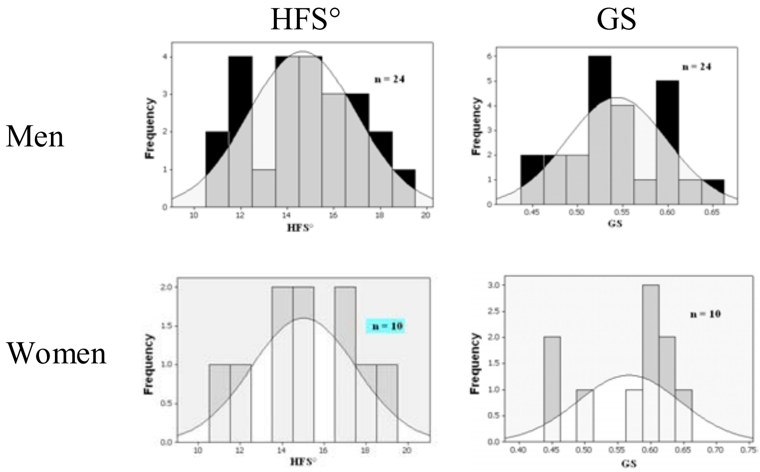


Figure 16. **General sample distributions of men's and women's extrinsic data.**

In some cases, multiple tests generated by a single participant yielded variances of greater than one standard deviation in both HFS° and GS. Some of these variances could be explained by some runner's variance of pace and stride frequency between tests; for this reason, the data from any participant who failed to achieve pace and stride frequency tolerances had to be omitted entirely from the filtered sample in order to test for the possible relationship of relative timing of hip extensors and the kinematic variables.

The Filtered Sample Results

Although high variance in the values of intrinsic and extrinsic variables was desirable, a wide variance in pace and stride frequency was not. The general sample pace and stride-frequency statistics (see table III) determined the limits of the filtered sample.

Filtering tolerances were one standard deviation from the mean pace and stride frequency values; Because the sample sizes were relatively small, data values which were outside of the limits, but were within a tenth of a meter per second of pace limits and/or were within a single revolution per minute of stride frequency limits, were retained in the filtered samples. The limits for testing the hypotheses were set; for men, the allowable paces were from 5.6 to 6.3 m/s and the allowable stride frequencies were from 93.5 to 101.5 rpm. For women, the allowable paces were from 4.5 to 5.3 m/s and the allowable stride frequencies were from 90.9 to 97.5 rpm.

Table III

Means and standard deviations in men's and women's pace and stride frequency values.

	Pace[a]		Stride frequency[b]	
	M	*SD*	*M*	*SD*
Men (n = 24)	5.95	0.62	97.5	3.97
Women (n = 10)	4.90	0.41	94.2	3.33

Note. The statistical values do not necessarily reflect the precision to which pace and stride frequency were measured.

[a]Pace values are in meters per second.

[b]Stride frequency values are in revolutions per minute.

Correlations in Men's Data

In the men's filtered sample, the relationship that participant height shared with respective observed angle of foot-strike, FS° (r = - .320, p = .195) was contrasted with the respective height-adjusted angle, HFS° (r = - .152, p = .547). This provided reasonable assurance that no correlation using the angle of foot-strike could have been contaminated by the influence of participant height.

The first observation from the men's data was the relationship between the two kinematic variables, HFS° and GS (r = 0.67, p = 0.003); this agreed with the findings of Williams and Cavanagh (1987), who uncovered a relationship (r = 0.66) that existed between the shank angle at foot-strike and the ground-contact time.

Table IV shows that the relative timing of onset of Biceps femoris muscle had a significant association with ground-speed; relative timing of peak muscle activation and termination of contraction also shared significant covariance with the angle of foot-strike. It was expected that there would be a higher r value in the relationship between muscle onset and angle of foot-strike (r = .38); variance in effective muscle-producing force may explain for the absence of a significant correlation.

Table IV
Pearson correlations in the men's filtered sample (n = 18)

Biceps femoris	$INIT_{BF}$		$PEAK_{BF}$		$TERM_{BF}$	
	r	*p*	*r*	*p*	*r*	*p*
HFS°	.38	.117	.51	.030**	.52	.028**
GS	.56	.017**	.19	.455	.62	.007**
Semitendinosus	$INIT_{BF}$		$PEAK_{BF}$		$TERM_{BF}$	
	r	*p*	*r*	*p*	*r*	*p*
HFS°	.23	.357	.24	.336	.43	.072*
GS	.34	.166	- 0.05	.856	.63	.006**

Note Subscript tags, "$_{BF}$" and "$_{ST}$" specify variable association with a specific muscle.
*p < .10. **p < .05
(α < .05)

It appeared that ST onset contraction and peak activity shared no association with the runners' kinematics. Some insight, however, was gained from the observations of the data spread of the larger men's sample (n = 24); there was a distinguishing gap between runners whose peak ST occurred before foot-strike from those whose peak ST occurred after foot-strike. Upon comparing the EMG data of both groups, it was noted that there was not a large difference in the patterns; runners in both groups exhibited two peaks: (a) a pre ground-contact peak and (b) a support phase peak. Of the three runners whose support phase peak was slightly larger than the respective pre ground-contact peak, only the pre ground-contact peak was included in the correlations of all the runner's ST peak values with extrinsic values. Table V shows the strength of the relationship between ST pre ground-contact peak with HFS° and with GS.

Table V

Correlations of pre ground-contact $PEAK_{ST}$ and extrinsic variables

n = 18	$PEAK_{ST}$	
	r	p
HFS°	.532	.023**
GS	.553	.017**

*p** < .10 ; *p*** < .05 (α < .05)

Although causative relationships were not pursued in the present study, it was reasoned that the support phase (post foot-strike) peak would not likely have a direct causative effect on consequent kinematic events. It was important, nevertheless, to find an indicant that could better reflect the impact of late muscle peak as part of the whole running gait pattern. Because the participants' intrinsic variable values were each defined by a chronological relationship to the investigated stride, a mean muscle activity which reflected the onset, peak and termination , called the *peak-influenced mean of muscle activity* (PIMMA), could be calculated; this would better describe the influence of a single (largest) peak value that occurred either before or after ground-contact.. This was accomplished by averaging the timing of neural events recorded as chronological D-line elements. A total of four PIMMA values (two muscles paired with two extrinsic variables) were calculated. Table VI shows PIMMA correlations for BF and ST in men and figure 17 illustrates the correlation for BF using a scatterplot with least squares regression line. The formula for calculating the PIMMA values is shown in Appendix A.

Without using any measurement of integrated EMG activity (except for calculating RMS) A mean value (PIMMA) allowed for the investigator to assess the distribution of muscle activity in relation to kinematic events. PIMMA also provided a way to identify grouping of runners according to what may be two distinct attractor running behaviors. A division in the data, as occurred in peak activation of men's ST, suggests a categorical condition of early vs. late peak-influenced mean muscle activity; this may also indicate two distinct running styles.

Table VI
Pearson correlation of PIMMA and extrinsic variables in men's Biceps femoris and Semitendinosus

n = 18 Statistics	$PIMMA_{BF}$ M = 0 .94 : SD = 0.10		$PIMMA_{ST}$ M = 0.89 : SD = 0.13	
	r	*p*	*r*	*p*
HFS°	.75	.001**	.41	.088*
GS	.62	.007**	.34	.163

Note. The "statistics" show means and standard deviations for $PIMMA_{BF}$ and $PIMMA_{ST}$.
*p < .10. **p < .05.
(α < .05)

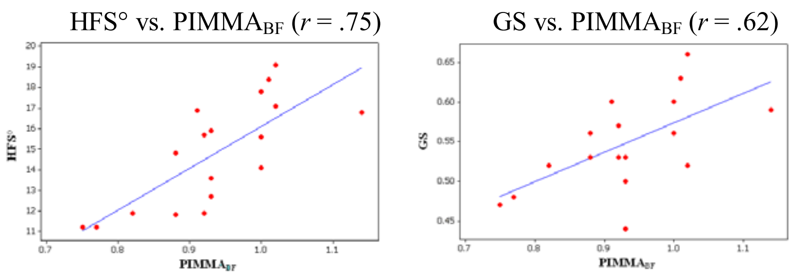


Figure 17. **Scatterplot (showing least squares regression) of extrinsic variables and peak-influenced mean of EMG activity in Biceps femoris.**

Although the y-axis clustering of the data on either side of the gap (shown in scatterplots of figure18) illustrates the very strong relationship between HFS° and GS, it may also indicate a likely a combination of foot-strike patterns, vertical compliancy variance, and other neuromuscular factors affecting hip-extension and preactivation.

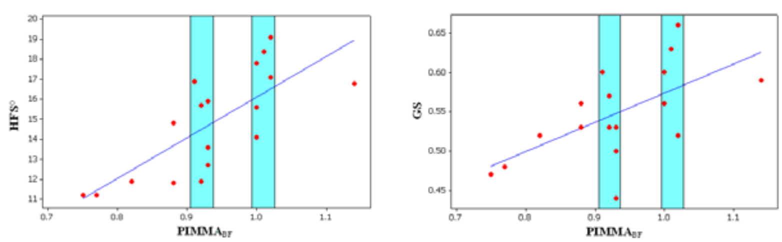


Figure 18. **Scatterplots (from figure 17) showing y-axis clustering and the absence of individual PIMMA values at the time immediately before foot-strike (1.00 represents the moment of foot-strike).**

Conclusions from Men's Results

It is clear that hamstring timing (relative to running stride) shared a significant relationship with ground contact components, angle of foot-strike and relative ground contact time; this was conclusively evident in Biceps femoris (shown in tables IV and VI) and conditionally evident in Semitendinosus (shown in part in table IV), with the inclusion of the "before foot-strike" (versus "after foot-strike") peak-activation correlations (shown in table V). The causes of weak correlations may be due to (a) the variance in relative muscle power across the sample, (b) variance in knee stability at mid-stance and (c) variance in preactivation of lower leg at ground contact. It is the combination of these factors, along with perhaps others that were not detected or measured, that may have significantly affected the influence of hamstring activation timing to produce predictable kinematic values in runners at constant pace and stride frequency.

Correlations in Women's Data

As with the men's filtered sample, HFS° compensated for any influence height might have had in the relationships between the intrinsic variables and the angle of foot-strike. Height versus FS° showed $r = -.391$ and $p = .338$ (a weak but possibly significant contaminant); height versus HFS° yielded $r = -.121$ and $p = .775$ (the weak trend was practically eliminated).

Because it was assumed, for both men and women, that a relationship would exist between angle of foot-strike (HFS°) and ground-speed (GS), this relationship was not part of the testing of the hypothesis; Williams and Cavanagh (1987) had already observed a correlation between runner shank angle at foot-strike and ground contact time ($r = .66$). It was surprising, however, to observe a significantly strong Pearson correlation in the women's data ($r = .90$ and $p = .002$) in the present study. It is believed that this relationship illustrates the effect kinematics has on knee compliancy which has been shown to be directly associated with ground contact time; Cavanagh (1990) put it, "…the length of time required to…rebound from the ground is determined by the stiffness of the spring….effective spring stiffness was related to the amount of knee flexion" (pp. 240-241).

Table VII offers no evidence that the neuromuscular timing of hamstrings had any relationship with body kinematics; other than the possibility of an outlier within the small sample, some reasons for this may be the same that were suggested for the men: (a) the variance in relative muscle power across the sample, (b) variance in knee stability at mid-stance (c) variance in preactivation of lower leg at ground contact, and in addition (beyond the men's list) (d) a low stride frequency mean of 94 rpm.

There were also other possible factors affecting the resultant statistics in women's data; the issue of frontal plane mechanics (which was not observed in the present study) may be more critical in evaluating women's running mechanics. The apparent difference between men's and women's medial hamstring, mentioned earlier in this chapter, could be a result of anatomical factors; although there is no predictor for Quadriceps femoris angle (Q angle), Horton and Hall (1989) reported that the accepted mean was 11.2° +/- 3.0° and 15.8° +/- 4.5° for men and women, respectively. Any combination of the above factors could help explain why hamstring performance failed to produce predictable kinematic behaviors in both the men and the women.

Table VII
Pearson correlations in the women's filtered sample (n = 8).

Biceps femoris	$INIT_{BF}$		$PEAK_{BF}$		$TERM_{BF}$	
	r	*p*	*r*	*p*	*r*	*p*
HFS°	.29	.493	.23	.589	.06	.893
GS	.21	.616	.24	.572	.09	.827
Semitendinosus	$INIT_{ST}$		$PEAK_{ST}$		$TERM_{ST}$	
	r	*p*	*r*	*p*	*r*	*p*
HFS°	- 0.02	.960	- 0.17	.685	.23	.586
GS	- 0.77	.856	- 0.27	.515	.11	.793

($\alpha < .05$)

In the present study, there was also an extreme variance in amplitude of pre ground-contact EMG. Figure 19 shows the EMG (in Biceps femoris) of two different participants exhibiting similar timing patterns of peak activation but showing very different pre ground-contact muscle activity; the variance of relative power occurring before ground-contact was likely responsible for variant kinematic outcomes.

Runner A Runner B

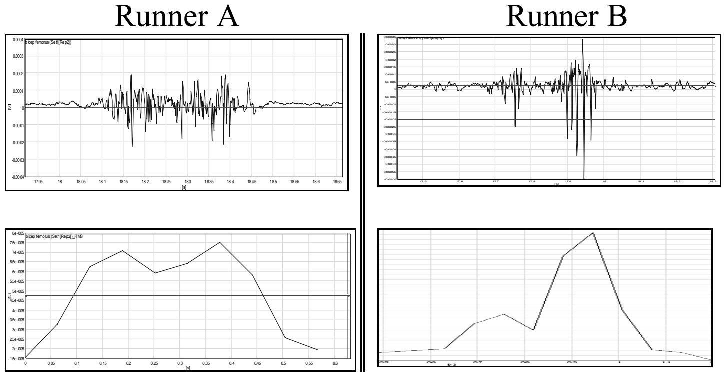


Figure 19. **Raw EMG signal and smoothed RMS graph (showing relative power) of Biceps femoris in two different runners**

The differences in muscle activity, shown in figure 19, were believed to be caused by the differences in the respective execution of the individual running motor program. Whether or not physical limitations may have affected these patterns, it is believed that the improvement (increasing) of the pre ground-contact peak muscle activity can benefit runners and is a worthy objective of future study.

Another factor overshadowing the relative timing of muscle activation may be found in interference by other muscles. Hamilton and Luttgens (2002) described two important motor behaviors; the first behavior is called *reciprocal inhibition*, which develops as familiarity with a specific movement or skill increases. The behavior is identified by the relaxing of opposing muscle groups to the agonist; this relaxation increases "…to the degree to which the agonists are activated" (p. 91). The second behavior, called coactivation, occurs when a movement or skill is accompanied by uncertainty; the behavior is identified by the stiffening of muscles around joints for protection. A study conducted by Busse, Wiles, and van Deursen (2006) suggested that "co-activation may be relevant to individuals with muscle weakness"; this would be associated with "uncertainty" and apprehension.

If running were to be assessed as a complex motor skill (with which some are either more familiar or have received more instruction than others), the occurrence of coactivation in hip joints, in response to the impending foot-strike (in the way a day-hiker might hop from boulder to boulder while crossing an unfamiliar stream), the coactivation of hip extensors, hip-flexors and stabilizers would likely inhibit angular displacement (reducing the progress of hip-extension) and cause what may appear to be "over striding." It is likely that such a situation might arise that would create a specific profile: runners who produced early onset of hamstring contraction but failed to effectively extend the hip joint by the time of foot-strike; this category of runner was observed in two cases in the women's data. The same category of runner would likely include men but it would only take one or two such occurrences in the small women's sample to overshadow the appearance of neural/kinematic relationships. The present study did not investigate antagonist muscles; however it would be a worthwhile research aim to determine the effect coactivation behavior, involving agonist and stabilizing muscle groups, has on neural/kinematic relationships.

During the course of this investigation it became apparent that the link between increased angle of foot-strike ("over striding") and increased relative ground contact times ("…slow on-and-off the running surface foot action" Hunt, 2004, p. 1) was compliant knee behavior (which absorbs shock according to Cavanagh, 1990). It was hypothesized that the likelihood of a smaller angle of foot-strike could be associated with the earlier hamstring activity (hip extension) during the running cycle. What became apparent during the present investigation was the problem of (forced) compliant knee behavior (for shock attenuation), associated with large foot-strike angle (a result of ineffective hip extension); this ought to lie in the crosshairs of researchers who are concerned with the prevention of anterior cruciate ligament (ACL) injuries. Simply, runners who exhibit a large angle of foot-strike have limited options for protecting the knee. There are some, like DeMont and Lephart (2004), who have looked at "preactivation" as possibly protecting the ACL; early (unimpeded) hip extension preceding ground-contact, however, is paramount for producing a condition for effective (protective) knee, hip and ankle preactivation to manifest that doesn't sacrifice kinematic efficiency.

Conclusions from Women's Results

Evidence supporting the existence of an association of hamstring muscle timing indices with kinematic components, HFS° and GS, was notably insignificant in the women's sample. More studies need to be undertaken to uncover the specific reasons for limited hamstring function in women and men. Further correlations (i.e. PIMMA and sub-groups) revealed no further explanations; they can be found in Appendix A.

The very high correlation between HFS° and GS illustrates that women's running performance may be more affected by the kinematic determinants than men; the accepted strength disparity between men and women may explain why a substantially lower correlation was shown in the men's sample. Muscle weakness in both men and women may compound poor running mechanics by way of muscle coactivation behavior, making it more difficult to learn a more efficient motor-behavior.

General Observations

In the way Kyrolainen, Belli & Komi (2001) described the importance of hamstring activation, "…unusually high braking and mediolateral forces, which may be caused by limited action of the hamstring muscles". Evidence was found among the male and female runners (in the correlation between HFS° and GS) that support this observation. The present study also confirmed the observations of Kyrolainen, Avela, and Komi (2005) of very high pre ground-contact EMG readings in hamstring muscles; there were cases (in the present study) of substantial pre ground-contact muscle activity exceeding the relative power and peak amplitude observed in the runner's maximum voluntary contraction (originally reported by Kyrolainen et al 2005).

The findings of Williams and Cavanagh (1987) of the strong relationship existing between shank angle and ground-contact times were confirmed in the present study by HFS° and GS in both men and women. It was also noted in randomly observed cases of runners who exhibited the same foot-strike patterns, that knee compliance played a significant role in this relationship, as described by Cavanagh (1990).

To address the question, posited in chapter one, on the behavior of muscles in efficient runners, the BF behavior of a "high caliber" runner (who had sub 4 minute mile capabilities) is shown in Figure 20.

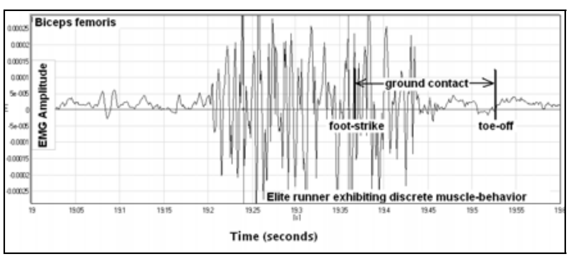


Figure 20. **Electromyogram of a "high caliber" runner (peak BF muscle activation occurring before foot-strike).**

Substantial pre contact BF activity accomplished the task of accelerating the foot in a backward direction prior to ground-contact; although it appeared that there was also substantial activity immediately upon and after ground-contact, the work-period of the muscle was completed well before the foot left the ground. This early termination of muscle contraction was likely an indication that the "rebound" of the runner's CM from downward to upward momentum was efficiently achieved by the effective preactivation of muscles surrounding the ankle, knee and hip, afforded by the proximity of the foot under the CM (i.e. HFS°) at the time of foot-strike.

The "…increased pre-contact EMG …subsequently increases tendomuscular stiffness" mentioned in (Kyrolainen et al., 2005, p. 1101). Effective preactivation, like other muscle functions that rely on a "chain" of neuromuscular events, is also accomplished through the functional stability of the core, according to Kibler, Press and Sciascia (2006).

Figure 21 shows the EMG signal of a runner exhibiting a large HFS° (i.e. > 15 degrees) and with a peak ST activation occurring after foot-strike; this was usually seen accompanied by long ground contact times and excessive vertical compliance (observed as knee and hip flexion during ground contact). Although GRF was not measured, the high vertical to horizontal ratios, ascribed to runners of "high caliber" by Paavolainen et al. (1999), was not likely in the case of the example in figure 21; excessive "braking forces," described by Kyrolainen et al. (2001), resulting from "limited" pre contact hamstring activity, would likely be measured, in this case.

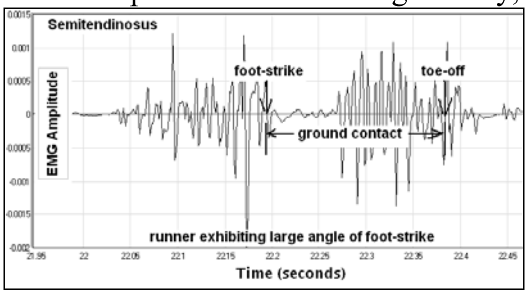


Figure 21. **Electromyogram of "lower caliber" runner.**

The temporary cessation of muscle activity which occurred immediately after foot-strike (figure 21) was also commonly accompanied by vertical compliance (observed as knee and hip flexion) and longer ground contact times. This behavior provides the benefit of shock attenuation but is costly in oxygen consumption, according to Cavanagh (1990). The high EMG activity during the latter part of the stance phase likely indicates acceleration to regain lost momentum caused by the deceleration occurring upon ground contact.

In the present study, there were four participants who exhibited evidence of what could be interpreted as learned neuromuscular motor patterns. Although this study did not investigate the early swing phase prior to ground contact, the prominence of hamstring EMG activity during the early mid-swing could not be ignored. Figure 21 shows substantial muscle activity (between the vertical cursors) occurring 180 degrees out of phase of peak activity during hip extension; video data verified this as BF initiated knee-flexion occurring during the early and mid-swing phases. An informal post data-collection interview with three of the four participants who displayed this behavior (the fourth participant was not available for an interview) revealed that all three had participated in football and had vivid recollection of extensive practice periods performing "butt-kick" drills; according to conventional football training methods it is commonly accepted that the purpose of butt-kicks in team sports is to develop plyometric skills for performing evasive running maneuvers. Emphasis is placed on establishing this behavior in all competitive tasks involving running.

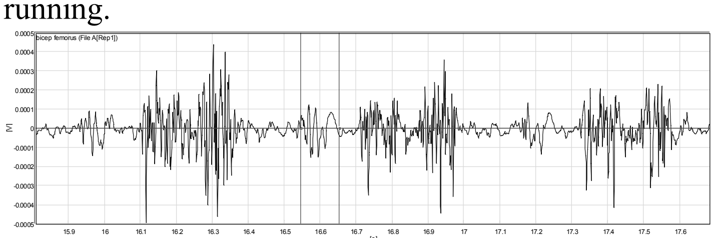


Figure 22. **Raw EMG signal of a male participant's Biceps femoris during running.**

A definite benefit from the butt-kick drill is that it potentiates the utilization of passive energy (some may say it helps reduce ground-contact times); however, not all distance running coaches agree that butt-kicks are the best way to promote high recovery leg swing which is believed to be what causes this potentiation to occur (as was cited by Hunt in chapter two). Nevertheless, this current observation does prompt the considering of how learned neural patterns may impact athletic performance later in life.

Conclusions

It was evident, especially in men, that neuromuscular timing is strongly linked to kinematic running efficiency. Research should be undertaken to link specific motor patterns to known efficient biomechanical behaviors. Running instruction methods should include drills and intervention techniques that generate the neural patterns which produce efficient mechanical behavior.

Research should also be directed to investigate gender specific needs in the designing of development level running skills; such objectives should be undertaken to improve specific strength assessment methods to take into account gender differences.

In training youth (8 years and older) general activities that involve running, jumping, skipping, and hopping are the best activities for promoting the acquisition of advanced running motor skills in youth, regardless of sex; children capable of performing these activities qualify to be trained in formative running neuromuscular patterning. Early formative neuromuscular behavior modification may likely permit the successful translation of important performance factors such as motivation, anaerobic muscle power development, and physiological development into higher physical performance capacities during the physical maturation process into adulthood.

The teaching of motor skills to mature youth and adults requires attention to factors that can affect motor behavior modification: A common obstacle occurring in training running behavior is what Magill (2001) calls *negative transfer*, which is the "…negative effect of a prior experience on the performance of a skill…" (p. 205). With respect to running, negative transfer can be seen in how Hunt (2004) described the dominant response of self-trained runners as "over striding" and long ground contact times; the "previous experience" could be qualified as *having had no running motor training, whatsoever.* Magill assures that the appearance of negative transfer during the process of skill training is only a "temporary" condition; through "practice" the *positive transfer* (benefits of having practiced a "new skill") of learning can occur.

Overcoming "poor" running mechanics requires temporary abandonment of self "interpretation" of proper running form; getting past the uncertainty which is experienced in learning new skills is something that requires a teacher or coach with a discerning eye. It is also important to recognize the importance of developing anaerobic strength in order to access the benefits that come from modifying motor behaviors. The awareness of limits goes beyond running science, alone, because it addresses the very boundary that distinguishes efficacy in physical and cognitive performance (acquired through instruction) from reactive ("uncertain") behaviors or dynamic "core" instability. The impact neuromuscular training methods can have on the psychological makeup of an individual is sufficient reason to address the undertaking of motor behavior modification with empirical insight coupled with deliberate resolve.

Finally, if significant attention is placed on teaching neural/kinematic efficiency in children, although awkward as it may be for some for a time, familiarity with the activity will eventually result in the exhibiting of a lesser degree of conflicting motor patterns (greater degree of muscular reciprocal inhibition) which yields smooth physical coordination.

APPENDIX A

Participant Classification Criteria

The participants were classified by *a*, *b*, or *c* group categories; the classifications were differentiated by weekly training mileage and past performances. Runners pertaining to category "a" trained a minimum of 30 miles per week and 50 miles per week for men and women, respectively. Mileages of the "b" category were 20 – 30 miles per week and 30 – 50, for women and men respectively. The "c" category runners were currently training less than 20 miles per week and 30 miles per week for women and men respectively. A Participant's past running performance was considered if an advanced performer had recent weekly mileage decreases due to reasons other than injury (e.g. a four minute miler on moratorium who was training at "b" level volume would likely be categorized in the "a" group).

Maximum 400 meter velocity (V_{400m}) Prediction Formula

A test of anaerobic limits (i.e. running speed) can be used as a predictor of aerobic long distance performance; a version of this methodology was published in (Hunt, 2003). The purpose of using the V_{400m} coefficient was to set a competitive target 5,000 – 10,000 meter pace that was achievable by every participant without causing unnatural strain. Target goal paces were based on a fraction of a maximum anaerobic performance pace; the target pace for the present study was based on the mean of the pool of participants' best 400m time (reported on the participant questionnaire) and using the prediction value (see Table I) associated with 5,000m and 10,000m distances. The actual pace run by the participants during the test varied somewhat from the men's and women's target pace (computed from this formula). The target test pace for men and women should not be confused with mean paces calculated from the test data used for trimming the general sample.

The following example demonstrates the process in determining the target test pace: The women's mean reported 400m time (from the questionnaire) was 64 seconds; Table VIII provides a coefficient (.75) for the simulated distance race pace.

(a). Mean $V_{400m} = \frac{400\text{m}}{64\text{s}} = \frac{6.25\text{m}}{\text{s}}$ (b). Target 5–10k pace = $\frac{6.25\text{m}}{\text{s}}(.75) = \frac{4.7\text{m}}{\text{s}}$

Table A-I

V_{400m} prediction coefficients for various race distances.

Distance:	400m	800m	1500m	3,000m	5,000m	10k & steeple
% V_{400m}	1.00	.91 – .92	.84 - .85	.77 - .78	.75 - .76	.74 – .75

Root Mean Squared (RMS) Formula

From (Delsys, 2005) (RMS) …is calculated using a moving window (set at 0 .125s with an overlap of .0625s). It is calculated for each window of data according to the equation:

$$\text{RMS} = \left\{ \frac{1}{S} \sum_{1}^{S} f^{2}(s) \right\}^{1/2}$$

S = window length

F(s) = data within the window

According to the equation, the RMS calculation consists of three steps:

1. Square of all values in the window
2. Determine the mean of resultant values
3. Take the square root of the result

Intrinsic Variable and GS Formulas

With the exception of HFS° all variables, INIT, PEAK, $\text{TERM}_{(\text{BF \& ST})}$ as well as GS are calculated from the d-line critical elements (Table A-II.) using the formulas in Table A-III.

Table A-II

Selected elements from a participant's d-line element set

test#	OFS	OTO	IFS	ITO	Onset BF	Peak BF	Term BF	Onset ST	Peak ST	Term ST
3	17.05	17.20	17.36	17.51	17.20	17.25	17.50	17.10	17.50	17.60

Note: All of the chronological values are in seconds.

Table A-III

EMG variable and ground-speed formulas

Intrinsic Variable (Same procedure for PEAK & TERM)	$\text{INIT}_{\text{BF}} = (\text{OnsetBF} - \text{OFS}) \div (\text{IFS} - \text{OFS})$ $= (17.20\text{s} - 17.05\text{s}) \div (17.36\text{s} - 17.05\text{s})$ $= 0.48$ (or 48% of time period of mid + late-swing phases)
PIMMA	$\text{PIMMA}_{\text{BF}} = \left[\left(\frac{\text{Onset} + \text{Peak} + \text{Term}}{3}\right) - \text{OFS}\right] \div (\text{IFS} - \text{OFS})$ $= \left[\left(\frac{17.20 + 17.25 + 17.50}{3}\right) - 17.05\right] \div (17.36 - 17.05)$ $= 0.86$ (86% of investigated stride)
Ground-speed	$\text{GS} = (\text{ITO} - \text{IFS}) \div (\text{IFS} - \text{OFS})$ $= (17.51\text{s} - 17.36\text{s}) \div (17.36\text{s} - 17.05\text{s})$ $= 0.48$ (or on the ground 48% of the time)

Height Adjusted Angle of Foot-strike (HFS°)

Shown in Figures A-1 and A-2, segment *d* is the linear displacement between the point of foot-strike of the investigated limb and the point directly below VSCM at the time of foot-strike. It is a directly related to FS° and runner SCM height. The segment is re-calculated for each individual running test; it determines the relationship between FS° and HFS° through the *sine function*; whereas "*d*" (segment of displacement forward of point on running surface beneath SCM) = the side opposite angle "θ" and r = the height of SCM (hypotenuse).

$sin\theta = d/\text{r}$ **:**

$d = sin\ \text{FS°(HSCM)}$ *and*

$$\text{HFS°} = arcsin\left(\frac{d}{\text{MHSCM}}\right)$$

substituting for *d*:

$$\text{HFS°} = arcsin\left(\frac{\text{HSCM}}{\text{MHSCM}}(sin\,\text{FS°})\right)$$

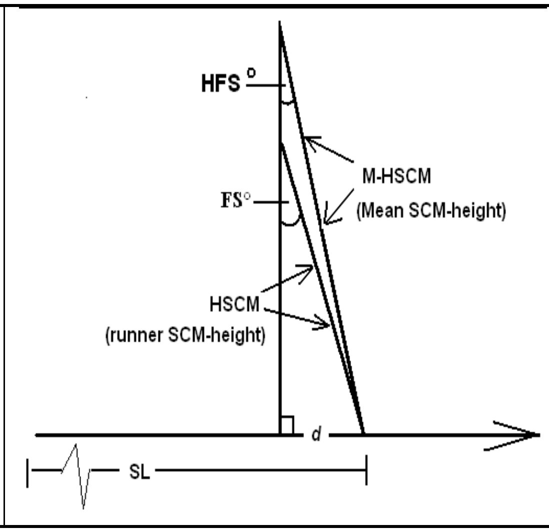


Figure A-1. **Height adjusted angle of foot-strike formula (and legend).**

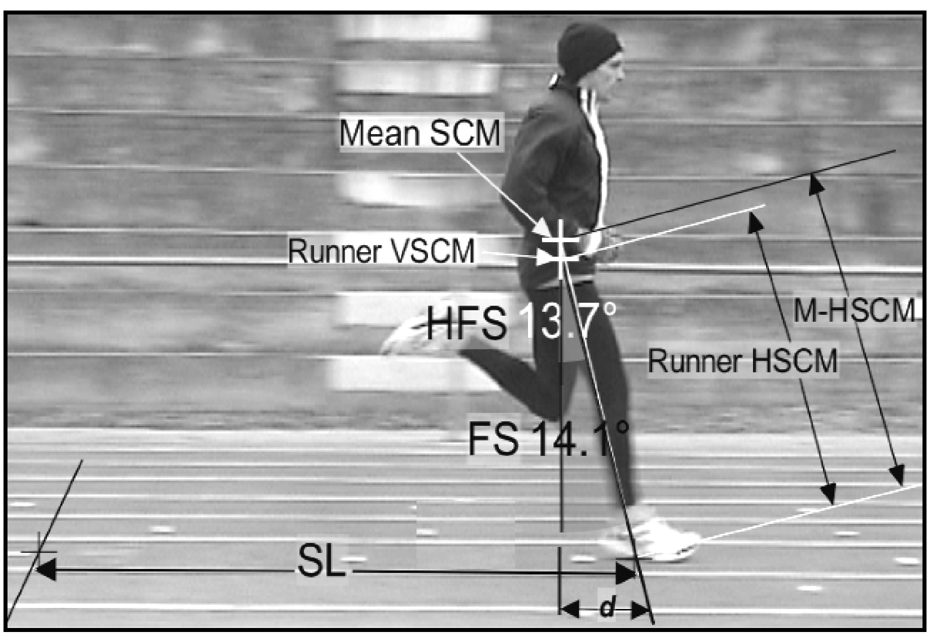


Figure A-2. ***Adjusted angle of a runner (shorter than the mean height)***

Table A-IV
Pearson correlation of PIMMA and extrinsic variables in women's Biceps femoris and Semitendinosus.

n = 8	$PIMMA_{BF}$		$PIMMA_{ST}$	
Statistics	*M* = 0 .94 : *SD* = 0.12		*M* = 0.90 : *SD* = 0.175	
	r	*P*	*r*	*p*
HFS°	.29	.483	- .03	.946
GS	.29	.489	- . 17	.692

(α < .05)

APPENDIX B

KRAM System Components

The Kinematic Running Assessment Method is a set of individual components that indicate specific biomechanical behaviors which have been shown to be associated with running efficiency. The system was generated from (a) common assessment practice (e.g. stride frequency), (b) various authorities in the track and field community including Olympic development programs individual distance running coaches, and (c) personal revelation gleaned from competition experience, training experience and coaching experience, and (d) meta-analysis.

The construction of the six-component kinematic running assessment method (KRAM) was predicated on idea that a diagnostic kinematic efficiency assessment tool can also be used as a formative assessment tool to improve running mechanical efficiency in adults as well as children as young as nine (Snowman and Biehler, 2003, explain that at the fourth grade level, children show evidence of increased fine motor control).

Three of the six components were used in the present study; these were stride frequency, angle of foot-strike and relative ground-contact time. Although the other three components, *recovery-leg swing height*, *knee-compliance* and *foot-strike pattern* were not evaluated in the present study, they can be extracted from the video data with sufficient reliability for performing pilot studies on the validity of this assessment method (the remaining components were also used in casual observations during the collection of data as well as during data analysis).

The components of this method are either measured by categorical qualification (e.g. foot above the knee vs. foot below the knee of recovery leg swing) or measured quantitatively in either degrees of freedom (e.g. degrees to the nearest tenth of a degree or decimal to nearest one-hundredth) or decimal fraction of a proportional value, as in GS. Because the present study enforced certain performance demands (i.e. controlled pace and stride frequency), “height-adjusted” angle of foot-strike was a necessary modification to the natural measurement of angle of foot-strike (which is abbreviated “FS” for KRAM purposes)

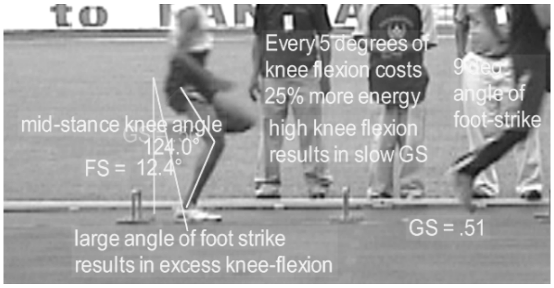


Figure B-1. **Sample video clip (Dartfish still image) from a 2007 formative-assessment running clinic in the Philippines (using mini-hurdles).**

The KRAM system was used in various clinics during the summer of 2007 held at Bacolod City and Cadiz City on Negros Island, Philippines (see figure B-1), The High Altitude Running Camp at Grouse Ridge in the Sierra Nevada Mountains, as well as the Simplot Track and Field Clinic at Idaho State University in Pocatello.

The measurement of these components in individual runners provides substantial information for assessing their competencies in relation to running efficiency. Table B-VIII shows the diagnostic assessment of male college cross country runners; these values were extracted from video analysis taken during a training run. This type of diagnostic analysis can be used for any age runner; formative, “in training” assessment would be recommended for ages eight years and older.

These components were also designed for use in research in athletics, as in the present study. Several considerations for use of KRAM for future studies include (a) effectiveness of neural modification intervention in athletes; this would measure the effectiveness of training methods for modifying motor-behavior in runners, (b) determining correlations of certain attractor running behaviors (combination of similar component values across a sample) and running performance indices (timed runs and physiological response), (c) special case studies involving runners who exhibit extreme forward lean from the hip, as well as other unique behaviors and (d) longitudinal studies; the American Association of Health, Physical Education and Dance (AAHPERD) has submitted a call to researchers who might provide empirical solutions to the dilemma facing our nation’s communities. An area of need is for evidence that shows “the relationship between physical competence (motor skills), learned in school physical education classes, and physical activity participation throughout the lifespan”. A longitudinal investigating of the association of physical skill acquisition and academic performance would also be a useful study in concert with the study conducted by the California Department of Education (2005) whichshowed a strong link between fitness and academic performance.

The KRAM components are identified and functionally defined in table B-I. Figure B-2 illustrates the categorical and quantitative data elements pertaining to the six KRAM components. Table B-II describes how quantitative data elements (taken from the examples in figure B-2) are used to compute the non-categorical component assessment values. Table B-III shows a KRAM assessment score for 12 different male college aged cross country runners.

Table B-I
KRAM components description and unit of measurement

Component	Abbreviation	Function / Description	Unit of measure
Angle of Foot-strike	FS	Hamstring performance and kinematic efficiency (Kibler, Press and Sciascia, 2006)	Degrees to the nearest tenth
Foot-strike Pattern	SP	Assessment of Passive energy potential and determinant of performance.(Williams, 1985)	Category: Heel-striker, Midfoot striker, and forefoot-striker.
Stride Frequency	SF	Neuromuscular control of Kinetic distribution and Calculation of Ground-speed (Slawinski and Ballat, 2002).	Revolutions (full right-left cycle) per minute (RPM)

Table B-I ***(continued)***

Component	Abbreviation	Function / Description	Unit of measure
Ground-speed	GS	Indicant of running efficiency (Hunt, 2004); associated with vertical compliance (Cavanagh, 1990) and ground-speed (Williams and Cavanagh, 1987, and current study).	Ground-contact time of both feet divided by one revolution.
Recovery-Leg Swing-Height	SX	Potential energy at foot-strike (Hunt, personal communication); affects foot-strike pattern (Scholten et al, 2002).	Category: Over the knee, at knee-height, below the knee.
Knee compliance	KC	Measurement of vertical compliance, indicant of efficiency and assessment of knee-stiffness (Cavanagh, 1990); affected by FS.	Knee-angle (in degrees) at foot-strike minus knee angle at mid-stance.

Figure B-2. **KRAM assessment elements**

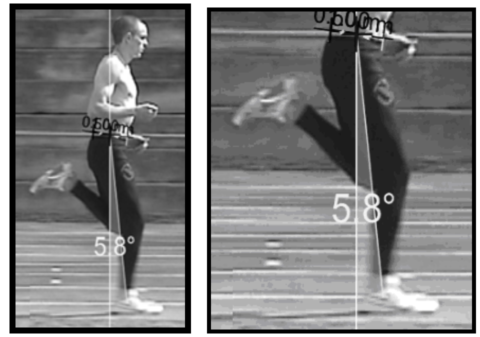
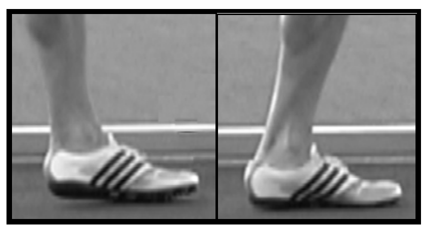
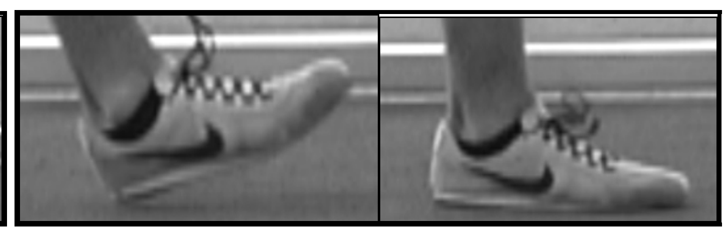
Component Name	Abbrev.	Assessment Element
Angle of foot-strike	**FS**	 Degrees to the nearest tenth
Foot-strike Pattern	**SP**	 *Midfoot-strike*  *Heel-strike*
Stride frequency	**SF**	 foot-strikes time / one stride (opposite limb) / One revolution

Figure B-2 **(continued)**

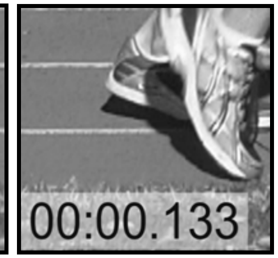
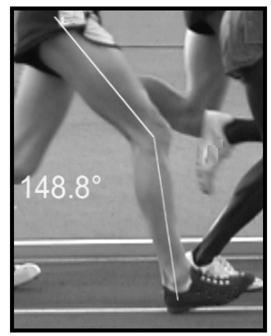
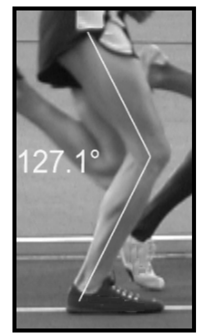
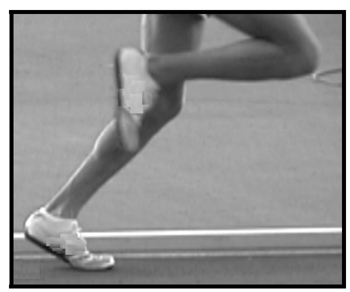
Component Name	**Abbrev.**	Assessment Element
Ground-speed	**GS**	 Pre ground-contact  Foot-strike (time)  Toe-off (time)
Knee compliance	**KC**	 Pre ground contact knee-angle  Mid-stance knee-angle
Recovery leg swing-height	**SX**	 Ankle: *above the knee*  Ankle: *below the knee*

Table B-II
Formulas for computing the quantitative KRAM component values

Angle of foot-strike	FS is assessed using video analysis tools; Dartfish Pro-Suite 4.08 was used in the sample shown in figure 26.
Stride frequency	$SF = \frac{\text{1rev}}{.667\text{s}}\left(\frac{60\text{s}}{1\,min.}\right) = 90$ rpm
Ground-speed	$GS = \frac{\text{ground} - \text{contact}}{\text{Stride}} = .\frac{.133\text{s}}{.333\text{s}} = .40$ or 40% of stride
Knee compliance	KC = (pre ground-contact knee angle) – (mid-stance knee angle) = 148.8° - 127.1° = 21.7°

Note. Sample stride frequency, ground-contact time, and knee angle element values were taken from figure 26.
1 stride = ½ revolution (one revolution is the period of time marked by two consecutive foot-strikes of the same foot).

Table B-III
Diagnostic KRAM Values observed in male distance runners

	SP[a]	SX[b]	FS[c]	KC[d]	SF[e]	GS[f]
John A	M	0	13	20	90	0.52
John B	RM	(+)	10	*25*	90	0.50
John C	RM	0	13	19	91	0.55
John D	RM	0	12	24	92	0.49
John E	M	0	9	16	95	0.47
John F	RM	0	13	20	90	0.60
John G	RM	0	10	*18*	88	0.58
John H	H	(+)	15	28	84	0.60
John I	M	0	8	19	84	0.51
John J	M	(+)	8	20	88	0.44
John K	M	(0-)	10	*24*	95	0.55
John L	H	0	10	22	90	0.60

Note. 1 Stride = ½ revolution
[a]SP: Foot-strike pattern: F = forefoot, M = midfoot, RM = rear midfoot, H = heel
[b]SX: Recovery leg swing height: (+) = above the knee, 0 = knee-height, (-) = below the knee
[c]FS: Angle of foot-strike
[d]KC: Knee-compliance: the number of degrees the knee collapses during the stance phase
[e]SF: Stride frequency: 60 seconds ÷ revolution period = revolutions per minute
[f]GS: Ground-speed: decimal fraction of stride of that foot is on the ground (e.g. 0.50 = 50%)

Appendix C

Consent to Voluntary Participation in Research

You have been asked to participate in a research study conducted by

Todd Nunan: BA in Physical Education.
449 S. 10th Ave.
Pocatello, ID 83201.
Phone: 530-277-5653.
Email: twnunan@yahoo.com

This project is approved by the Department of Physical Education at Idaho State University; information from this study will be used in a Masters Thesis.

You are being recruited as an able bodied and healthy representative of ISU Athletics. You should read the following information below, and ask questions about anything you do not understand before deciding whether or not to participate.

Purpose of the Study

Sport science research contributes to the advancement of athletic, educational, medical and public treatment of all manner of physical activity. The purpose of this study is to increase understanding of the neuromuscular aspects of running; results from studies in this area can bring more enjoyment of sport by increasing individual athletic success and reducing injuries resulting from applying less-than-optimal practice methods.

Procedures

If you choose to participate in this study you will be asked to engage in medium effort running and drill-exercises at ISU track at Davis Field. The testing session will take from 1-1½ hours. You will be asked to: (a) complete a questionnaire asking your age, height and recent running training history (you will be assigned to a running group consisting of no more than three runners), (b) come prepared in standard running shorts and t-shirt, (c) wear non-invasive muscle activation sensors over specific muscles while running (d) consent to being video taped while performing running tests and (E) to perform 8-16 short running intervals (60-100 meters) at less than full effort. You will have plenty of rest between intervals; this is not a test to measure maximum running performance.

Potential Risk or Discomfort

Testing sessions: The experiment will not include any activity that is considered outside of easy standard training activities commonly associated with distance running. If your regular weekly physical activity consists of less than 10 miles of running per week, the training sessions may be perceived as moderately strenuous. You will be required to only run the minimum number of intervals required to record acceptable data for each of the two sessions and you may withdraw from the session at any time.

Wearing of EMG measuring apparatus: Muscle EMG sensors will be applied to cleaned skin (with alcohol and finely abrasive pad) using medical tape. In case of excess hair on designated surfaces, you will be advised to shave the area in advance of the testing session in order to avoid discomfort during tape removal as well as to avoid a non-detection of muscle activity (you will be assessed for potential irritation to skin; you will also be asked if you have incurred any injuries or have pre-existing skin conditions which may limit your ability to wear EMG sensors). There may be slight discomfort in carrying the 2 lb. amplifier on the waist during running.

You may encounter a possible risk or discomfort that is not foreseeable by the investigators. It will be assumed, in accordance to ISU policy, every student participant either has personal or university provided medical insurance coverage, should an unforeseen injury occur.

Participant Benefits

You should not expect to directly benefit (either monetarily or otherwise) for having participated in this study. You have the right to refuse participation in this research study; this includes the right to withdraw from participation at any time.

Societal Benefits

Your participation in this research study will directly contribute to the body of knowledge of human neuromuscular physical behavior shared by professional and educational members of society.

Alternatives to Participation

Should you decide not to participate as a research subject in this investigation but would like to contribute in the process, your volunteered help in the following areas will be welcomed: (a) investigative recorder (help record written data of participants), (b) investigative technician (help conduct experiment procedure by assisting with technical equipment set-up and operation), (c) investigative assistant (help participant with determining [measuring] position of visible body marks for video detection, measuring and set-up of running apparatus, and timing) and (d) volunteering for any multiple combination of the above mentioned roles.

Emergencies

This research study will be conducted under the assumption all participants have medical coverage in the event of an emergency, whether or not the emergency is directly related to the research study. Participation in this study does not grant additional rights, nor does it require forfeiting any individual protections (public or private) guaranteed to all students.

Privacy and Confidentiality

All information, data and video footage gathered from the participant will be used only as a source to compile statistical data which will be reported in the study. In no way will it be possible to associate any findings reported in this study with any individual participant's identity or participant's data. All data collected will be stored by Idaho State University for a time required by law and policy of ISU and cannot be accessed without official ISU authorization (for verification and new research purposes).

Participation and Withdrawal

Your participation in this research is VOLUNTARY. If you choose not to participate, that will not affect your relationship with Idaho State University, or your right to receive services at Idaho State University to which you are otherwise entitled. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without prejudice to your future at Idaho State University.

Withdrawal of Participation by the Investigator

The investigator may withdraw you from participating in the research if circumstances arise which warrant doing so. If you experience any of the following: (a) adverse physical reaction to running activity, (b) inability to wear EMG measuring apparatus for any reason or (c) if you for any reason are unable to adhere to investigator's guidelines that are deemed to protect you from injury, you may have to drop out of the research, even if you would like to continue. The investigator, Todd Nunan, will make the decision and let you know if it is not possible for you to continue. The decision may be made either to protect your health and welfare, or because it is part of the research plan that people who develop certain conditions may not continue to participate.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have any questions regarding your rights as a research subject, you may contact the Human Subjects Committee office at 282- 3811 or by writing to the Human Subjects Committee at Idaho State University, Campus Box 8056.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I have read (or someone has read to me) the information provided above. I have been given an opportunity to ask questions, and all of my questions have been answered to my satisfaction. I have been given a copy of the informed consent form.

BY SIGNING THIS FORM, I WILLINGLY AGREE TO PARTICIPATE IN THE RESEARCH IT DESCRIBES.

Signature: ______________________________ Date: ______________

Witness: ______________________________ Date: ______________

Witness: ______________________________ Date: ______________

Consent to Be Photographed for Illustration Purposes

In addition to consenting to participate in the above research, I consent to having personal photographs taken during the running testing (which may or may not show facial profiles) to be used in the published draft of the thesis manuscript as illustrations. I also am aware that my name and personal information (including data generated by my participation in the study) will be omitted. Nevertheless, it may be possible to be identified by visual recognition. In consideration of the possible implications that may ensue from being associated with this study, I ________________________ fully consent to the use of video photographic material, which includes me within reasonable limits of the study as the subject content, to be used by the investigator for illustration purposes. By signing I willingly waive any legal rights, copyright or rights pertaining to the protection of privacy with regard to the photographs used in the study. I also realize that I will receive no monetary compensation for permitting the use of the photographs.

Signature: Date:

Witness: Date:

Witness: Date:

Department of Physical Education
Research Participant Questionnaire

Participant ID#: ____(leave blank)
Sex: ____
Age: ____
Height: ____'____"
Weight: ____lbs.

Average weekly mileage over last 30 days	mileage last week
____________miles	____________miles
best 400m time: _____minutes______seconds	best 800m time: _____minutes______seconds
best 1500m time: _____minutes______seconds	best 1600m time: _____minutes______seconds
best 3000m time: _____minutes______seconds	best 5k time: _____minutes______seconds
best 10k time: _____minutes______seconds	best (other):_________(specify) _____minutes______seconds

Have you had any injuries in the last 60 days?
Yes___ No___
If yes, Please describe:

Have you had any illnesses in the last 60 days?
Yes___ No___
If yes, Please describe:

Do you have any condition that may limit your participation in this study?
Yes___ No___
If yes, Please describe:

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