Bio-mechanical differences between male and female runners

BUILT TO RUN: BIOMECHANICAL DIFFERENCESBETWEEN MALE AND FEMALE MARATHON RUNNERS

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“ More than by brain size or tool-making ability,

the human species was set apart from its ancestors

by the ability to jog mile after lung-stabbing mile

with greater endurance than any other primate.”

INTRODUCTION

The introductory quotation (Hotz, 2004) simply, yet vividly, expresses the results of a recent study completed by two American scientists, Dennis Bramble and Daniel Lieberman, and released in the journal *Nature* (2004). Bramble and Lieberman contend that “ the ability to run long distances was the driving force shaping the modern human anatomy.” Hotz’s characterization of early humans as “ *marathon men and women* from the tips of their distinctively short toes and long Achilles tendons to the tops of their *biomechanically* balanced heads” (emphasis added) sets the backdrop for this essay—an exploration of the biomechanical differences between male and female marathon runners.

After a few additional historical comments, this essay opens with a presentation of anatomical differences between men and women with specific reference to running then continues with definitions and descriptions of the term marathon, as a form of organized running sport, and definitions for the term biomechanics in preparation for a discussion of how the field of biomechanics is applied to running. With this information as a foundation, the objective and scope will be articulated followed by presentation of previous methods and findings revealed from a search of the literature on the topic of biomechanical differences between male and female marathon runners and closely-related topics. These findings will be discussed and conclusions drawn. Finally, recommendations for further research will be presented.

To return briefly to the research findings of Bramble, a paleontologist and biomechanics expert, and Lieberman, a physical anthropologist, to continue setting the backdrop for the essay, Bramble states: “ Running made us human, at least in an anatomical sense. We think running is one of the most transforming events in human history” (Chui, 2004). Endurance running is an activity that is reserved for humans in the primate world and not common in other mammals with the exception of dogs, horses and a few others. Bramble and Lieberman contend that running permitted humans to scavenge and hunt for food over significant distances and that the high protein food they secured was instrumental in developing larger brains (Wilford, 2004).

To facilitate running, humans developed several traits including large buttocks with strong muscles which connect the femur to the trunk of the body preventing the body from “ over-balancing with each step.” In addition, “ humans have a lengthy arm-swinging stride” and “[l]ong ligaments and tendons—including the Achilles tendon—[which] serve as springs that store and release mechanical energy during running.” (Hotz, 2004).

Bramble’s reference to today’s running in the evolutionary context he and Lieberman established provides an appropriate introduction to the exploration of the biomechanical differences between male and female marathon runners (Wilford, 2004): “ Today, endurance running is primarily a form of exercise and recreation, but its roots may be as ancient as the origin of the human genus.”

Anatomical Differences between Men and Women with Specific Reference to Running

The description of anatomical differences between men and women, which is focused on anatomical features that are involved in running, begins with a gender-neutral discussion to establish a foundation for the more gender-specific information.

Rossi (2003) emphasizes the complexity of walking, a precursor to running. He writes that half of the 650 muscles and tendons in the human body are involved in what most people consider to be the simple act of walking. He suggests that, in the evolution of the human body, there were " hundreds of adaptations" that had to take place, adaptations that required " repositioning of everything in the body" over several million years. Rossi writes:

" The arms, no longer needed for branch swinging, became shorter, the legs longer, the pelvis wider, the shoulders narrower, the neck longer and more slender, the spine changed from C-shape to S-shape. Major changes were required in the hip, knee and ankle joints. Hundreds of muscles, tendons, ligaments and joints gradually shifted in position, size and function. And of course, the new posture and gait required important changes in the size and position of all the organs of the chest and abdomen."

Rossi suggests that some of these changes were extremely significant from a biomechanical perspective. For instance, he calls attention to the blood pumping requirement of the upright human form: Daily in each individual, approximately 74, 000 quarts of blood must travel through 100, 000 miles of blood vessels from the brain to the feet and legs in a circular pattern. Rossi emphasizes the human “ engineering” challenge that was required to design a system that would counteract the effects of gravity in moving blood vertically in this manner. Rossi’s comments are particularly important in the context of the current discourse because they provide some insight into the current state of relevant anatomical features of today’s runners and how those features were derived.

The anatomy of humans, unlike that of other living creatures, provides for speed and endurance. The unique characteristics related to running include (*Science in Africa* , 2005, citing University of Utah Public Relations, 2004):

- *Skull features* . These features, which include sweating from the scalp and face, cool the blood.
- *A balanced head.* This shape of head with a relatively flat face, small teeth, and short snout moves the center of the mass backward which helps to counter the effects of moving upward and downward during running.
- *A ligament running from the rear of the skill and neck downward to the thoracic vertebrae.* This feature serves as a shock absorber that aids the arms and shoulders in counterbalancing the head during running activity.
- *Shoulders “ decoupled” from the head and neck.* This feature allows rotation of the body while the head faces forward during running.

- *A tall body.* This feature, which includes a narrow trunk, waist and pelvis, provides for increased skin surface allowing for enhanced body cooling and permits the upper and lower body segments to move independently.
- *Short forearms.* This feature permits the upper body to act as a counterbalance to the lower body during running activity while reducing the muscle power required for maintaining flexed arms.
- *Large vertebrae and disks.* This feature permits the human back to accepted heavier loads when runners impact the ground.
- *Large, strong connection between the pelvis and the spine.* This feature supports more stability and shock absorbing capacity during running activity.
- *Large buttocks.* This feature, and the muscles that form it, stabilize the body during running activity. The connection of these muscles to the femur prevents the body from pitching forward.
- *Long legs.* This feature allows humans to take large strides during running activity. The tendons and ligaments permit the legs to be lighter and less muscular thereby requiring a smaller amount of energy to propel them while running.
- *Large hip, knee, and ankle joint surface areas.* These features provide enhanced shock absorption by reducing the impact in any one specific area.
- *Arrangement of bones in the foot.* This feature provides for a more rigid foot by creating a stable arch, allowing runners to push off in a

more efficient manner and to use ligaments located on the bottom of the feet as springs.

- *Large heel bone, short toes, and a big toe* . These features provide for enhanced shock absorption and increased capacity to push off during running activity.

With the running-related anatomical features applicable to all humans as a foundation, the focus now turns to the differences in anatomical features between men and women, specifically those features that are involved in running activity. Holschen (2004) writes that, until puberty, males and females are equal in terms of strength, aerobic power, heart size, and weight; they also have similar amounts of body fat.

Starting at puberty, according to Holschen (2004), male and female sex hormones begin affecting bone and lean body mass, circulation, and metabolism in different ways. A female typically has a wider pelvis, femoral anteversion (inward twisting of the femur), genu valgum (knees touch but ankles are separated), and external tibial torsion (feet do not line up in a straight manner because of out-toeing from outward rotation of the large calf bone). Center of gravity differences between men and women are minimal, correlating more by body type and height than with gender. (Atwater, 1985, cited in Holschen, 2004). When compared with males, females typically have smaller bones accompanied by smaller articular surfaces. They also have proportionately shorter legs with resulting decreased potential force in certain maneuvers. (Holschen, 2004).

At puberty, girls gain both fat and lean muscle mass due to the influence of female hormones; boys lose body fat and add muscle mass due to the influence of male hormones (Holschen, 2004). Women in adulthood have about ten percent more body fat than do their male counterparts (Greydanus, D. and Patel, D., 2002, cited in Holschen, 2004). The basal metabolic rate is approximately ten percent lower in women than in men. The presence of female hormones mandates that women rely more on fat metabolism at any given exercise level when compared to men. In addition, glycogen uptake, storage, and use are increased. (Holschen, 2004, citing Bonekat, H. W. et al., 1987; Dombovy, M. L. et al., 1987; Frankovich, R. J. and Lebrun, C. M., 2000; Nicklas, B. J. et al., 1989; Tarnopolsky, L. J., 1990) Cureton and associates (1988, cited in Holschen, 2004) attribute the differences in muscle strength between men and woman to skeletal and cardiac muscular hypertrophy and muscle mass percentage; they contend that muscle mass in men is forty percent compared to twenty-three percent in women.

Changes in body composition and circulatory capacity beginning at puberty result in approximately twenty percent higher cardio-respiratory capacity in men. Men also have comparatively higher oxygen-carrying capacity, larger heart and lung mass, a higher stroke volume, and higher maximal cardiac output which result in greater effectiveness in aerobic and anaerobic activities, although training can overcome the inherent differences (Williford, H. N. et al., 1993, cited in Holschen, 2004).

The results of the current research point to fundamental anatomical differences between men and woman, differences that largely begin to appear during puberty and which have some bearing on running capability.

Definition of the Term *Marathon* with Comparison to Other Types of Running

The term *running* can be defined as “[moving] swiftly on foot so that both feet leave the ground during each stride” (*American Heritage Dictionary of the English Language* , 2000). The research by Bramble and Lieberman (2004, cited in *Nature* , 2004), which was presented earlier, seems to indicate that running has been part of human existence since its beginnings and, in fact, contributed significantly to development of human life today. Humans no longer require running for survival, at least in their normal affairs; that is, typically, humans do not have to run from danger or run in pursuit of animals to kill for food. In modern times, running has taken on a new form—competition foot racing. This competition racing can be against oneself to achieve one’s own “ personal best” or with others. Racing against others can take many forms ranging from informal competitions between two young friends racing against one another on a playground to very formal competitions such as those in the quadrennial Olympics. The more formal running competitions are typically classified by the length of the run: 100, 200, 400, 800, 1500, 5000, and 10000 meters as well as marathons (Dollman, 2003).

There are many terms that refer to specific forms of foot racing: run, dash, sprint, relay, meet, competitive trial of speed, footrace, and marathon (*Webster’s New World Thesaurus* , 1997). Of these, the terms dash and sprint are typically used interchangeably to describe “ a short, fast run or race” (*Webster’s New World Dictionary* , 1988) or “ a short, swift movement” (*Webster’s New World Thesaurus* , 1997). Organized dashes and sprints are commonly of 50 meters, 100 meters, 200 meters, 50 yards, 100 yards, and 200 yards in length (*Webster’s New World Thesaurus* , 1997). Marathons are a form of *long-distance running* , which are on- and off-the-track competitions of more than 3000 meters (Hlus, 1997). Specifically, a *marathon* is “ a footrace of 42 kilometers, 195 meters (26 miles, 385 yards) run over an open course,” or “ any long-distance or endurance contest” People who compete in marathons are called *marathoners* (*Webster’s New World Dictionary* , 1998). Physiologically, there is a fundamental difference between a sprint or dash and a marathon. According to Pritchard (1994), “ A sprinter can exert maximum force throughout the run, but this is not possible for longer runs, where propulsive force must be reduced to match energy availability.”

Historically, marathons are not new events. According to legend, the name *marathon* is derived from the Greek city, Marathon, to commemorate Pheidippides’s run from that city to Athens to announce Greek victory over the Persians. The marathon was introduced to the Olympics in 1896 and today’s official distance was established in 1908. (Hlus, 1997; *The Columbia Encyclopedia* , 2005) Today, in addition to marathon races in the Olympics, many cities throughout the world serve as sites for annual or other periodic marathons (*The Columbia Encyclopedia* , 2005).

A new form of marathon race has recently taken form—the *ultramarathon* , which is “ any organized footrace extending beyond the standard marathon running distance of 42 kilometers, 195 meters…[they] typically begin at 50 kilometers and extend to enormous distances” (Blaikie, n. d.). Standard distances for ultramarathons are 50 and 100 kilometers and 50 and 100 miles (Meyers, 2002) with the longest certified race being the Sri Chinmoy, a 2092 kilometer race held annually in New York (Blaikie, n. d.).

Definition of the Term *Biomechanics*

The research produced numerous and varied definitions for the term *biomechanics* . The following are representative of the findings:

- “ The study of the mechanics of a living body, especially of the forces exerted by muscles and gravity on the skeletal structure.” (*The American Heritage Dictionary of the English Language* , 2000).
- [The] application of mechanical engineering principles and techniques in the field of medicine and surgery, studying natural structures to improve those produced by humans” (*The Hutchinson Encyclopedia* , 2003).
- “[A] science examining the forces acting upon and within a biological structure, and the effects produced by those forces” (The University of Calgary, n. d.).
- “[T]he science that deals with forces and their effects, applied to biological systems” (Freivalds, 2004).
- “[T]he application of the principles and techniques of mechanics to the human body in motion” (Snowden, 2001).

- “ Biomechanics is a specific field which evaluates the motion of a living organism…and the actions of forces on that organism…a combination of several different areas of study [including] anatomy and physiology, kinematics (the study of motion without regard to its causes), kinesiology (the study of human movement) and kinetics (the study of forces acting on a system)” (National Endurance & Sports Trainers Association, 2005).

In furnishing a definition for biomechanics, the Quintic Consultancy Ltd. (2005) provides some additional insight into the origin and details of the term, stating that the name “ is derived from the Greek *bios* meaning life and *mekhaniki* meaning mechanics,” adding that these individual terms are combined to mean “ the mechanics of life forms.” The biomechanics discipline includes research into various life forms including plants, insects, reptiles, birds, fish, humans, and others. Within the human specialty, topics include mechanics “ of bone, tooth, muscle, tendon, ligament, cartilage, skin, prostheses, blood flow, air flow, eye movement, joint movement [and] whole body movement” (The Quintic Consultancy Ltd., 2005).

Historically, according to Knudson (2003), the study of human biomechanics has alternated between emphasizing each of its two components—the biological and the mechanical. Atwater (1980, cited in Knudson, 2003) claims that, during the first half of the twentieth century, scholars emphasized medicine and anatomy under the term kinesiology. The distinct field of biomechanics was born from the work of biomechanists in the 1960s and 1970s. From that point the field began to emphasize mechanics over biology.

Today, the competing forces to move the discipline either toward a biological emphasis or toward a mechanical emphasis continue (Knudson, 2003).

Application of Biomechanics to Running with Reference to Marathon Runners

The field of biomechanics, already narrowed in a previous section from consideration of all life forms to only humans for the purpose of this essay, can be focused even further to a sub-field called *sports biomechanics* (The Quintic Consultancy Ltd., 2005):

“ Sports biomechanics uses the scientific methods of mechanics to study the effects of various forces on the sports performer. It is concerned, in particular, with the forces that act on the human neuromusculoskeletal system, velocities, accelerations, torque, momentum, and inertia. It also considers aspects of the behavior of sports implements, footwear and surfaces where these affect athletic performance or injury prevention. Sports biomechanics can be divided up into two sections: performance improvement [and] injury prevention.”

The Australian Sports Commission (n. d.) furnishes additional descriptive information on the application of biomechanics to sports, using a term the Commission calls *applied sports biomechanics* which “ incorporates techniques from physics, human anatomy, mathematics, computing and engineering to analyse technique to prevent injury and improve performance.” The Commission’s division of sports biomechanics into two categories—performance improvement and injury prevention—echoes the classifications offered by The Quintic Consultancy Ltd.

Williams (2003) describes how biomechanics can help runner performance, specifically that of the marathoner. Leading into his recommendations, he describes how marathon runners use a simple biomechanical strategy known as “ drafting off another runner” when running into the wind to reduce the adverse effects of air resistance and reduce oxygen consumption for the latter part of the race. He writes:

“ The goal of the sport biomechanist is to improve movement efficiency, mainly by maximizing propulsive forces and minimizing resistive forces, and thus provide the athlete with a mechanical edge. Using high-speed cinematography, the biomechanist can analyze a runner’s form and detect problems in running form that may be inefficient, such as overstriding, and that may waste energy. Although most elite and experienced marathoners have developed efficient running styles, even a small improvement in running efficiency may make a significant difference over the duration of a marathon.”

In addition to the strategy of “ drafting off another runner,” Williams offers several other “ biomechanical strategies” including selecting the proper sportswear (i. e. uniform and shoes) and optimizing body weight and composition.

Thus far the topics of anatomical differences between men and women with specific reference to running; definitions and descriptions of the terms marathon (as an organized, competitive form of running) and biomechanics; and the application of biomechanics to running have been presented and discussed. With this as a foundation, the focus of the discourse now turns to the topic of biomechanical differences between male and female marathon runners and closely-related topics.

OBJECTIVE AND SCOPE

The objective of this portion of the essay will be to explore the biomechanical differences between male and female marathon runners through a review and analysis of selected literature on the topic and related issues.

The scope of the literature review will include marathon running with specific reference to available information on the differences between males and females. Although running of shorter distances (e. g. sprints and dashes) and longer distances (e. g. ultramarathons) as well as other sports activities are excluded from the specific scope of this essay, references will be made to these activities when they related to marathon running. Performance improvement and injury prevention were mentioned as the two primary areas addressed by applied sports biomechanics. Gender-specific issues in each of these areas will be explored briefly as well.

REVIEW OF EXISTING RESEARCH ON METHODS AND FINDINGS

One researcher who has studied gender differences in endurance performance, including marathon running, is Stephen Seiler (1996) of The Institute for Sport, Agder College in Kristianstad, Norway. He writes: “ Some years ago it was proposed by some that women would actually perform better [than men] at ultra-endurance type activities. This theory has been disproved in the laboratory and in practice.” “ As long as women are women, I don’t think they will surpass men,” states Norway’s perennial marathon winner Grete Waitz (quoted in Holden, 2004). The anatomical differences between females and their male counterparts, specifically those that affect running, were presented in the introduction. Now an attempt will be made to show that the general anatomical differences between men and women extend to biomechanical differences that affect marathon running performance and injury.

Holschen (2004) writes that “[T]he female athlete remains less well understood and less well studied compared with male athletes, especially in the areas of performance factors, repetitive stress, and acute injuries.” She continues: “ Logical reasons for this include: (a) a limited two-generation span of the high-profile elite female; (b) fewer females involved in coaching, research, and sports medicine; and (c) limited areas of female youth sports historically (gymnastics, swimming, dance).” The reality of Holschen’s findings proved to be true in the current research activity. There were remarkably few available sources on the biomechanics involved in women’s marathon running. Most of the research either applied to males or did not identify the gender. Results from a review of selected research literature will be presented in this section beginning with gender-differentiated research results on running performance. Following this, results of research into the two applied sports biomechanics specialties will be presented with a focus on studies concerning footwear and injuries.

Holden (2004) writes about performance in running with special attention to female runners. She quotes physiologist Henrik Larsen of the Copenhagen Muscle Research Centre in explaining women’s marathon performance vis-à-vis men: “ Women had not developed long distance; that’s why the improvement is much greater on the marathon." Larsen, who seems to attribute the performance improvements of female marathoners to focused training instead of anatomic factors, claims that "[w]e don't see any higher oxidative capacity in women." Holden also offers comments by exercise physiologist Timothy Noakes of the University of Cape Town, South Africa who agrees with Larsen's assessment: " A smaller body frame gives women an edge on endurance…but men can run 10% faster even when the difference in body size is controlled for."

Stephen Seiler (1996), who was quoted at the start of this section stating that the proposal that women could perform better in ultra-endurance activities has been disproved, confirms that " there are some physiological differences between the sexes that impact performance in females independent of age." He notes that there is a ten percent difference in marathon times between men and women, adding that this difference is the same " across the distance running performance spectrum." He attributes this difference, not to a difference in training, but to physiological differences. He studied maximal oxygen consumption, the lactate threshold, and efficiency to analyze the differences between men and women as these factors might affect long-distance running performance:

- *Maximal Oxygen Consumption.* There is a 43 percent difference between men and women with men possessing a VO_2 max (oxygen-delivering capacity measure) of 3. 5 liters per minute and women with a capacity of 2. 0 liters per minute. Seiler attributes this in part to male size; men are larger. But, even when size is factored in, male oxygen consumption capacity is still fifteen to twenty percent higher. Males have a greater capacity to deliver oxygen to their muscles and organs.

- *The Lactate Threshold.* This is the point at which lactic acid begins to accumulate at higher than normal levels in the blood stream indicating an exercise intensity boundary at which the level of intensity can be maintained over a long period and that which will result in quick fatigue. Seiler does not believe that lactate thresholds are different for men and women as a percentage of their VO_2 max.
- *Efficiency.* After finding conflicting information comparing the efficiency of males and females—revealing that females are less efficient, more efficient, or the same as males in terms of efficiency—Seiler believes that differences in efficiency do not account for the differences in endurance performance.

Seiler concludes with his determination that the ten percent performance difference between men and women in endurance running can be attributed to the first of the three physiological factors he studied—maximal oxygen consumption.

Another researcher who explored gender differences in athletics, and especially in endurance events, is Dollman (2003). Citing Shepard (2000), Dollman writes that there is consistent evidence, based on observations, that males possess “ larger measures” of the following (quoted):

- *Heart volume* , even when corrected for stature.
- *Haematocrit* , which gives males a 13 percent greater oxygen-carrying capacity than females.

- *Plasma volume.*
- *Total muscle mass* , which means that females perform the same absolute task at a higher percentage of maximum voluntary contraction, with concomitant vascular impedance limiting cardiac ejection and peak cardiac output.

In addition, male skeletal muscles may have a higher succinate dehydrogenase (an integral membrane protein) concentration (Dollman, 2003, citing Costill, et al., 1987). Males may produce better mechanical efficiency during running (Dollman, 2003, citing Miura, 1997) although this is arguable as it may be rooted in cultural origins (Dollman, 2003, citing Shepard, 2000).

Now attention will turn briefly to a review of selected research into the two primary application areas addressed by applied sports biomechanics: running performance and injuries. Regarding performance, footwear will be discussed followed by a presentation of selected findings on research into injuries. Gender issues will be introduced.

Lipsky (2001, citing Hennig, 2001) presented research findings on gender-specific requirements for athletic footwear designed for running. The research experiment involved fifteen women and seventeen men of the same body weights, heights, and ages. Each subject wore the same shoe size and each tested five types of shoes which included three styles of men’s shoes and two styles for women. Using “ Kistler” force platforms at a set velocity, ground force reactions, tibial acceleration, angular foot motion, and plantar pressures at eight strategic locations on the foot were measured.

Accordin