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THE INFLUENCE OF KARATE TRAINING
ON POSTURAL STABILITY

A Thesis in
Kinesiology
by
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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science
December 2012
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ABSTRACT

This paper explores two issues of importance for fall prevention programs. First, do relatively short 15-week postural stability enhancement programs produce meaningful improvements as measured by center of pressure (COP) metrics? Secondly, does a 15-week training program in Karate produce better results than a Strength Training program? Individual program evaluations, and between program comparisons, are based on pre- and post-training COP metrics.

Injuries incurred from falls are a major public health concern. In the U.S., falls are the leading cause of injury across all ages. The morbidity and mortality rates increase dramatically for the segment of the population over the age of 65. Researchers have thus investigated various forms of exercise for their potential to improve postural stability. One fall prevention strategy that has received much attention recently is the use of the ancient martial art of T’ai Chi to improve balance. While T’ai Chi has been shown to improve static balance, it may not be effective in reducing the risk of falls in more dynamic tasks such as recovering from tripping over an obstacle while one is walking, or when one experiences sudden perturbations, such as being jostled in a crowd.

In contrast, other martial arts, such as Karate, incorporate training in both stationary and dynamic postures. In addition, Karate emphasizes the maintenance of balance against perturbations. It is hypothesized that
improvements in balance can best be obtained through an exercise program, such as Karate, that incorporates both static and dynamic training, as well as practice in postural responses to perturbations. The purpose of this study is to examine the difference in postural characteristics between Karate students and a control group after a relatively brief 15-week physical training session. It is hypothesized that the Karate students will show more improvement in balance as their training progresses compared to the control group. To test this hypothesis, anthropometric measures were obtained from two groups of subjects: Karate students and a control group consisting of students engaged in strength training.

Before training, there were no statistically significant differences between the two groups in their body segment inertial parameters. Postural stability tests were performed at both the beginning and the end of a relatively brief 15-week training period. During these tests, data on the movement of the center of pressure was obtained using a force plate while subjects performed balancing tasks; both with and without perturbation. Analysis of this data indicates that there were only a limited number of statistically significant differences between the pre- and post-training center of pressure motion for the two groups. These differences did not show any trends in the metrics which were different from the pre- and post-training values. In summary, there were no statistically significant changes in the center of pressure motion for either the Strength Training group or the Karate Training group as a consequence of training for a period of 15 weeks. The
conclusion of this study is that brief training periods will have no appreciable
effect on improving postural stability. Future research on fall prevention
programs should focus on the development of programs of longer duration.
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ACKNOWLEDGEMENTS

First and foremost, I am indebted to my thesis advisor Professor John H. Challis for his guidance, encouragement, and patience. As a true Sensei, he has helped me translate my innate sense of proper technique, learned through many years of training, into a more concrete form. Thus, he has greatly contributed to the search for the principles and biomechanics that form the basis of Karate-Do. In recognition of his contributions, the Okinawan Karate Masters have awarded him the Kenpo Gokui (Fist Way Higher Knowledge) certification.

I am also grateful to Professor William E. Buckley and Professor R. Scott Kretchmar who have served as sources of inspiration throughout my time at Penn State. Without knowing it, they have both motivated me to explore the connections between biomechanics, physiology, and the philosophy and history of sport. However, I could not have even begun this study without the initial opportunity, which Professor Karl M. Newell provided.

I am forever indebted to my Karate Senseis, as they have passed on to me the knowledge that they gained through a lifetime of study. Throughout my years of Karate training, I have been especially fortunate in only having true Masters as my teachers. I would not have learned true Karate without the selfless assistance of two U.S. Marines: Stuart A. Dorow and Carol A. Liskai. They were dedicated to fulfilling their promise to “a little old man in Okinawa” to pass on the
knowledge of the “Way”. Since that time, I have been assisted along the “Way” by my other Senseis: Grand Master Kichiro Shimabuku, Grand Master Angi Uezu, and Master Tsuyoshi Uechi.

I also owe a debt of gratitude to Sensei Vance McLaughlin and Sensei Chet Cinamella. They have helped me translate the principles of an ancient art into effective training methods for modern law enforcement and military warriors. This bridging of the old and the new gave me the impetus to examine the biomechanics of effective technique and control of posture as they apply to maintenance of balance, defensive tactics, and marksmanship.

I am indebted to Sensei Paul J. Cote, Professor, Georgetown University, for his assistance in exploring T’ai Chi and the other Internal Arts. Paul also assisted greatly through his comments on the draft of this manuscript.

I extend a special thanks to Coach Michael J. Morse for serving as a role model of a teacher and mentor. He continues to demonstrate how to apply the philosophy and practice of sport and fitness to everyday life. Coach Morse also assisted in this research by his excellent training and recruitment of the subjects for the strength training group.
Sensei Matthew T. G. Pain, Senior Lecturer, Sports Biomechanics Department, Loughborough University, provided invaluable assistance through his guidance and comments on the draft of this manuscript. Matt also served as a role model of how to pursue a degree and still maintain a strict training regimen.

Special recognition and thanks goes to Adam Crebs who spent many night and weekend hours assisting me in obtaining the subject’s anthropometric measurements and force plate data, and in assuring the safety of the subjects during testing.

However, the greatest impact on this research is the sharing of knowledge with my fellow Black Belts over the more than 40 years that I have been on this path. Each of these Black Belts has spent more than 20 years on this same path with me: Professor Paul J. Cote, Joseph M. Kurata, Gregory B. Sutton, Regan “Sig” Williams, Denny Nau, Donald L. McCandless, Ralph H. Miller, Carl E. Clark II, James W. Miller, Dr. Dayton G. Sauerman, Jonathan A. Marmon, J. Mark Sapia, Professor Ira D. Sasowsky, Dr. Que Dang, John L. Smith, Captain Frederick A. Wasser, Jr., Robert A. Cook, Nicole Little, Jonathan R. Green, David K. Groff, and Joseph E. Trocchio.

I would also like to thank my fellow Penn State Karate Black Belts and the Penn State Karate Club members for their continued encouragement and insights.
Sensei Jaeson B. Koszarsky, Sensei Jennifer G. Koszarsky, and Sensei David Willey served as invaluable assistants in coaching the Penn State Karate subjects. Sensei John David (JD) Swanson, the Penn State Shotokan Karate Instructor, was instrumental in the recruitment of the Shotokan Karate students.

Of course without subjects, I could not have completed this research. The Penn State Exercise and Sport Activity Karate students, and the Kinesiology Strength Training students, were especially helpful, as they first volunteered to be subjects, and then fulfilled their commitment by continuing to train and to complete the study. I continue to learn from my students.

To my family and friends, you create a stable base from which I draw strength. You have kept me focused on what is important in life.

I especially draw strength from my love, Que. She has also shown by example, that with perseverance one can produce a good thesis, using a broken-down typewriter, while sitting on the floor in a poor and lonely grad student's apartment, surrounded by nothing but stacks of books and papers.
CHAPTER 1

INTRODUCTION: THE WAY

Footprints on the sands of time

Many millions of years ago, mankind’s ancestors began the long journey down the evolutionary path toward upright posture and locomotion. Along this path or “way”, many physical and behavioral adaptations were necessary to not only rise to a standing position but then to maintain postural stability once there. Modern humans are still looking for the best strategies for maintaining balance. In order to know the direction to take on the path ahead, it is important to know as much as we can about our past journey. The method of the ancient Martial Arts is often referred to as Dō (道, The Way). This denotes an actual footpath, a correct method, or a philosophy of doing and being. “The Way” is symbolized by a path along which we must travel. The challenge is to choose the correct way to proceed when faced with alternative paths. Modern science is now looking back at the path that hominids took during the evolution of bipedalism. It is hoped that this will provide insights into the mechanisms that underlie upright posture and movement. Science is also exploring the “Way” of the ancient Martial Arts in order to develop effective programs for rehabilitation and fall prevention.
1.1 A Bipedal Disadvantage

Humans have gained various advantages by adopting a bipedal gait. The primary advantages are increased movement efficiency, and the freeing of the hands for tool use and resource carrying. These advantages, coupled with a parallel expansion of language skills, resulted in the growth and spread of human populations and the development of culture. However, these advantages have come at a cost. Raising the center of gravity, and decreasing the support base, have increased the risk of falling. Falls account for one out of every five injuries, one-third of hospitalizations, and one-fifth of all non-hospitalized injuries (CDC 2005). The overall rate of non-fatal falls for which medical attention is required is 43 per 1,000 population. These rates increase with age for adults beginning with age 18. The age group 18 to 44 years has the lowest rate of medically consulted falls at 26 per 1,000; persons aged 75 and above have the highest rate at 115 per 1,000 (CDC 2012b).

In an effort to decrease this risk, much recent research is focused on understanding the mechanisms of postural control. This paper explores the problem of maintaining postural control in various environments, the body’s response to postural perturbations, and the potential of training programs for improving balance. Currently, various training and rehabilitation programs are being evaluated for use in fall reduction programs; among these are strength training and disciplines such as T’ai Chi. However, many of these programs are
of short duration. For example, studies conducted under the National Institutes of Health, Frailty and Injuries: Cooperative Studies on Intervention Techniques (FICSIT) trials, propose using 15-week T’ai Chi programs for fall prevention (Wolf, Barnhart et al. 1996). While T’ai Chi does help reduce the rate of falls while standing still, many falls occur during movement, and as the result of perturbations. Thus, a training program involving more dynamic movements and changes in posture may have a greater effect.

1.2 Purpose and Outline of Paper

This research paper will evaluate these two questions. Is a 15-week program long enough to show meaningful improvements in posture control? Does a discipline such as Karate provide better outcomes than Strength Training over a relatively short 15-week training period?

In this first chapter, we will explore the history and importance of bipedal posture and gait. Chapter 2 will look at how a Way, or lifestyle, of fitness and skill development can influence postural stability. The concepts of physical and philosophical balance will be discussed in Chapter 3. We will also gain an appreciation for the development and evolution of philosophical concepts to the point where they are considered to be “Laws”. Chapter 4 will review the history of the science of biomechanics and how it can be used to examine postural characteristics. Chapter 5 is a review of the pertinent literature regarding the risk
of falls in modern society and research on the current methods of fall prevention. 
In Chapter 6, we find a description of the methods used in this research study to 
examine postural stability in two groups of subjects: Strength Training and 
Karate. Chapter 7 presents the results of the processing of the subject’s data 
and Chapter 8 discusses the implications this study has for the use of Karate 
training in future fall prevention programs. Throughout this paper when Chinese 
names are mentioned in the text, they are written as family name first followed by 
the given name. Exceptions are made in the bibliography if the sources give an 
alternate listing. Also, Chinese names and terms are written in both Wade-Giles 
and Pinyin Romanization depending on how they appear in the sources used for 
the citations.

1.3 The Human Path

Unique among living hominoids, man is an obligate biped; meaning that there is 
no reasonable alternative for posture and locomotion other than to habitually 
stand and walk on two legs. In order to understand the origins and mechanisms 
of this uniquely human characteristic, one must look at evidence from both living 
and fossil hominoid bipeds. One must also understand man’s relationship to the 
other hominoids. All great and lesser apes and their close fossil relatives belong 
to the superfamily Hominoidea (hominoids). This superfamily consists of two 
families, Hylobatidae and Hominidae. Hylobatidae, the lesser apes, contains the
gibbons and siamangs. The family Hominidae (hominids), the great apes, consists of two subfamilies:

- Subfamily Ponginae contains the genus *Pongo* (pongines), the orangutans.
- Subfamily Homininae (hominines) contains three tribes:
  - Tribe Panini contains the genus *Pan* (panins), the chimpanzee and bonobo.
  - Tribe Gorillini contains the genus *Gorilla* (gorillins), the gorilla.
  - Tribe Hominini contains the genus *Homo* (hominins). Modern humans are the only extant member of this tribe.

Although originally based on morphological and fossil evidence, the above classifications can now be verified by DNA analysis. A species genome is a record of the sum total of double-stranded DNA within the nucleus of a fertilized embryo. This DNA is duplicated within every cell of the body. With the recent sequencing of a bonobo genome (Prufer, Munch et al. 2012), the genomes of all of the great apes have now been obtained. This DNA analysis has revealed that our closest relative is the chimpanzee, followed closely by the bonobo.

Comparison of the human and chimpanzee genomes indicates that we share 99% of our genes with the chimpanzee (Waterston 2005). When insertions and deletions are included, the genome-wide nucleotide difference between the two species is about 4% (Varki and Nelson 2007). This implies that we share 96% of our genes with the chimpanzee. Therefore, based on molecular, genetic, and anatomical evidence, of all extant species the closest relative to modern humans is the chimpanzee (*Pan troglodytes*). This is also true based on hominin fossil
evidence. The fossils of *Ardipithecus ramidus*, a stem hominin from 4.4 million years ago, indicate that it was a terrestrial biped with substantial arboreal adaptations. *Ardipithecus* possessed many of the same traits as present day chimpanzees. Thus, chimpanzees serve as a model for understanding early hominin behavior and ecology (Stanford 2012). The similarities and differences between humans and chimpanzees provide insight into hominin bipedal evolution.

Although small, there is something truly special about this 4% difference. It is remarkable that such a small genetic difference can produce such a dramatic phenotypic difference in traits such as brain size, cognition, communication, posture, and locomotion. The evolutionary changes that produced this difference must be especially important. Also within this 4% lie the functionally important genetic changes that produce the phenotypic differences such as bipedalism. When an alteration in gene function produces an increase in fitness, positive selection acts on the gene. Genomic comparison greatly assists in determining the functionally important alterations and the time when they first appeared within the hominin clade (lineage).

### 1.4 Human Accelerated Regions

Prior to the discovery of DNA, the study of fossil remains (paleontology) was the only means to determine a timeframe for species evolution. The idea of a
“molecular clock” emerged after biochemists discovered that molecular changes in DNA accrue at a steady rate (Zuckerkandl and Pauling 1965). Comparisons of rates of molecular evolution in the genomic regions of different species, coupled with the fossil record, have provided increased accuracy for the divergence dates between hominoid species. Studies on the rate of change of mitochondrial DNA sequences indicate that the divergence date for the *Homo* and *Pan* lineages is between 6.1 and 8.7 million years ago (Ma) (Hasegawa, Thorne et al. 2003). In the time since the last common ancestor (LCA) of *Homo* and *Pan*, mutational forces have changed the genomes of these two lineages. The changes in the *Homo* genome have produced the uniquely human traits of an enlarged brain, complex language, and obligate bipedal locomotion. By comparing the accumulated genetic differences between the *Homo* and *Pan* genomes, we can gain insights into the evolutionary forces that have influenced these changes. We can also improve our understanding of the molecular basis behind unique human traits such a large brain, language, and bipedality.

Positive selection during hominin evolution has produced accelerated changes in specific regions of the human genome, which caused significant and rapid phenotypic changes. Positive selection for these regions occurred sometime since divergence from the LCA of humans and chimps. There are 202 of these human accelerated regions (HARS), with 49 of these regions being highly significant (Pollard, Salama et al. 2006). Somewhere within the HARS may lay the source of the development and control of the uniquely human traits such as
bipedalism. Comparison of the human genome with that of the chimpanzee produces insights into the genetic changes that produced these phenotypic differences in the hominin lineage. For example, during hominin evolution, the brain underwent unusual expansion and development after the divergence of the \textit{Homo} and \textit{Pan} lineages. The earliest hominin, \textit{Sahelanthropus tchadensis}, appeared about 7 Ma and had an endocranial capacity of 350 cm$^3$ compared to modern \textit{Homo sapiens} with 1330 cm$^3$ (Conroy and Smith 2007). Hominin brain volume had increased only slightly to about 384 cm$^3$ by the time of \textit{Australopithecus afarensis} around 3.6 Ma. However, since the time of \textit{Australopithecus}, hominin absolute brain volume has tripled and the size of the brain in relation to body size has more than doubled (McHenry 1994).

Although studies are far from complete, through comparison with the chimpanzee genome, specific human genes have been identified that may have contributed to the unique traits of the human phenotype. Four of these genes are suspected of playing key roles in the regulation of human brain size: microcephalin (MCPH1), CDK5RAP2 (MCHPH3), ASPM (MCPH5), and CENPJ (MCPH6) (Evans, Vallender et al. 2006). When defective, they result in the human syndrome of primary microcephaly (small head and brain) producing a 70% reduction in brain size. These genes exhibit evidence of recent accelerated protein sequence evolution in primates. This accelerated evolution is most prominent within the panin and hominin lineages. There is compelling evidence that two of these
genes, microcephalin and ASPM, have been positively selected for in the hominin lineage (Zhang 2003).

An upright posture affords increased opportunities to interact with the environment and thus it provides a tremendous survival advantage. However, in comparison to a quadruped, the upright bipedal posture of the hominins causes the center of mass to be raised and the support base to be reduced. Maintenance of balance is further complicated due to the increase in degrees of freedom, and a loss of passive stability against inertial moments, such as head and trunk rotations, and arm movements, especially when handling objects. In order to resolve these problems the hominins were required to develop a more complex nervous system (Sekulic, Podgorac et al. 2012). Shortly after our LCA there were dramatic and rapid changes in the hominin neocortex and pyramidal systems.

About one-fourth of the HARs are associated with genes that control neurodevelopment. Recent research has identified accelerated evolution within the human lineage of these genes (Dorus, Vallender et al. 2004). HAR1, the most accelerated region of all, is associated with an RNA gene (HAR1F) which is expressed during neocortical development in the human embryo. The neocortex is the outer layer of the cerebral hemispheres which is very highly developed in humans. This region has many sulci (deep grooves) or folds that greatly increase surface area without greatly increasing brain volume. It is associated
with higher cognitive functions such as conscious thought, complex language, spatial-temporal reasoning, social and emotional processing, sensory perception, and motor commands. The pyramidal tracts conduct impulses from the brain to the spinal cord to control voluntary movements such as precise control of the fingers.

By comparing the human and chimpanzee genomes, we can identify the segments of human DNA that have undergone the most change. Among the DNA regions that have changed the most are those associated with neurodevelopment. It has been shown that significant divergence has occurred in brain size and neurodevelopment since our LCA with the chimpanzee. Genomic comparison provides a valuable tool in our attempt to understand the evolution of uniquely human characteristics such as bipedalism.

Likewise, the genes responsible for the human trait of complex language are being sought. Studies of individuals with an inherited speech production disorder led to the isolation of the gene FOXP2; often called the “language gene”. This gene plays a major role in speech articulation and in linguistic and grammatical processing. Mutations in this gene cause severe speech and language disorders (MacDermot, Bonora et al. 2005). The only difference between the human and chimpanzee genes is that the human FOXP2 gene has two amino acid changes in a functional part of the molecule. The FOXP2 rate of protein sequence evolution in the Hominin lineage increased more than 60-fold since divergence of
the *Homo* and *Pan* lineages (Zhang, Webb et al. 2002). Analysis of this gene suggests that it was positively selected for during hominin evolution and then became fixed in the human population within the past 200,000 years (Enard, Przeworski et al. 2002).

The time when the human variant of the FOXP2 allele became fixed in the human population establishes the beginning of complex language development. In turn, the unique human trait of language is essential to the development of human culture. Thus, it is likely that effective language skills developed immediately preceding the great expansion in human populations, the development of culture, and the subsequent appearance of modern humans. Accelerated evolution of the HARS controlling brain size and complexity, and nervous system development, allowed for the development of bipedalism in hominins. Increased movement efficiency, coupled with language skills, resulted in the growth and spread of human populations. Understanding the molecular basis of HARS, and thus hominin bipedalism, will open up new avenues for research in postural stability and fall prevention programs.

### 1.5 Primate Bipedalism

Besides birds, humans are the only extant species who are obligate bipeds when walking or running, meaning that humans have no reasonable alternative. Humans however are not the only species that use bipedal posture or
locomotion. The ability to stand upright on the hind limbs has many advantages for any animal. Many quadrupeds temporarily assume an upright stationary stance while reaching for food, or when visually searching for resources or predators, and for maintaining group integrity. In addition, some primates use bipedal walking for short periods (facultative bipedalism) especially while carrying food (Figure 1.1). In general though, frequent use of bipedalism is very rare in primates and is found in only three families:

- Hylobatidae or lesser apes: gibbons and siamangs.
- Hominidae or great apes: chimpanzees, bonobos, gorillas, orangutans, and humans.
- Indriidae: the lemurs.
Figure 1.1: Examples of Primate Bipedalism
Figure 1.1: Image Sources and Notes
Note: All examples are of wild animals behaving naturally.

A) Young chimpanzee practices two skills simultaneously: bipedal walking and manipulation of a stick as a tool. During play young primates mimic familiar adult actions and thus develop behavioral and locomotor skills. (Jolly 1985)

B) Sifaka lemur demonstrating its unique bipedal loping gait which it uses to quickly and efficiently travel over open ground between patchy resources. (Attenborough 2002)

C) Adult male chimpanzee walking bipedally while carrying three papayas, one in each hand and one in the mouth, during crop-raiding. Papayas are a scarce and highly valued food resource. Bipedal transport is often used in such situations especially when there is increased competition from other chimpanzees. (Carvalho, Biro et al. 2012)

D) Bonobos walking bipedally while carrying pieces of sugar cane, a limited and high value food resource. The female on the right is walking bipedally while carrying both food and an infant. By using an upright posture, she is also able to more effectively scan the environment for resources or threats. (Lanting and Linden 1992)

E) Adult female gorilla wading bipedally using a branch in her right hand, as both a walking stick for balance, and to test either the depth of the water, or the substrate stability. (Breuer, Ndoundou-Hockemba et al. 2005)

F) Female chimpanzee wading bipedally while simultaneously holding and nursing an infant. She still has one arm free to assist in balance, or to use for foraging. (Attenborough 2002)

Primates are the only mammals who use striding bipedalism; that is the alternating footsteps are half a cycle out of phase with each other. Humans are the only primates that exhibit full striding bipedalism which involves full extension of the hip and knee joints. Nonhuman primates use a form of bipedalism in which the hip and knee joints are flexed. Whether striding, running, or just standing, humans are the only primate species that are obligate bipeds. For the
other primates, bipedalism is a secondary form of posture and locomotion. The primary mode of locomotion for the lesser apes is arboreal brachiation; they swing from limb to limb using only their arms. However, when moving on large horizontal branches, or when on the ground, they frequently move bipedally. Within the great apes, the genus *Pan* (chimpanzee and bonobo), the Genus *Pongo* (orangutans), and the genus *Gorilla*, primarily use quadrupedal knuckle-walking. The great apes do not normally brachiate with the exception of the orangutans. The lemurs primarily use a form of arboreal locomotion called vertical clinging and leaping (VCL). All the other non-human primate species can sit upright and all have some limited bipedal ability. Many, such as baboons, macaques, spider monkeys, and capuchins will at times use a bipedal gait for brief periods when carrying objects, especially food.

Of particular interest is the unique bipedal locomotion pattern of the lemur family the Indriidae, which comprises three genera with 19 species. Indriids move arboreally through vertical clinging and leaping. Since the Indriidae lemurs have extremely long legs and short arms, they cannot move quadrupedally when on the ground. They stand erect and are forced to use a bipedal hopping gait. In particular, the members of the genus *Propithecus*, the Sifaka lemurs, use a very unique mode of bipedal locomotion. Arboreally, Sifaka cling to trees in a vertical posture using both hands and feet to grip the tree trunks. They propel themselves through the trees by using their powerful hind legs to leap from tree to tree. Sifaka start in a vertical position on a tree trunk, push off sideways with
their legs, and then twist in mid-air to land feet first on the next tree. When on the ground a Sifaka lemur walks bipedally at slow speeds. However, when it wants to cover long distances quickly, it uses a graceful bipedal sideways bounding gait with the arms held out at chest height for balance. Thus, it conserves energy by taking advantage of its VCL specializations. Referred to as a bipedal lope, canter, or gallop, the use of this mode of bipedalism, as a preferred mode of terrestrial locomotion, was unique to Propithecus. Until recently, this type of loping gait was not observed in any other primate. As discussed later in this chapter, in the near future a similar gait will be seen more frequently as man ventures into new environments.

1.6 Advantages of Bipedalism

There are several theories as to how and why hominins developed fully functional bipedalism. This trait began to appear at a time when the hominin environment was shifting from forested areas to an open savannah where resources were distributed in widely spaced patches. These environmental shifts initiated a hominin response of increased bipedal behavior. It is unclear though as to which selective pressures led to the adoption of a fully bipedal posture. Present theories focus on the benefits derived from bipedal posture and gait which include improved: sight and vigilance, ability to carry, tool use, foraging efficiency, thermoregulation, postural threat display, and locomotion. The most obvious advantage of raising the head higher is that it improves the ability to
hear, to smell, and to visually search the environment. Freeing of the arms and hands from involvement in locomotion allows for the carrying of food, tools, and infants. This greatly increases the efficiency of transporting any object. Also, freed from a major role in locomotion, the hands could be better used for more effective tool use. The photographs in Figure 1.1 above show wild primates demonstrating many of these advantages of bipedalism.

A major impetus driving the development of bipedal locomotion was an increase in foraging efficiency. The energy cost of foraging is reduced through more efficient locomotion between widespread patches of resources, and the ability to carry both food and tools. A study of wild chimpanzees indicates that when presented with highly valued but scarce food resources, the frequency of bipedal transport increases fourfold. This occurred especially in situations of increased competition from other chimpanzees. They not only carry more food, they also simultaneously carry more objects for use in food processing; such as rocks for cracking nuts (Figure 1.2). This ability has energetic advantages. Compared with quadrupedal transport, the chimpanzees carried more than twice as many objects by using a bipedal gait (Carvalho, Biro et al. 2012). Thus early hominins would have decreased energy expenditure and increased energy intake by assuming an upright posture and gait.
Figure 1.2: Chimpanzee Carrying Food and Tools

A) Adult male chimpanzee simultaneously carries highly valued nuts in right hand and mouth, a hammer stone in left hand, and an anvil stone held in left foot for use in cracking the nuts.

B) After moving away from competing chimpanzees he sits down to process and consume the nuts.

Source: (Carvalho, Biro et al. 2012)

It is most likely that such energetics played a dominant role in the evolution of the hominin posture and gait. Most of the energy expended during movement is due to the muscle force needed to support body weight. Hominin bipedal locomotion is more energy efficient relative to the more ape-like last common ancestor. Biomechanical advantages of hominin bipedal gait can be determined by comparison with the chimpanzee kinematics and muscle activation levels during bipedal movements. It is readily seen that joint angle and ground contact time
greatly affect locomotor efficiency. Compared to the chimpanzee bipedal gait, humans activate less muscle volume per unit of ground force, and with each step, the foot stays in contact with the ground for a longer time.

There are two main reasons for the observed differences in energy expenditure. First, the crouched, bent hip and flexed knee, posture of the chimpanzee positions their center of mass in front of the hip joint which increases the moment arm of the ground reaction force (GRF). This causes chimpanzees to use a larger amount of muscle per unit of ground force for both the hip extensor muscles and the muscles at the knee. By adopting an upright posture, hominins orient the GRF vector closer to the knee and hip joints which both reduces muscle exertion and confines large moments to the ankle joint. Second, chimpanzees have shorter legs. For a given walking speed, a shorter leg results in a shorter ground contact time for each step. Shorter contact time provides less time to produce an impulse, as a result the peak forces must be higher. Thus, the shorter hind legs of a chimpanzee require it to generate greater GRF impulses per step, and at a faster rate than a human, which increases energy expenditure. Because of these differences, human bipedal walking takes approximately 75% less energy than both quadrupedal and bipedal walking in chimpanzees (Sockol, Raichlen et al. 2007).

Another important factor which contributes to the benefits of a bipedal gait is that there is a higher energy recovery compared to that of the crouched ape-like
posture. In human erect bipedal walking, much of the increased efficiency is due to conservation of energy. Energy fluctuations occur between kinetic and potential energies, with these fluctuations being largely out-of-phase. Due to the extension of the hip and leg during bipedal walking, the body center of mass rises to a peak height at mid stride as the body moves over the weight bearing leg. The kinetic energy is then transformed into potential energy. This potential energy can then be used to assist in moving the body forward. Thus the out of phase nature of erect bipedal locomotion allows energy transformation resulting in a conservation of total energy. In human bipedal walking, the highest energy recovery occurs at a pace midpoint between slow and fast walking.

In the more ape-like bipedal gait, the bent hip and bent knee posture, the energy fluctuations are in-phase so that the energy transformation between kinetic and potential energy is minimized (Wang, Crompton et al. 2003). If early hominins transitioned through a bent knee gait on their way to a fully erect position, the other benefits of bipedalism added together must have counterbalanced the energy demands of the bent knee gait. A more efficient mode of movement reduces the cost of foraging, of maintaining group integrity, and of avoiding dangers; which affords a greater survival advantage. By evolving habitual upright bipedal posture and locomotion, hominins gained increased efficiency in walking and running long distances. Bipedalism also frees the arms and hands for foraging, transporting of food and other resources, infant carrying, using tools
and throwing for defense and hunting. These advantages assured that bipedalism was selected for at a very early point in hominin evolution.

It is believed that the first preadaptations for hominin bipedalism arose more than 20.6 Ma during the early Miocene. The fossil scapula, vertebrae, and femurs of the extinct hominoid *Morotopithecus bishopi* indicate that it displayed significant vertical climbing and suspension behavior. The scapula indicates that *Morotopithecus* possessed substantial forelimb mobility, which facilitated its forelimb dominated climbing and suspension. This marks the earliest record of such behaviors in hominoids (MaClatchy 2004). The lumbar vertebrae display features that are present in extant hominoids including a stiff lumbar region, which allows for a stable lower back and an upright posture. The femoral shaft thickness also indicates a significantly higher axial loading than is seen even in most extant primates. The orthograde (vertical torso orientation) adaptations of *Morotopithecus* provide the earliest evidence of the modern hominoid body plan. This orthograde trunk position is a prerequisite for bipedal stance and locomotion. Thus, *Morotopithecus* provides the earliest evidence of the evolution of the locomotor characteristics and upright posture of the hominoids (MaClatchy, Gebo et al. 2000).

This orthograde posture, an ability to abduct the arm above the shoulder, and forelimb dominated suspension and locomotion behavior, have tremendous adaptive significance. These traits are linked to advantages in foraging for the
main hominoid food resource, ripe fruit, which is most often found on highly flexible terminal branches at the periphery of trees. Use of the forelimbs for suspension also allows for facultative bipedalism, as the hands can assist in balancing while standing on branches. Vertical trunk position, suspension, extended hip and knee positions, and hand-assisted bipedality facilitate mobility, and increased speed of movement, through the three-dimensional space of a tree canopy. The energy efficiency of movement between trees is also improved. Suspension also allows for an increase in body size, which in turn improves both foraging energetics and predator deterrence. A stable environment coupled with large body size reduces both adult and infant mortality. It also allows for a prolonged maturation period and a lower reproductive rate. An increase in longevity promotes learning and allows for the development of complex social interactions. Increased body size would continue to favor the evolution of the suspensory and orthograde behaviors of the early hominoids. Thus, natural selection in hominoids would favor vertical torso and extended hip and knee positions. These traits would have preadapted early hominins for the acquisition of habitual terrestrial bipedalism.

1.7 The First Obligate Hominin Biped

Footprints leading the Way

Bipedalism is a defining trait of the hominins. The hominin clade (lineage) includes all species that are more closely related to modern humans than to
other species. This clade consists of modern humans and their fossil relatives, with the only extant member being *Homo sapiens*. The earliest hominin fossils are attributed to *Sahelanthropus tchadensis* and are dated to the late Miocene epoch, about 7 Ma (Brunet, Guy et al. 2005). This evidence consists of a nearly complete cranium, a mandible, and several teeth. The morphology of the cranium demonstrates several features shared with later hominins including a relatively vertical face and an anteriorly positioned foramen magnum which suggest that this hominin was an upright biped (Zollikofer, Ponce de Leon et al. 2005).

The earliest postcranial hominin fossils are assigned to *Orrorin tugenensis* and dated to about 6 Ma. Orrorin means “original man” in the Tugen language spoken by the natives in the area of Kenya where the fossils were discovered. The name is fitting, as it may well have been the first truly bipedal hominin. The morphology of the fossilized femora indicates that these hominins possessed the distinctive hip biomechanics necessary for bipedal stance and locomotion (Richmond and Jungers 2008). *Orrorin* was a habitual biped when on the ground and it may even have been an obligate biped (Senut, Pickford et al. 2001). These fossils provide evidence that the earliest hominins were bipedal and that this trait evolved almost immediately after the divergence of the *Homo* and *Pan* lineages about 7.4 Ma. Thus, bipedalism appeared much earlier than most other hominin traits and involved a very rapid and complex evolution of morphology.
Despite the early emergence of a bipedal posture in the hominin lineage there was no direct evidence of this until a trackway of fossilized footprints was discovered. The footprints were discovered at Laetoli, Tanzania and represent the earliest direct evidence of hominin bipedalism (Raichlen, Gordon et al. 2010). The footprints were found in a layer of ancient volcanic ash and have been dated to 3.66 Ma. They are believed to be that of *Australopithecus afarensis*. The track of prints was made by at least two individuals. One set of these tracks at the southern end of the trackway is especially well preserved which allows for detailed analysis of the prints (Figure 1.3 A). Analysis of the footprints indicate that the foot of the printmaker possessed most of the functional features of the modern human foot, indicating that it had an efficient upright posture and was fully bipedal (Crompton, Pataky et al. 2012). This proves that hominins developed a bipedal gait long before the expansion of human brain size or stone tool making. In addition to demonstrating that these hominins were obligate bipeds, the tracks provide insights into aspects of cooperative behavior and learning of early hominins.

It is believed by some that the tracks were made by three individuals walking together across a barren and desolate landscape of wet ash; possibly a family unit composed of an adult male, female, and an adolescent. They were walking in step and so closely together that they were most likely holding onto each other; which would assist the group in traversing the wet muddy ground. The smallest individual was following behind the adult male and carefully placing
each foot in the adult’s footprint. Towards the end of the northern section of the track the female’s prints indicate that she paused, half turned, and looked back before continuing on (Leakey 1981). Other interpretations of the tracks conclude that the third set of tracks were made sometime after the first two. Whatever the timing, this demonstrates that the following individual carefully placed their feet in the prints of another. This demonstrates an important aspect of hominin learning: following the one who has gone before.

The Laetoli footprint evidence indicates that by 3.66 Ma hominins had developed an efficient, fully upright posture, and bipedal gait. This adaptation permitted the free use of the hands for tasks which improved the hominins survival advantage. Several million years after the Laetoli tracks were made, hominids left similar trails of footprints on another barren and desolate landscape (Figure 1.3 B). The advantages gained from a bipedal posture had culminated in mankind setting foot on another world; leading the way for others to follow. Several million years from now these footprints in the sands of time will still be visible for others to ponder. Hopefully they will provide encouragement for others to continue the journey:

Lives of great men all remind us
We can make our lives sublime,
And, departing, leave behind us
Footprints on the sands of time;

Footprints, that perhaps another,
Sailing o’er life’s solemn main,
A forlorn and shipwrecked brother,
Seeing, shall take heart again. (Longfellow 1886)
Figure 1.3: Footprints on the Sands of Time

A) 3.66 million year old Hominin footprints discovered in Laetoli, Tanzania. (Leakey 1981).

B) Footprints of Apollo astronauts on the lunar surface (NASA 1972).
1.8 Cultural Influences on Posture

Cultures throughout the world, and over all time periods, have felt the need to leave their mark for others to see; for someone to know that they had once been there. It is interesting to note that primitive peoples universally chose to leave symbols of the three defining features of hominins. These three commonly recurring symbols are upright human figures, handprints, and footprints; all of which have profound and widespread cultural symbolism. Of special interest for this paper are the representations of footprints, and of figures in various postures: standing, running, fighting, and dancing. These figures can be interpreted as symbols of philosophical concepts, historical events, and practical knowledge. Many times, images are intended to simultaneously convey all three. In any case, it is clear that the artists wanted others to ponder, and to learn from, the symbols.

1.8.1 Symbols of Man

Depictions and symbols of human posture and movement all help to document instances of both change and stability within a culture; sometimes leaving a record of a cultural tradition that extends thousands of years into the past (Figures 1.4 and 1.5).
Figure 1.4: Ancient Symbols of Man: Hand, Foot, and Bipedal Posture
Figure 1.4: Image Sources and Notes

A) 40,000-10,000 BP: Sculpture, Paleolithic footprints in mud floor, carefully and intentionally created. Niaux Cave, France. (AHDVRC 2012i) These footprints were deliberately made by two young children, most likely as part of a ritual.

B) 32,000-30,000 BP: Painting, Panel of Handprints. Chauvet Cave, France. (AHDVRC 2012f) Handprints often symbolize the transfer of spiritual and physical potency.

C) At least 35,000 BP: Sculpture, Female figurine carved from mammoth ivory. Hohle Fels Cave, Germany. (Conard 2009) This is the earliest example of figurative art worldwide.

D) 24,000-17,000 BP: Rock art painting, Footprint. King Edward River, Kimberly Region, North West Australia. (BradshawFND 2012a) The earliest confirmed painted rock dates to 28,000 BP. Used ochre crayons indicated that the Australian tradition of painting with pigments dated to at least 50,000 BP (Bruno, Barker et al. 2012).

E) 24,000-17,000 BP: Rock art painting, Older Bradshaw Painting with Hand. Kimberly Region, North West Australia. (BradshawFND 2012c)

F) 24,000-17,000 BP: Rock art painting, Gwion-Gwion Figures. Kimberly Region, North West Australia. (O'Connell 2012)

G) 12,000-5,000 BP: Petroglyph of Hands. Kunlun Shan Mountains, Xinjiang China. (Chen 2011)

H) 2,500-1,800 BP: Rock Art Painting, Dancing figures. Mountain of the Pictures, Hua Shan, Zuojiang River Valley, Guangxi, China. (Chen 2011) The figures are the Maling (Frog God) in the “frog dance posture”. The frog is the totem of the local tribal group, the Zuang. Every year the Zuang hold an ancient Maling Festival and imitate the frog’s movements in dance. This is another example of how rock art figures can help document posture and movement, and transmit cultural practices over thousands of years.

I) 5,000-3,000 BP: Petroglyphs, Figures. Sarmish Gorge, Sarmishsay, Republic of Uzbekistan (Rozwadoski 2012). This rock art tradition dates back to 17,000 BP (UNESCO 2008). Over 10,000 petroglyphs are located in Sarmish Gorge, making it the largest petroglyph site in Central Asia. This rock art depicts cultural traditions that still exist in this region. This collection of petroglyphs offers another example of ancient art serving as a means to document movement and posture, and to transmit cultural practices over long periods of time.
Figure 1.5: Ancient Symbols of Man Continued: Hand, Foot, and Bipedal Posture
Figure 1.5: Image Sources and Notes

A) 3,000-300 BP: Petroglyph of 6-toed human foot. Twyfelfontein Valley, Namibia, Africa. (Ouzman 2012) This site contains over 5,000 images. Bushman (San) hunter-gatherer rock art is the oldest African artistic tradition dating to at least 25,000 BP. This tradition continued until about 100 years ago. The images at this site are dominated by human footprints and animal tracks which simultaneously represent identity and journey. The paintings in this area depict dances that are still practiced today by the San. Thus, this rock art has transmitted posture and movement knowledge over many thousands of years.

B) 6,000 BP: Bushman rock painting, Handprints. Elands Bay Cave, Western Cape Province, South Africa. (ARTstor 2012c) The handprints are the size of 10 to 13 year old children suggesting that the prints were part of an initiation ceremony. If so, this suggests that the rock art helped to document and promote the ritual for thousands of years. It is interesting to note that other entirely separate cultures practiced similar rituals. In Europe, Upper Paleolithic cave art containing handprints and footprint indicates that adolescents were often present during rituals (Owens and Hayden 1997). On the other side of the World, at Cueva de las Manos in Argentina, the local culture was practicing a similar ritual around 9,000 BP (BradshawFND 2012b). Present day adolescent aborigines of Australia still practice a similar ritual (Manhire 1998). This is another example of how ancient art can serve to document and transmit cultural practices such as ritual, posture, and movement.

C) 10,000-300 BP: Painting, Black Figures. San Bushmen, South Africa. (BradshawFND 2012e) This image can be interpreted as four individuals closely following each other or as one individual performing a series of moves; ending by balancing on one leg. Thus it could serve as a very early form of movement annotation.

D) 150 AD-1400 AD: Petroglyph, Two Footprints. Jornada Mogollon Culture, Three Rivers Petroglyph Site, New Mexico. (ARTstor 2012k) A series of footprints in succession can serve to document an actual direction to travel, markers for foot placement in skill development, or a symbolic “Way”.

E) 1054 AD: Petroglyphs of 1054 Supernova. Anasazi Culture. Pueblo Bonito Petroglyphs, Chaco Culture National Historical Park, Chaco Canyon, New Mexico. (ARTstor 2012d) Chaco Canyon was a center for Anasazi astronomy. The public buildings are constructed according to astronomical alignments.

F) 850-1250 AD: Petroglyph of figure with large hands. Anasazi culture. Chaco Culture National Historical Park, Petroglyph Trail, Chaco Canyon, New Mexico. (AHDVRC 2012b) Chaco Canyon was the Anasazi hub for trade, ceremony, and administration. All buildings were associated with specific petroglyphs. As a
cultural center, all of the Chacoan people would have been exposed to, and influenced by, the symbolism of the local rock art. The Anasazi used this rock art to document clan symbols, ceremonies, and migration events.

G) 12,000-9,000 BP: Sculpture, Footprints carved in stone. Abrigo do Sol (Shelter of the Sun), Brazil. (von Puttkamer 1979)

H) 9,000 BP: Stencil, Hand Painting Panel. Cueva de las Manos (Cave of the Hands), Argentina. (BradshawFND 2012b) The majority of the handprints are the size of a 13-year-old boy’s, indicating that this practice was most likely part of an initiation ceremony.

I) 12,000-9,000 BP: Petroglyph, Lapa do Santo Rock Shelter, Brazil. (Neves, Araujo et al. 2012) This anthropomorphic figure is the oldest reliably dated figurative petroglyph in the New World. It was most likely linked to a fertility ritual.

1.8.2 Symbols of The Way

The symbolism behind the depictions in cave paintings and petroglyphs is open to interpretation, and this may have been the artist's intention. An outline of a hand can simply be a notice that the individual had been there. It is also an easy way to create a realistic image without having to master the skill of drawing. It can also be a signature of approval of the surrounding scene; indicating that this is the proper method, or that this is the animal to hunt. It is interesting to note that all cultures, over all time periods, have chosen to use the open hand symbolism. This could be simply because the open hand has a more aesthetically pleasing form than a closed fist; however the open hand is also a universal sign that one has friendly intentions. This tradition can be seen in the earliest forms of the martial arts and has continued to this day in Karate Do (空手道), the Empty Hand Way.
Ancient images and petroglyphs of footprints frequently occur, and at times are in a line; indicating perhaps that this is the correct path (Figure 1.6). In some instances, these can be interpreted literally as the correct direction to follow, as when they occur on a horizontal surface; or they may symbolize an historical event, a sequence of foot positions to imitate, or a correct path through life. This “correct path” symbolism has persisted to this day and is present in many philosophical systems, such as Buddhism and the martial arts. Inherent in these systems is the concept of balance, both physical and philosophical; which is obtained by following “The Way”. In Buddhism the “right path” is referred to as The Noble Eightfold Path which will lead one to enlightenment; and insight into the true nature of phenomena. This path is described in the collection of the Buddha’s teachings known as the Pali Canon:

\[
\text{And what is that ancient path, that ancient road, traveled by the Rightly Self-awakened Ones of former times? Just this noble eightfold path: right view, right aspiration, right speech, right action, right livelihood, right effort, right mindfulness, right concentration.} \\
\text{(Bhikkhu 2012)}
\]

Within Karate, the Way has been passed down from master to student for many generations through a collection of precepts known as Kenpo Gokui or “Fist Way Higher Knowledge”. The Way is expressed in eight aphorisms such as:

\[
\text{A person’s Heart is the same as Heaven and Earth.} \\
\text{The eye must see all sides.} \\
\text{(Dorow and Liskai 1969)}
\]

Thus, by following The Way, one can maintain balance and obtain true knowledge, but only if one can sense the hidden harmonies of the Universe.
Figure 1.6: Symbols of The Way: Footprint Trails
Figure 1.6: Image Sources and Notes

A) 900-1400 AD: Petroglyph, Footprint Trail. Culture: Jornada Mogollon. Three Rivers Petroglyph Site, New Mexico. (BradshawFND 2012d)

B) 10,000 BP to present: Rock Painting, Footprint Trail. Culture: Australian Aborigines, Amata. Musgrave Ranges, South Australia. (ARTstor 2012i) This rock art tradition continues to this day as the Aborigines of this area frequently visit these sites and repaint the images in order to preserve the tradition (Layton 1992). Australian rock art commonly depicts footprints of both men and animals. Tracks (Guruwari) are a central philosophical concept, allowing the Aborigines to “follow” the ancestors just as they can follow animal tracks. Ancient cultures often used perishable medium when creating symbols, and thus rock art was often a subsidiary form of representation. An example of this is that the most frequently used form of representation in this area of Australia is the drawing of images in the sand, sometimes supplemented with charcoal, plant material, clay, and blood. These sand drawings are frequently used when instructing young initiates in sacred myths and cultural traditions.

C) 2,500-1,100 BP: Birthing Rock Petroglyph, Footprint Trail. Culture: Ancestral Puebloan. Kane Creek Road, Moab, Utah. (ARTstor 2012a)


E) 2,200-1,600 BP: Sculpture in marble, Buddhapada (Footprints of the Buddha). Culture: Indian. Andhra Pradesh, Amaravati, India. (ARTstor 2012b) Footprints are commonly used to symbolize Buddhism. Often depicted within each footprint is an eight-spoked Dharma Wheel which symbolizes the Wheel of Truth/Law. The eight spokes refer to the Nobel Eightfold Path which is believed to lead to self-awakening and insight into the true nature of phenomena.

F) 3,800-2,500 BP: Petroglyph of Footprints. Culture: Scandinavian. Stjordal, Trondelag County, Norway. (Haug 2011) This is an example of a type of Bronze Age rock art known as South Scandinavian Agricultural Carving. A total of eleven footprint petroglyphs were found at this site during the excavation of a burial mound. Several other petroglyphs of footprints with toes were found nearby along with two images of boats. There are several other sites in Norway and Sweden where petroglyphs, particularly footprints, are associated with Bronze Age burials.

G) 400 A.D.: Sculpture in rock. Carved footprint in stone at Dunadd Fort. Culture: Gaelic. Dunadd Hill Fort, Kilmartin Glen, Argyll, Scotland (Historic-Scotland.gov 2012). This footprint is the symbol of Scottish Kingship. During an inauguration ceremony, Gaelic kings would place their foot in this footprint,
symbolically taking their first step on the path of kingship, and following in the footsteps of previous rulers. This also represented the king’s union with the land and nature, which was believed to be a female spirit. The date of the sculpture is not certain. Nearby petroglyphs have been dated to 5,000 BP.

1.8.3 The One-Legged Stance

“One-Legged Resting Stance”

There are many factors that affect one’s posture such as: anatomy, age, gender, physical fitness, physiology, environment, psychology, technology, and culture. One’s habitual postures are closely related to the physical circumstances of the environment, the repeated movements required by one’s lifestyle, and one’s cultural norms. Humans and animals also use posture socially in order to communicate intent as well as emotion. Some stances can be considered to be dominant and are used universally throughout all cultures; such as the erect two-legged quiet standing. Others, although possible for most people to assume, are used infrequently; unless reinforced by the demands of the environment, or through the influences of culture. Cultural attitudes have a great influence, as posture can be used to define clan associations, etiquette, taboos, gender differences, and social hierarchy.

An example can be seen with the various one-legged stances (Figure 1.7). This stance is more common and prominent in herding and hunter gather cultures, and is perhaps now less universal due to the decline of these cultures. Waist high vegetation is common in areas of open savannah or grassy plains.
Generations of individuals, having to daily watch herds or scan the horizon for prey, must spend many hours on their feet. People in such cultures employ variations of the one-legged stance. In some of these variants, the foot of the non-weight bearing leg also touches the ground but it is only used to assist in balance. Many of these stances employ canes, spears, spear throwers, staffs, or assistance from another; again, not to support body weight, but in order to help maintain balance. Often, instead of a staff, the hand is used to assist in balance by lightly touching an object such as a branch (Hewes 1957). One-legged stances are also common in both Chinese Martial Arts and Okinawan Karate. The Okinawan masters observed the posture and movement of animals in order to gain insight into postural control. Three commonly used one-legged stances are: Neko Ashi (Cat Foot), Tsuru Ashi (Crane Foot), and Kagi Dachi (Hook Stance).
Figure 1.7: Symbolic One-Legged Stance Depictions
Figure 1.7: Image Sources and Notes

A) 1181-1219 AD: Sculpture in stone. Dancing Celestials (Apsarases). Architectural feature of Buddhist temple. Culture: Cambodian Khmer. Angkor Thom, Bayon, Cambodia. (ARTstor 2012e) In Buddhist and Hindu mythology, Apsarases are female spirits of the clouds and waters who are superb dancers. They are frequently depicted in a very difficult one-legged stance, which demonstrates mastery of poise and balance. The Apsara Dance was traditionally performed as a moving prayer ritual. Apsara Dance is still practiced in Cambodia. The costumes and dance postures are based on those depicted on the temple sculptures. Thus, these temple Apsarases serve as a basic form of movement annotation that has facilitated the transmission of this art form.

B) 3,500 BP: Rock Art Painting, Woman on one leg. Culture: Australian Aborigine, Yanyuwa people. Kunminyini Springs, Borroloola, Northern Territory, Australia. (Kuipers 1983)

C) 6,500-5,500 BP: Rock Art Painting, Figure on One Leg, Head Hunter. Chalcolithic Period (Copper Age). Culture: Indian. Pachmarhi Hills, Madhya Pradesh, India. (Pathak 2012a) Seven other similar depictions occur in this area.

D) 10,000-300 BP: Petroglyph. Figure on one leg, Trance Dance. Culture: South African San Bushmen. Herbert District, Northern Cape Province, South Africa. (AHDVRC 2012j) This is one figure taken from a scene depicting multiple figures performing a Trance Dance. These petroglyphs depict men and women in typical Trance Dance postures. This Trance Dance is still practiced by the San. Scenes such as this are used as a reference of dance postures by the San as they provide a stable record of cultural practices that survive over thousands of years.

E) 650 AD: Sculpture in stone, Arjuna standing on one leg. Relief Sculpture from panel of images Descent of Ganges. Culture: Pallava Dynasty. Pallava Heritage Site, Mamallapuram, Tamil Nadu, India. (ARTstor 2012f) Arjuna, a standing ascetic, is shown on one leg performing an austerity Tapas. Tapas (Tapasya) means “heat” or “essential energy” and refers to a one-legged Yoga posture. Tapas are performed as a form of discipline in training to achieve a goal despite pain and suffering. Among the other images on the panel of the Descent of the Ganges is a cat standing on one leg also performing a Tapas.

F) 3,500-800 BP. Illustration of Petroglyph, Man standing on one leg. Culture: Australian Aborigine. Mootwingee, Western New South Wales, Australia. (McCarthy and Macintosh 1962) This posture is still common in Aborigine culture.
G) 17,500 BP: Rock art painting, Figure on one leg. Early Clothes Peg Figure Era. Culture: Australian Aborigine. Kimberley, North Western Australia. (BradshawFDN 2012a) These figures are referred to as Gwion Gwion, or Bradshaw Paintings, and are dated to a minimum of 17,500 BP. Pigment art of some form began around 50,000 BP and the earliest found so far in Australia dates to 28,000 BP (Bruno, Barker et al. 2012). There are over 100,000 rock art sites in the Kimberly region of North Western Australia.

H) 10,000 BP: Petroglyph of stick figure standing on one leg. Culture: South American. Orozas, Tarija Region, Bolivia. (SIARB 2012) The date of this petroglyph is unknown but it resembles other stick figures in Bolivia of Paleo-Indian origin. Paleo-Indian movement into the high altitude areas of Bolivia, such as Orozas, occurred after deglaciation around 11,000-10,000 BP (Dillehay 1999).

I) 880-1279 AD: Copper statue of Shiva, Lord of the Dance. Culture: Southern Indian, Chola period. Tamil Nadu, India. (ARTstor 2012j) The depiction of Shiva as Lord of Dance (Nataraja) began around the fifth century. Shiva is shown dancing at the center of the Universe. In his dance of ecstasy, Shiva holds in his upper right hand the Damaru, a hand drum from which emanates the primordial vibration of creation; the hidden harmony of the Universe. His lower right hand makes the gesture of Abhaya, protecting and preserving. The upper left hand holds Agni, the fire and flux of dynamic destruction. The lower left hand directs attention to his raised left leg, in a gesture known as the Gaja Hasta; to provide refuge. The circle surrounding Shiva is a flaming body halo that symbolizes the boundaries of the Cosmos. Thus the symbolism of Shiva is one of maintaining balance by controlling the complementary forces of stability and change; and thus allowing one to be in harmony with the Universe. The Dance of Shiva is intended to convey the means by which one can escape from illusion and ignorance to reach an understanding of the true nature of the Cosmos.

J) 1963: Painting on Bark, Figure standing on one leg. Culture: Australian Yolngu Aborigines, Yirrakala, Eastern Arnhem Land, Northern Territory Australia. (ARTstor 2012g) This is the front panel of a historic Aborigine petition for land rights presented to the Australian Federal Parliament. The painted designs on the petitions proclaim Yolngu law and depict traditional Aborigine relations to the land. These painted designs were intended to depict central themes of Aboriginal Culture.

K) 3,400-3,100 BP: Chinese Oracle Bone Script. Chinese character depicting a one-legged spirit or monster. Bronze Age China (Sears 2003). The Oracle Bone Script character Kui is a pictograph originally depicting a one-legged monster or dragon. By 2,300 BP it was used to depict a god in the form of a one-legged dragon that rises from the water and brings wind, rain, and thunder. The Oracle Bone Script characters were first used in carving divination texts on bone for the predication of events. In one type of use, these texts were burned and the
results were then interpreted. Thus, it was an attempt to use the process of change in order to find hidden truths. The modern 21-stroke Chinese Kui character 龜 combines five elements: Shou 首 "head"; Zhi 止 "stop"; Si 巳 "6th (of 12 Earthly Branches)"; Ba 八 "8"; and Zhi 已 "walk slowly". These enigmatic elements were graphically simplified from the ancient Oracle Bone Script and Seal Script pictographs.

L) 6,000-3,500 BP: African Rock Art Painting, Women on One Leg. Tassili-n-Ajjer Caves, Algeria, Africa. (AHDVRC 2012a) Over 15,000 paintings and petroglyphs have been identified in the Tassili-n-Ajjer region. The earliest rock art figurative painting found so far in Africa dates to 26,000-28,400 BP. Pigments used in art have been discovered that date to 77,000 BP, but they could be as much as 100,000 years old.

In the early 20th century literature the one-legged stance was referred to as the "Nilotic stance", "Nilotenstellung", or the "one-legged resting stance". The term "Nilotic" was a racial sub-classification referring to the body morphology of the ethnic groups of the upper Nile valley. At the time, it came to be used to refer to the one-legged stance as used by any aboriginal group worldwide. The Nilotic stance is described as standing on one leg with the sole of the other foot positioned on the support leg somewhere in the knee region (Figure 1.8). In a study of 481 cultural groups it was found that many of these groups commonly use a one-legged stance particularly in: Southern Sudan, Nigeria, India, Australia, Melanesia, South America, and Southwestern North America (Hewes 1957).
Figure 1.8: One-Legged Nilotic Stance
Figure 1.8: Image Sources and Notes

A) 1792-1797: Drawing and Watercolor, Aborigine Standing On One Leg. Title: Native man standing in an attitude very common to them all. Culture: Australian Aborigine. New South Wales, Australia. (Watling 1792)

B) 1928. Photograph, Aborigine on one leg holding a bundle of spears. Culture: Australian Aborigine. Forest River, Northern Kimberly, Western Territory, Australia. (Elkin 1953) The author notes: “Natives sometimes stand on one leg without movement for up to 15 minutes; this has been timed. They sometimes change occasionally from one leg to the other, mainly because the conversation has been rather prolonged. One of my observers says that he has rarely seen them change from one leg to the other, because they are more likely to move on rather than take up a fresh stance.”

C) 1948. Photograph, Aborigine standing on one leg holding a spear thrower. Culture: Australian Aborigine. Arnhem Land, Northern Territory, Australia. (Elkin 1953) The author notes: “It is quite a regular practice for an Aborigine who stops to talk to anyone to draw up one leg and place the foot of it on the thigh of the other just above the knee.”

D) 1957: Drawings, Variations of the one-legged Nilotic stance (Hewes 1957). The author notes: "Nilotic stance" – is a stork-like pose consisting of standing on one leg with the sole of the other foot planted against it somewhere in the knee region. It is a favorite stance of the tall tribesmen on the Upper Nile in the southern Sudan, and it crops up elsewhere in Africa, among hill folk in India, among the aborigines of Australia and among Indian tribes in South America. In the Sudan it is a common resting position for cowherds, who go barefoot and naked and therefore have no problem in assuming the posture.”

E) 1930: Photograph, Mongandu Boy in One-Leg Position, standing on one leg without support. Culture: African. Mongandu, Democratic Republic of the Congo, Africa. (Fagg 1950) The author noted that he has also observed this one-leg position being used four times in widely separated areas of Nigeria. He also suggests that: “…the storks or cranes referred to by Homer as having a famous battle somewhere in Africa with the pygmies are none other than tall African tribesmen, whose peculiar posture of rest had gained them this nickname…”

F) 2012: Photograph of Australian Aborigines standing on one leg (AustralianAborigines.net 2012).
1.9 Apollo: Light and Knowledge

There’s no walking on the Moon.

To the ancient Greeks and Romans, Apollo was the god of the sun and oracles; giver of light and knowledge. On July 20th, 1969, at 10:56 PM, Apollo astronaut Neil A. Armstrong descended the ladder of Apollo 11’s lunar module Eagle, and stepped onto the Sea of Tranquility. The Apollo lunar missions symbolize not only mankind’s first step from earth into the Cosmos, but also the next step in the evolution of hominin bipedal motion. After taking his historic first step, astronaut Armstrong found that the 1/6g lunar environment was pleasant to work in and that adaptation to movement in this new environment was rapid. Subsequent Apollo astronauts adapted within 5 to 10 minutes and their efficiency of movement improved with each excursion.

1.9.1 Balance on the Moon

Loss of balance and falls were generally caused by the astronauts jumping too high, tripping over obstacles, slipping at the edge of craters due to unstable regolith, and slipping on the loose regolith of the lunar surface while getting up off their knees. The Apollo crews felt that the risk of injury from falls was low as they had considerable time to react due to the low gravity. In addition, since the Moon has one-sixth the gravity of Earth, they impacted the lunar surface with less force than they would have from a similar fall on Earth. One area of concern though was the risk of falls on terrain with slopes of greater than 20-26°, such as on the
sides of steep craters. They felt at an increased risk of tumbling forward due to the unstable surface regolith and their higher center of gravity, caused by wearing their heavy back packs. To avoid falling in these situations, the astronauts used a hopping gait, or a parallel skiing motion, while descending the slopes (Scheuring, Jones et al. 2007).

To adapt to the lunar environment the astronauts had to modify both their posture and gait. In general, balancing on the lunar surface was not difficult despite the increased mass of the space suit and life support backpack, which added 194 pounds (on Earth) to the astronaut’s mass and raised the center of gravity (CG). However, since the CG was raised and shifted toward the rear, to maintain their balance the astronauts had to adopt a forward leaning stance. Apollo 12 Commander Charles “Pete” Conrad during his first Extra-vehicular Activity (EVA) noted how his posture had changed. The following is his conversation with fellow Astronaut Alan L. Bean:

Conrad: Am I really leaning over, Al?
Bean: You sure are. On Earth, you’d fall over, I believe.
Conrad: Huh?
Bean: On Earth, you’d fall over leaning that far forward.
Conrad: It seems a little weird, I’ll tell you.
(NASA, Jones et al. 2012)

Conrad further commented on the adaptations necessary to maintain an upright posture due to the decreased lunar gravity and the added mass of the Portable Life Support System (PLSS):
Al commented to me and I noticed, watching him, that you look like you’re standing with quite a forward tilt; but all you’re doing is putting your C.G. over your feet. Your C.G. is quite far aft with the PLSS, so you have the tendency to lean at what, at first glance, looks quite far forward; it’s not. (NASA, Jones et al. 2012)

In the 1/6g lunar environment, the astronauts in their suits and backpacks weighed only about sixty pounds, but their total mass had not changed. The astronauts thus had to adapt to the increased inertia relative to normal ambulation on the Earth. Once moving forward it took two or three steps to come to a stable stationary position. Apollo 11 Commander Armstrong stated:

*On Earth you only worry about one or two steps ahead; on the Moon, you have to keep a good eye out four or five steps ahead.* (NASA 1969a)

Armstrong preferred a skipping or loping type of movement over a kangaroo-like hopping.

### 1.9.2 Doing the Moon “Walk”

When Apollo 12 astronaut Pete Conrad was asked what it was like to walk on the Moon in one-sixth gravity he replied:

*There’s no such thing as walking on the lunar surface. Wherever you go, you just want to go at a lope.* (NASA 1969b)

Conrad’s fellow Apollo 12 astronaut, Alan L. Bean, commented on how they had to change their gait and emphasize the use of their toes to push off. Bean
commented that their footprints demonstrated how much they used their toes to propel themselves:

If you look at somebody’s footprints on the Moon, it’s almost exactly opposite of the way they are on the Earth. On the Moon, you can see a flat footprint as the guy lands and then he pushes off with his toe so it ends up being sort of dug in at the toe and flat in the rest of the print. (NASA 1969b)

Bean then described the gait that they used:

This sort of bouncing along, using your toes for springing and moving from side to side so that the CG is always over the foot that’s landing, allows you to move out at a pretty good pace and to move a good distance. (NASA 1969b)

When the astronauts attempted to move rapidly they found that they would very quickly change gait from a very slow shuffling walk and immediately transition to a bounding lope. As Armstrong’s fellow Apollo 11 astronaut Edwin “Buzz” Aldrin stated:

I don’t think there is such a thing as running. It’s a lope and it’s very hard to just walk. You break into this lope very soon as you begin to speed up. (NASA 1969a)

In discussing the difference between loping and attempting to run on the lunar surface, Aldrin continued:

The difference there is that in a run, you think in terms of moving your feet rapidly to move fast, and you can’t move your feet any more rapidly than the next time you come into contact with the surface. In general, you have to wait for that to occur. (NASA 1969a)
1.10 Hidden Harmonies

*Of ships at sea, lemurs, children at play, and men on the Moon.*

As can be seen from the NASA films, the Apollo astronauts experimented with several types of locomotion while on the lunar surface: walking, running, hopping, skipping, and jumping (NASA, Jones et al. 2012). In adopting a particular gait, the two factors that seemed to determine the selection were first, the time per distance traveled, and second, the energy expenditure. The preferred gait for most of the astronauts was a bounding skip-like motion or a lemur-like lope (Figure 1.9). Since the astronauts could neither walk nor run efficiently, they transitioned into this lope very rapidly from either a standing position or a slow shuffle.

1.10.1 The Lemur Way

On Earth, habitual use of this loping type of bipedal movement is unique to the Sifaka lemurs. When on the ground, a Sifaka lemur walks bipedally at slow speeds, but it only occasionally uses this mode. The range of speeds with which it can walk efficiently is very narrow, thus like the astronauts, it also quickly transitions to another mode of locomotion. When a Sifaka wants to cover long distances over open terrain, it uses a graceful bipedal sideways bounding gait, with the arms held out at chest height for balance. With this faster gait there is an aerial phase and the footfall pattern resembles a skip or gallop rather than a hop. When using this loping gait, Sifaka lemurs angle the trunk 30° to the
direction of travel, and the trail and lead limbs are sequenced with the trailing limb switched every five to seven steps (Wunderlich and Schaum 2007).

Similarly, an astronaut when using the loping gait, angled his body and stance forward slightly, and both feet pushed off simultaneously; with one foot always preceding the other. The arms were held up and away from the body. During mid-stride there was an aerial phase, and then the rear foot touched down followed rapidly by the front foot. The lead and trailing foot were switched periodically. The astronauts attempted to set up a dynamic motion, keeping up their forward momentum, and were thus able to cover long distances quickly and easily. This skipping or loping had a lower metabolic cost than walking, which was more difficult and took more time.
Figure 1.9: Astronaut and Lemur Gaits
Figure 1.9: Image Sources and Notes

A) 1969: Image of Apollo 12 Astronaut skipping (LPI 1969). Lunar Module Pilot Alan L. Bean can be seen skipping and hopping at the eastern wall of Head Crater during his second Extra-vehicular Activity (EVA). Astronaut Bean commented on the gait that he and fellow Apollo 12 Astronaut Charles “Pete” Conrad used most frequently:

*We tried the bunny (hop), but it was too much work. The loping was the easiest. For short distances, sometimes you just walked, you just kind of bounced over. Where you did the loping was for long distances.* (NASA, Jones et al. 2012)

Bean also commented on traversing steep lunar slopes:

*The key to success is confidence in your ability to control your center of gravity and, when going downhill, hopping side slope. For work on steep slopes, Apollo 15 was the learning experience and, by the time of Apollo 17, that experience had turned into confidence.* (NASA, Jones et al. 2012)

B) 1972: Image of Apollo 17 Astronaut hopping (LPI 1972). Apollo Astronaut Harrison H. “Jack” Schmitt during EVA 3 Close-out hopping to regain his balance after throwing his geology hammer. This is the last photo of an astronaut taken on the lunar surface.


D) 1971: Image of Apollo 15 Astronaut loping (NASA-JSC 1971). Commander David Scott, is seen moving away from the Lunar Rover on the slope of Hadley Delta during Apollo 15 EVA-3 at Station 10. Scott primarily used a loping gait with some hops mixed in.

E-F) 2002: Images of Verreaux’s Sifaka Lemur (*Propithecus verreauxi*) performing terrestrial loping gait (Attenborough 2002). These images show a Sifaka lemur during the aerial phase of its unique gait. When using this loping gait, Sifaka lemurs angle the trunk 30° to the direction of travel, and the trail and lead limbs are sequenced with the trailing limb switched every five to seven steps. The arms are held up for balance. Similarly, an astronaut when using the
loping gait, angled his body and stance forward slightly, and both feet pushed off simultaneously; with one foot always preceding the other. The arms were held up and away from the body. During mid-stride there was an aerial phase, and then the rear foot touched down followed rapidly by the front foot. The lead and trailing foot were switched periodically.

Without knowing it, by adapting a new gait pattern the astronauts were demonstrating a phenomenon that is predicted by gait modeling using the “Froude number”. In 1874, William Froude, a naval architect, introduced a dimensionless parameter in order to compare the characteristics of ships of varying hull length. Now known as the Froude number or $Fr$, this parameter is equal to $v^2/gL$; with $v$ being velocity, $g$ gravitational acceleration, and $L$ length. It is used to determine the resistance of an object moving through water; the larger the Froude number, the greater the resistance. The Froude number can then be used to compare objects of different sizes. This parameter has found widespread use in many disciplines for the study of various phenomena such as ship hydrodynamics, avalanche and debris flows, tidal waves, and dolphins swimming. In biomechanics it has been found to be useful for comparing gait characteristics between animals of different sizes. The dynamic similarity hypothesis predicts that the differences in locomotion biomechanics between geometrically similar animals are due largely to the differences in size. An appropriate non-dimensional parameter such as the Froude number is necessary to serve as a standard (Alexander 1976). Thus, regardless of size, animals will adopt a dynamically similar gait when traveling at speeds that yield equal Froude numbers.
Bipedal locomotion can be modeled as an inverted pendulum. The body’s center of mass (COM) rises and falls during the gait cycle. This vertical movement causes changes in the body’s potential energy which in turn requires complementary changes in the kinetic energy that is required for forward movement. The Froude number is directly proportional to the ratio of this kinetic energy to the potential energy. Despite differences in body size, animals that utilize pendulum-like movements, and that have geometrically similar bodies, can be compared. They will have similar gait characteristics if their Froude number is the same. The optimal speed of any gait is achieved when the exchange of potential and kinetic energies is maximized.

1.10.2 Back to Childhood

*I was strolling on the Moon one day*

Skipping is a gait adopted by children at about age four or five, but it is abandoned for the most part in adulthood. Although adults can skip, it is about 150% more metabolically demanding than running (Minetti 1998). Thus skipping is not a locomotion pattern normally used by adults. However, children often use this gait especially during play. Skipping simultaneously uses two basic mechanical energy saving strategies: pendulum-like, and elastic mechanisms. On Earth, the optimal walking speed of an average sized adult male is 1.5 m/s which corresponds to a Froude number of 0.25. A change in gait from walking to running is required at 2.0 m/s with a Froude of 0.5. The Froude number can be
used to predict where the transition from a walk to another form of gait must occur in the reduced gravity of the lunar environment. At one-sixth the gravity of Earth, the Moon’s environment requires that the transition occurs at speeds of about 40% of those on Earth (Minetti 2001).

Thus, with the impossibility of walking on the Moon at Earth speeds, the Apollo astronauts had to transition to another gait in order to efficiently move about. The astronauts reverted to a child-like gait. In fact during one excursion, the Apollo 17 astronauts joyously sang, “I was strolling on the Moon one day”, as they skipped along (NASA, Jones et al. 2012). In the NASA film astronaut Eugene Cernan can be heard saying “Boy, this is a neat way to travel.” Gait type, step length, and speed are primarily determined by the energy expenditure per distance traveled. On Earth, the astronauts have only two energy efficient bipedal gaits. Walking is used at speeds of approximately 2.0 m/s, above this they immediately transition to a run. The low gravity of the lunar environment offered a third gait. On the moon, rather than a walk-run transition there is a walk-skip transition. Thus lemurs, children, and men on the moon share a gait suitable for high speeds, with a mechanical model that differs from either walking or running.

The T’ai Chi Classics state that there is stillness in motion, and motion in stillness. Understanding dynamic movement can lead to insights into the mechanisms that control upright quiet standing and responses to perturbations.
Likewise, understanding of the dynamics of quiet standing can contribute to the understanding of stable movement. The dynamic similarity hypothesis and the use of concepts such as the Froude number are very useful in studying the movement characteristics of animals of different sizes. Similar approaches can be applied to postural stability. Bipedal locomotion can be modeled as an inverted pendulum. Upright bipedal quiet standing can also be modeled in this way. As mankind further explores reduced gravity environments it will be both interesting and important to understand how these environments affect both upright bipedal posture and bipedal locomotion.

Taking advantage of the reduced gravity, the astronauts adopted a form of skipping or a lemur-like bounding gait. This adaptation of gait has implications for the training of astronauts and the design of their living and working environments. It also has great implications for the future evolution of bipedal posture and locomotion as we look towards the eventual permanent colonization of Mars. The Froude number is an example of the interrelatedness of all things. With such approaches one can gain insight into the underlying principles that govern the Universe. This concept has its basis in the very origins of philosophy and science. For example, the Greek philosopher Heraclitus (c.535-475 B.C.) believed that there is unity in the World and that the interplay of forces produces the hidden Harmonies of the Universe. One must find these harmonies in order to understand movement and stability.
1.11 Summary

As can be seen from this chapter, man is unique among all the mammals in that he is the only obligate biped. The hominins began to follow the bipedal Way some 7 million years ago. Since that time, mankind has used the advantages of bipedalism to colonize the entire Earth, and is now poised to venture on to new worlds. Bipedalism was the driving force behind increased brain size, complex language, tool use, and culture. Mankind has long recognized its unique traits as the earliest examples of art depict the three defining morphological features of bipedalism: the foot, the hand, and an upright posture. To ancient man these attributes had both practical and symbolic significance. The use of these symbols is universal; occurring over all time periods, locations, and cultures, and has continued to this day. Succeeding chapters will demonstrate how mankind has used these symbols to understand not only the correct path to follow in daily life, but also his place in the world, and the underlying rhythms of the Cosmos.

1.11.1 Falls

There are many advantages to adopting a bipedal gait, among them are: improved vigilance, ability to carry food and infants, and an increased efficiency in tool use and foraging. Increased movement efficiency, coupled with language skills, resulted in the growth and spread of human populations. These advantages improved the hominins chances for survival and have allowed man
to spread and populate the entire Earth. However, with the increased efficiency of bipedalism there are associated costs. One such cost, and the focus of this paper, is the problem of maintaining postural control in various environments, and against various types of postural perturbations, throughout one’s lifetime. Due to the rise of the COM, and the decreased support base, bipedalism increases the risk of falling.

Injuries incurred from slips, trips, and falls are a major public health concern. In the U.S. falls are the leading cause of injury across all ages (Schiller, Adams et al. 2005). Falls account for one out of every five injuries, one-third of hospitalizations, and one-fifth of all non-hospitalized injuries. These injuries cause a dramatic increase in morbidity and mortality rates for those over the age of 65 (CDC 2005). Fall rates increase with age for adults beginning with age 18. The age group 18 to 44 years has the lowest rate of medically consulted falls at 26 per 1,000 population; persons aged 75 and above have the highest rate at 115 per 1,000 (CDC 2012b). The reduction in quality of life for the injured is incalculable, but the impact on the U.S. economy is an estimated loss of over $37 billion per year (Rice and MacKenzie 1989). In an effort to develop effective fall prevention and physical rehabilitation programs, researchers have investigated various forms of exercise for their potential to improve postural stability. Recently, the ancient martial art of T’ai Chi has received much research attention, and has been incorporated into many fall prevention programs, in an effort to improve balance in the injured and elderly (Wolf, Barnhart et al. 1997).
In China, T’ai Chi has been practiced for many centuries by people of all ages for the maintenance of overall health and wellbeing. Practitioners of this traditional exercise form believe that it improves cardiac function, respiratory efficiency, muscle strength, muscle endurance, flexibility, and balance control. The results of various research studies indicate that T’ai Chi does appear to have beneficial physiological, psychosocial, and neuromuscular effects. Research has demonstrated that balance interventions which emphasize T’ai Chi have the greatest effect on reducing falls compared to interventions such as balance training, strength training, and aerobics (Wolf, Barnhart et al. 1997).

1.11.2 The Aim of this Paper

Many falls occur when one slips, trips, or is subjected to perturbations such as when standing in a moving bus. Challenges to balance also occur during transitional tasks such as moving from a seated to a standing position, and during gait initiation, and gait termination. Thus, balance programs which emphasize training in rapid response to perturbations, and stress practice of transitional tasks, are potentially more effective in reducing the risk of falls than a more static discipline such as T’ai Chi. The martial art of Karate provides training in dynamic limb movement and the repositioning of the body’s COM. This study explores the potential of using the underlying principles of Karate training to improve fall reduction exercise programs. Two groups of subjects underwent a 15-week training program in either Karate or strength training and then were
tested to determine if either group had significant improvements in postural control. Although 15 weeks is a relatively short time in which to expect significant skill development, it was hoped that dynamic training such as Karate would show meaningful improvements.

In this first chapter we have looked at the history and importance of hominin bipedal posture and gait. To fully understand how a Way, or lifestyle, of fitness and skill development can influence postural stability, the following chapter will explore the origins of the martial arts and its philosophy. Two such Ways of physical and mental fitness are explored: The Dao (The Way) of Karate, and T’ai Chi, (Great Ultimate). To gain an appreciation of the concepts of physical and philosophical balance we will then explore the meaning of “balance” in Chapter 3. We will also gain an appreciation for the development and evolution of philosophical concepts to the point where they are considered to be “Laws”. Chapter 4 will review the history of the science of biomechanics and how it can be used to examine postural characteristics, and the influence of physical fitness and skill development on the control of balance. Chapter 5 is a review of the pertinent literature regarding the risk of falls in modern society and research on the current methods of fall prevention. Moving on to Chapter 6, we find a description of the methods used in this research study to examine postural stability in two groups of subjects. These subjects underwent two different physical training programs that are currently being considered for use in fall prevention programs: martial arts and strength training. Chapter 7 presents the
results of the processing of the subject’s data and Chapter 8 discusses the implications this study has for the use of Karate training in future fall prevention programs.
CHAPTER 2
KARATE: STABILITY WITHIN MOVEMENT

To search for the old is to understand the new.

The old, the new
This is a matter of time.

In all things man must have a clear mind.

The Way:
Who will pass it on straight and well?


2.1 Introduction: Ma-ai

For centuries, martial artists have sought to understand the principles behind posture, balance, and movement. Mastery of these leads to control of Ma (space and time). Eventually the martial artist hopes to achieve Ma-ai (space/time harmony), a balanced state with a unity of mind, body and spirit. This in turn helps one to defeat an attack, whether it be physical or psychological. As stated by the great Okinawan Karate master Gichin Funakoshi: “The Ma requires advancing and retreating, separating and meeting.” (Funakoshi 1973, p. 248).

The importance of the mastery of posture, balance, and movement is mentioned
in many ancient martial arts sources. However, the translation of the Chinese and Japanese characters within these documents is often difficult, and multiple interpretations can and have been produced. In addition, the classical Chinese and Japanese literary forms are terse and often follow a strict poetic style. Thus, both the individual characters, and the concepts expressed, usually have both concrete and abstract meanings. This is in part intentional as it encourages creative thinking in the student by providing multiple interpretations and novel associations of ideas and images.

The Martial Arts represent physical culture, and in all senses of the words, a culture of movement. It is a systematized study of skill, fitness, health, philosophy, and cultural history. All of these facets are simultaneously developed and transmitted through body movements. The basic intent of the martial arts is to develop movement patterns for use in self-defense. All postures, movements, and concepts must first be directly applicable to, and valid for, self-defense. However, this provides only a very basic understanding of the nature and purpose of the traditional martial arts. These self-defense systems are considered to be “Arts” with the ultimate goal of the perfection of the human physical, mental, and spiritual condition. The movements serve as a vehicle to develop health and fitness, foster morality and philosophy, and transmit a record of historical events.
The record of these studies stretches back many centuries but it obviously has roots as old as mankind itself. Examples of martial training can be seen alongside the earliest symbols of man, etched into stone and painted on the walls of caves and rock shelters, many thousands of years ago (Figure 2.1). For any knowledge to survive for that long, it must first be valued by both the individual and the culture. It must also be recorded so that the knowledge can be transmitted and practiced by succeeding generations. “Martial” is derived from the Latin *martialis*, meaning of or relating to Mars, the Roman god of war. When used today, the term “Martial Arts” generally refers to any systematized discipline of self-defense. The most common forms of modern martial arts are of Asian origin; however, all cultures throughout history had some form of martial training.
Figure 2.1: Ancient Martial Training
Figure 2.1: Image Sources and Notes

A) 3,200-3,000 BP: Petroglyphs of Competition. Sword Duel (Left); Boxers, (Right). Petroglyph found at Foppe di Nadro, Rock 6. Culture: Epipaleolithic Camuni to Mediaeval cultures. Valcamonica, Province of Brescia, Lombardy, Italy. (Italia 2012) Valcamonica's rock art consists of over 300,000 engravings spanning a period of 8,000 years. The scenes depict all facets of the culture including training, ritual, agriculture, navigation, war, and magic.

B) 3,200-3,000 BP: Petroglyph, Two Warriors Dueling. Culture: Epipaleolithic Camuni to Mediaeval cultures. Valcamonica, Province of Brescia, Lombardy, Italy. (Nash, Simões de Abreu et al. 2011) The petroglyphs made during the Iron Age constitute approximately 80% of all the rock art in the valley. Many of the petroglyphs are interpreted as representations of training as the figures wear minimal armor, use small shields, and appear to wear padding on their hands.

C) 6,000-4,000 BP (Bovidian Period): Rock Art Painting, Warriors With Spears. Tassili-Sefar area, Algeria, Africa. (Seligman 1984b) Tassili is a mountainous region in the center of the Sahara, situated to the south-east of the Algerian Sahara. It is world renowned for its rock paintings and engravings, which number over 15,000. The majority of the art was created in the Bovidian Period which is characterized by the depiction of domestic bovids. The representation of bovine herds and the scenes of daily life, incorporating a renewed naturalistic aesthetic, are among the best known examples of prehistoric mural art.


E) 9,000-6,000 BP: Rock Art Painting, Warriors with Bows. Culture: Bubalus to Roundhead Periods. Tassili-Sefar area, Algeria, Africa. (Seligman 1984a) A Bubalus is a genus of water buffalo. Many of the engravings from the Bubalus period have been dated to about 10,000 BP. The later Roundhead Period (c. 8,000 BP) depicts figures standing among cattle, hunting with bows, and dancing while wearing masks. There are many images of archers in various stances in which the strings of their bows and their leg muscles are visible.

F) 3,200-3,000 BP: Petroglyph, First Iron Age Martial Art School. Students are shown in the middle, and teachers on the left and right sides. Petroglyph found at Seradina, Valcamonica. Culture: Epipaleolithic Camuni to Mediaeval cultures. Valcamonica, Province of Brescia, Lombardy, Italy. (Arca and Fossati 2004)
It is interesting to explore these ancient martial systems as one can gain an appreciation of the value of the qualitative approach. This approach has been employed for many centuries and has yielded unique insights that have only recently been realized by today’s quantitative centered approach to movement research.

This chapter will explore the origins of the martial arts and its central theme of physical, psychological, and philosophical balance. Although the history of self-defense stretches far back into prehistory, the precursors of the systematized martial arts of today have their beginnings in Asia. There was essentially a simultaneous development of martial arts systems, and an interchange of ideas, between India and China throughout history. We will look at the early records of the martial arts in both of these regions, and then explore how these systems and ideas spread to Okinawa. There they blended with the indigenous art of Ti to form what we now know as Karate. Although many argue that Ti is as old as any of the other disciplines, unfortunately the early cultures of Okinawa did not leave written records.

It is important to study the origins of the martial arts so that we gain an in-depth appreciation of what it means to follow a lifestyle (Way) based on skill development, health, and fitness. Many of the current fall prevention programs promote the use of disciplines such as T’ai Chi over relatively short training periods. Although these programs show promise, the disciplines used were
designed for long-term study; as a way of life. The purpose of this study is to explore whether such short-term programs can be effective.

2.2 Origins of the Martial Arts: India

Knowledge about the techniques for achieving victory. The origin of a systematic method of training in the martial arts of India is lost in antiquity. The earliest record dates to around 1,000 B.C. where in India the warrior class known as Kshatriya practiced a systematized martial art known as Vajra Mushti (McCarthy 1987). The only form of this in existence today is Kalarippayattu (Balakrishnan 2003). It is believed to have originated in the present Indian coastal state of Kerala, which was formerly known as Malabar. This region is very hilly and covered in thick jungle. Unlike the vast plains of northern India, the Kerala region was unsuitable for the deployment of large military units, cavalry, or chariots. Thus, the warriors of the Kerala region developed methods of warfare that were more suitable to small bands of warriors or individuals. Also these warriors did not use the heavy armor or weapons of the other militaries at the time. Instead, they fought bare-chested using light weapons and depended more on their superior speed, agility, and confidence.

The martial art of Kalarippayattu was developed through a highly systematized study of philosophy, exercise, health, and martial techniques. The ancient aristocrats of India, known as Brahmins, were priests by heredity. They were
also responsible for the administration, agriculture, commerce, and security of the land. As priests, the Brahmins studied and interpreted the Vedas (Divine Knowledge) which are ancient metrical hymns concerning the epics of the Hindu deities, philosophical speculations, and historical accounts. The earliest of these dates from around 1,500 B.C. The Vedas are the basis for much of Indian religious and philosophical thought. They also contain invocations for health and medicinal purposes. The Brahmins chant mantras based on these hymns during rituals.

Although the Brahmins were not directly involved in military matters, they provided religious and philosophical guidance to the warrior caste, the Nayar (Chieftains). The Nayar were reported to be fierce in battle and preferred to die rather than to live in defeat (Balakrishnan 2003). They drew courage from their conviction that they were defending their society from the evil forces. Mankind’s struggle against evil is a major concept in Hindu mythology. For instance, one of the major Vedic deities is Indra the god of war who set order to the Cosmos, and protects mankind from the forces of evil (Dowson 1953). In addition, one of the Vedas contains a supplementary text called the Dhanurveda, which is considered to be the source of martial knowledge. The Dhanurveda describes the various weapons, those who are permitted to use them, and how the warriors should be taught. It also prescribes the role of the instructors, preparations for practice, and the deployment of the army. There was a widespread cultural acceptance of the warrior as an honored professional. The various Indian art forms are divided
into 64 categories with one of these being the art of fighting with weapons. This art form is called Vaijayiki Vidyagnanam. This is a Sanskrit term meaning “the knowledge about the techniques for achieving victory” (Balakrishnan 2003, p. 7). Thus, it can be seen that from its origin this martial system is bilateral. One part is philosophical and religious containing sacred concepts such as Aparajitha (the quality of never failing). The second part is the physical consisting of the Nayar training in health, exercise, and the technical martial art skills.

2.2.1 Systemized Martial Training

Being responsible for the security of the society, the Brahmins established a system for the administration and training of the military. The four major Brahmin sects selected twenty-one martial experts who then each established a training institution known as a Kalari. The martial training taught was called Payattu, thus the system name Kalarippayattu. Eventually 108 of these training centers were established throughout India. Each of these Kalari selected members from the local tribes to receive training in agriculture, crafts, and warfare. Those who excelled in physical skills and warfare were chosen to form the warrior caste known as the Nayar. In the Vedic text Dhanurveda, unarmed fighting is called Baahuyudham (Baahu meaning Hand) (Balakrishnan 2003).

In Western literature, the first record of the existence of the Nayars is believed to occur in Pliny the Elder’s Naturalis Historia that was written in 77 A.D. The
Nareae of India that he describes are believed to be the Nayar. Ibn Battuta, a Muslim traveler, wrote of the Nayar during his visit to the region between 1325 and 1354 A.D. However, the first detailed accounts of the Nayar occur after Vasco de Gama’s exploration of the region in 1498 A.D. The early accounts of Nayar society mention four distinguishing characteristics: the matrilineal kinship system, polyandrous marriage practices, the strict caste system, and the Nayars martial system (Fuller 1976). These characteristics all served to maintain a warrior society as they enabled the warriors to focus on their martial training. In particular, the physical fitness, dexterity, and martial skill of the Nayar warriors greatly impressed 16th century explorers who visited the Malabar region of India. In 1553 A.D. Luis de Camões, a Portuguese explorer, encountered these warriors and their unique martial culture. Particularly, he noted the strict division between the castes not only in their roles within the society but also in their philosophy:

But, when ye come into the Countrey, more,
And things of greater strangeness ye shall view.
The NAYRES onely go to war: Before
Their King they onely stand a Rampire trew
Against his Foes. A Sword they alway weild
With their right-hand, and with the left a Sheild.

Their Prelates are call’d BRAMENS (an old name,
And (amongst them) of great Preheminence):
Of his fam’d Sect, who Wisdom did disclame,
And took a stile of a more modest sence.
They kill no living thing, and highly blame
All flesh to eat with wondrous abstinence:

(Camões and Fanshaw 1655, p. 144)
In 1588, the historian Giovanni Pietro Maffei gave an account of the Nayars’ training and abilities. Warrior training began at about the age of seven and included exercise, massage, wrestling, unarmed striking, and the use of weapons. During training they would apply sesame oil to their bodies and during combat would only wear loin clothes (Fuller 1976). In addition to physical training the warriors received formal education in reading and writing (Balakrishnan 2003). Maffei commented on their dexterity in wrestling and their proficiency in combat:

> What is perhaps deadliest of all is that they hurl their javelins less accurately backwards than forwards.

> If either necessity compels or occasion demands they engage in hand to hand combat, they do most of the killing.

(Balakrishnan 2003, p. 6)

The Nayar training incorporated flexibility and gymnastic exercises. Giovanni Botero in 1592 gave this description of the Nayar training:

> At seven years of age they are put to Schoole to learne the use of their weapons, where to make them nimble and active, their sinewes and joynts are stretched by skifull fellowes, and annoynted with the oyle Sesamus; by this annoynting they become so light and nimble, that they will winde and turne their bodies, as if they had no bones, casting them forward, backward, high, and low, even to the astonishment of the beholders.

(Botero and Johnson 1630, p. 618)

Since the early 1500’s the Malabar region experienced control by a succession of foreign powers: Portuguese, Dutch, and British. The foreign controlled administrations prohibited the use of sharp weapons by the Indians. The Kalari
training thus gradually changed to employ blunt wooden and cane weapons.

Unarmed martial techniques were also given greater emphasis especially in the Venad region of Malabar, which is now southern Kerala. This region’s version of Kalarippayattu is known as Adithada or Adimura. This art is believed to be the modern version of the unarmed combat system that in ancient times spread to China and eventually influenced the development of Karate (Balakrishnan 2003).

2.2.2 Present Day Kalarippayattu

The present day Kalarippayattu system is believed to closely resemble the system employed in ancient times. The ancient Indian texts prescribe aspects of this training. Oral traditions and accounts of early explorers also describe similar training. The archeological evidence also supports this, as the training structures of today are the same size and configuration as the remains of those of ancient times. All Nayar training facilities are built to these very specific dimension and location conventions. The Nayar chief who is in charge of the warrior training at each Kalari is called the Gurukkal or Guru meaning “teacher”. The Guru also serves as a role model and holds a position of great respect within Indian society.

Physical training is conducted in Kalaris which are special structures resembling temples. These provide secrecy and reinforce the spiritual aspect of the training. The entrance always faces east and is locked both during and after training. Inside the Kalari, a special arc-shaped seven-step platform is located in the
southwest corner for the worship of the presiding deity Kalari Paradvata (Kalari Goddess). The other corners of the Kalari are reserved for various gods and goddesses of war and weapons. Two other small platforms honor the ancestry of the Kalari system. One is for the original four Brahmin sects and 21 Gurus. The other pays respect to the lineage of Gurus for that particular Kalari. Upon entering the Kalari, the students bow in respect to the training hall. At the start of each session, the students kneel and bow to the deities. They also show respect towards the Guru and his knowledge by bowing to him before and after each training session. These gestures of bowing and reverence reinforce discipline and the student’s total commitment to the training.

Kalarippayattu training includes philosophy, exercise, massage, the study of nerve centers, wrestling, striking and kicking, and the use of weapons. This system of training is also designed to teach discipline, concentration, and confidence. In addition to physical fitness, the health of the students is given consideration. The buildings used for training are constructed in a manner that prevents the students from being exposed to the cooler outside air after training. During practice, the trainees wear only loincloths and apply oil to their bodies before each session. The students are taught a system of massage techniques known as Uzhichal. The students also receive massage, which is performed by the Guru who first applies specially medicated oils and Kizhi (bundles of medicinal herbs dipped in hot oil). The Guru can also administer potions of medicinal herbs. The use of massage and medicinal herbs is part of a medical
treatment system called Kalari Chikitsa. This system is intended to treat injuries and physiological disorders. Splinting techniques for fractures and dislocations are part of this system. Injured members of the general public are also brought to the Kalari for treatment. Included in this treatment system is the study of Marmas (vital points) which teaches the student the location of nerve centers. A total of 107 Marmas are identified in the Kalarippayattu system. The identification of Marmas serves two purposes. First, it aids in identifying the specific nerve center which should be massaged as part of a remedy. Secondly, for combat purposes it identifies the specific points on the opponent that when struck will produce the greatest effect.

The basis of the formal training in Kalarippayattu is the practice of foot positions and postures known as Chuvadukal. Chuvadu means “step” or “foot position” however; the posture of the entire body is emphasized. Dhanurveda, the Vedic text on warfare, prescribes the specific posture for each martial purpose. The intent is to develop standardized and stable foot positions and body postures that are suited for specific situations or as a preparation for movement. These basic postures are of two specific types: Aakkachuvadu and Neekkachuvadu. Aakkam means “firmness” thus Aakkachuvadu (Firmness Position) is intended for use in situations where the body must maintain stability against perturbations. Neekkam means “movement” and so Neekkachuvadu (Movement Position) is employed when preparing for sudden advancing, retreating, evasion, or leaping. The upper body positions and the angles of the feet are defined. The dimensions
of the stances are measured in Charns. One Charn is the distance from the tip of the thumb to the tip of the little finger when the fingers are spread wide. These basic postures are practiced solely to develop body position awareness, stability, strength, flexibility, and fluid movement. They are practiced both in stationary positions and in stepping movements.

The two basic types of postures are further divided into different forms. The postures are also combined with movement patterns in order to facilitate specific movements and to produce more force. These modifications of the basic Chuvadukal postures are known as Vadivukal. They are the postures and movements that are designed for actual self-defense or attack applications. There are eight different Vadivukal; each designed to represent the movement and behavioral characteristics of a specific animal. The animals used as models are: the cat, cock, snake, lion, elephant, horse, pig, and fish. Exercises, postures, and sequences of movements are performed while moving length-wise along the Kalari floor. Prior to training in martial techniques, basic exercises are performed, which include flexibility training, full range of motion leg movements, balancing, and jumping. The basic formal martial training is called Mey Payattu (Body Exercises). These are a graded series of movement sequences designed to improve fitness and dexterity. These sequences form the basis of all postures and movements employed in Kalarippayattu martial techniques. Verumkai Prayogangal is the term for training specifically designed for balance and movement during unarmed combat and is practiced by sparring with a partner.
Throughout the development of the Asian martial arts, there has been an exchange of ideas between India, China, and Okinawa, on philosophy, training practices, and technique. Since the ancient Okinawans left no written account of their martial arts system, it is difficult to determine the source of much of the philosophy and practices of Karate. However, the Okinawan system displays many similarities to the ancient Indian martial arts.

In addition to balance, fitness, and skill development, the Indian system of martial training emphasized awareness, speed, and the development of reflexive movement. This is demonstrated by the emphasis on Mey Kannaakkuka. Mey is the Sanskrit term for body and Kannu means eye. The implication is that the entire body should be trained to imitate the eye: perceptive with very rapid reflex movements. A similar emphasis on the development of reflex movement and sensory perception can be seen in several of the aphorisms of the Okinawan Isshinryu Kenpo Gokui (One Heart Way Higher Knowledge):

*The body should be able to change direction at any time.*
*The time to strike is when the opportunity presents itself.*
*The eye must see all sides.*
*The ear must listen in all directions.*
*(Dorow and Liskai 1969, p. 2)*

In the Vedic text Dhanurveda, unarmed fighting is called Baahuyudham (Baahu meaning Hand). This form of unarmed combat spread to China and was absorbed into other martial art systems. The great influence of the art was not due mainly to the effectiveness of the techniques. Instead, it demonstrated the
effectiveness of a systematized and holistic approach to training. This systematized training is thought to be the origin of the art that spread throughout Asia and into Okinawa. There it combined with the indigenous unarmed martial art called Ti (Hand). This Ti eventually developed into modern day Karate (Empty Hand).

2.3 Origins of the Martial Arts: China

*The Five Happinesses*

In ancient China, the importance of the military arts varied between geographic regions and was greatly influenced by climatic and cultural differences. The climate of China ranges from the tropical South China Sea to the frozen tundra of Siberia. Within this vast area, demographic and anthropological historians have defined several main cultural types who inhabited the region prior to 960 AD (Riordan and Jones 1999). People of the coastal plains practiced agriculture, and near the coast, fishing; both of which require a sedentary lifestyle in order to remain close to their food resources. These groups tended to be less aggressive both toward each other, and in their approaches to physical training and sport. Cultural groups of the Himalayas and Tibet endured a harsh lifestyle and competed with each other for resources. Nomadic herders of the grasslands followed a lifestyle that required moving their herds over vast areas thus coming into conflict with many other groups. The cultures of the first two sedentary groups did not emphasize preparedness for systematized warfare. However, the
mountain people, and the nomadic herders, both endured more physically demanding lifestyles and were more frequently at war. The nomadic herding culture especially emphasized the development of skills in horsemanship, hunting, and warfare. Thus, the ancient Chinese warrior monarchies in these regions during the period 1,600-900 B.C. emphasized the development of physical fitness and Wushu (martial skills). This training was not confined to the military as social forms of these exercises and arts were part of the educational system of the aristocracy (Riordan and Jones 1999).

The physical culture of ancient China can be divided into three basic categories: military, medical, and recreational. Examples of military skill activities in addition to Wushu are archery, throwing, running, weight lifting, and swimming. Activities designed for health purposes included: Yangsheng (art of physical fitness and health); Yijinjing (relaxation exercises); Qigong (breathing exercises); Fushi (proper diet); massage; and martial arts skills adapted specifically for exercise and health (Knuttgen, Ma et al. 1990). Although there were many disciplines and activities centered on exercise they all shared a common goal: a search for Wufu (Five Happyhoods or Blessings). These are recorded in the Great Plan chapter of the Shang Shu (Documents of the Elder); also known as The Book of Documents. This is a collection of ancient documents from about 3,700 to 2,260 BP.

Of the five happinesses, the first is long life; the second is riches; the third is soundness of body and serenity of mind; the fourth is
the love of virtue; and the fifth is doing or receiving to the end the will of Heaven. (Legge 1861)

The "Five Happiness" concept still survives today in the folk culture of China (Ip 2011).

Concurrent with exercise and martial skill development ancient Chinese cultures evolved medical theories and philosophical systems. A major component of Chinese medical theory is the concept of Ch’i or Qi (vital energy, breath energy). This theory grew out of the philosophy of Taoism, which holds that everything in the Universe is interdependent and interactive. It is believed that Ch’i is responsible for all body movement and functions. It is also through Ch’i that the body interacts with the external environment and so human life is dependent upon this exchange of vital energy. Thus, the maintenance of Ch’i through posture, movement, and breathing techniques became a major component of Chinese physical culture.

Another philosophical concept that influenced both exercise and medicine is that of Yin and Yang; the negative and positive elements of the Universe. The origin of this theory dates to at least the beginning of the Xia Dynasty (2100 B. C.). By the start of the Zhou Dynasty (1066 B. C.) a complete theory was recorded in the first complete version of the I-Ching (Classic of Changes). It was further developed and refined by students of Confucius during the Warring States Period (475-221 B.C.) and recorded in the I-Zhuan (Commentary on the I-Ching). This
demonstrates that from its origins, Chinese culture fostered the simultaneous and interrelated development of exercise, martial skill, medicine, and philosophy.

2.3.1 T’ai Chi Classics

Stand like a balance and

Rotate actively like a wheel

Walk like a cat.

The T’ai Chi Ch’uan Classics are an early source devoted to the concepts of posture, balance, and movement. These are a collection of writings recording the theory and principles of T’ai Chi (Supreme Ultimate) Ch’uan (Fist or Boxing). T’ai Chi is a philosophical concept in Chinese cosmology referring to the evolution of the Universe from the Wu Chi (Void) into the complementary forces of Yin (passive) and Yang (active). These concepts have an origin in the I-Ching (Book of Changes) which was written 3,000 years ago (Smith 2003). The T’ai Chi Ch’uan Classics are a guide for the martial artist which describes the factors necessary for success in individual combat. They focus on the Tao (Way or Path) for the development of the mind, body, and spirit. In Taoism one of the major goals is the achievement of health and long life. By following the Tao one harmonizes both internally and externally with the Universe. Through T’ai Chi Ch’uan one develops Ch’i (breath energy) which is an internal force. Another example of an internal force is Chin which is derived from the muscles and then
applied to circular movements. By developing internal forces such as Ch’i and Chin one can then master movement in order to accomplish external goals such as self-defense. Although the Classics are meant to convey both abstract and concrete concepts the ideas must all be valid for balance and movement in the martial arts.

The earliest of the Classics is T’ai Chi Ch’uan Ching which according to the most popular theory was written by a Taoist monk Chang San-feng at the end of the Yuan Dynasty (1279-1386 A.D.). According to this theory the invention of T’ai Chi Ch’uan is credited to Chang. Other theories date the origin much earlier at either the beginning of the Chen Dynasty (550-560 A.D.) or during the T’ang Dynasty (618-907 A.D.) (Lo 1979; Draeger and Smith 1980). Some researchers believe that the most reasonable conclusion is that both the date of origin and the founder of T’ai Chi are unknown (Smith 1990). However, the T’ai Chi Ch’uan Ching manuscript is believed to be modeled after The Art of War by Sun Tze (also known as Sun Tzu) which was written about 400 B.C. (Lo 1979). While the immediate and basic purpose of the T’ai Chi Ch’uan Ching is to guide the development of balance and movement for self-defense this is not the sole purpose. A note at the end of the manuscript says:

*This classic was left by the patriarch Chang San-feng of Wu Tang Mountain. He desired the whole world to attain longevity, and not only martial techniques. (Lo 1979, p. 27)*

This sentiment is repeated in another Classic the author and date of which is unknown. In the Song of the Thirteen Postures it is written:
Think over carefully what the final purpose is: to lengthen life and maintain youth. (Lo 1979, p. 66)

2.3.2 Posture

In the T'ai Chi Ch'uan Ching, Chang describes the proper posture and the control of motion by the correct coordination of the feet, legs, waist, and fingers. He indicates that the feet, legs, and waist must act together otherwise the timing and position will be incorrect.

If the timing and position are not correct, the body becomes disordered, and the defect must be sought in the legs and waist. (Lo 1979, p. 21)

Chang also describes the Thirteen Postures. Five of the postures are the “Five Elements”: step forward, step back, look left, look right, and central equilibrium (Lo 1979). These elements are combined with the eight trigrams of the I Ching to form the thirteen postures. Associated with each trigram is a hand technique and the Five Elements are the footwork. While the Thirteen Postures represent formally defined postures and movements this is only a basic understanding of their purpose. An in-depth examination of the postures reveals that they are meant to represent thirteen fundamental skills and attributes which are intended to improve balance, movement, and to serve as a guide for advanced study.
2.3.3 Biomechanics

A basic understanding of biomechanical principles can be seen in the early writings of all three of these major disciplines: martial arts, philosophy, and medicine. The Tao Te Ching (Way Integrity Classic) is a philosophical treatise on the Tao; which according to cultural legend was written by Laozi (Old Master) a contemporary of Confucius (551-479 B.C.). However, it is more likely a composite of documents written from the sixth through the fourth centuries B.C. (Laozi and Hinton 2002). The earliest known copy of the texts attributed to Laozi was found in a tomb dating from about 300 B.C. (Laozi and Henricks 2000). One interpretation of a passage in the Tao Te Ching by Laozi (also known as Lao-tzu) reads:

*He who stands on tiptoe, does not stand firm: He who takes the longest strides, does not walk the fastest.*
_(Draeger and Smith 1980, p. 31)_

If this is an accurate translation it demonstrates that early T’ai Chi practitioners understood the relationship between stride length, stride rate, and velocity. However an alternate interpretation produces:

*He who stands on his tiptoes does not stand firm; he who stretches his legs does not walk (easily)._ (Laozi, Zhuangzi et al. 1891, p. 67)

In discussing “The Quality of Gravity”, Laozi goes on to say that gravity and stillness are attributes of the Tao:

*Gravity is the root of lightness; stillness, the ruler of movement._
_(Laozi, Zhuangzi et al. 1891, p. 69)_
Although one can debate the intended meaning behind these passages they do
demonstrate that the concepts being discussed were part of the knowledge base.

Wu Yu-hsiang (1812-1880), in his “Expositions of Insights Into the Practice of the
Thirteen Postures”, hinted at kinematics and compared body movement
characteristics to the mechanics of a bow:

   In the curve seek the straight, store, then release. (Lo 1979, p. 53)

The discussion of these concepts of balance and movement is continued in
another of the Classics the T‘ai Chi Ch‘uan Lun by Wang Tsung-yueh (1736-
1795 A.D.). Here Wang writes:

   Stand like a balance and rotate actively like a wheel.
   (Lo 1979, p. 38)

The idea of central equilibrium and balance is at the core of all the Classics.
Wang advises: “Don’t lean in any direction.”; and that one should let the Ch‘i sink
to the Tan T‘ien (Sea of Ch‘i) (Lo 1979, p. 33). In classical Chinese medical
theory the Tan T‘ien is precisely located at 1.3 inches below the navel and three-
tenths of the distance from the navel to the spine (Smith 1990). This
physiological and psychic center also marks the approximate center of mass of
the body in the upright stance (Smith and Pittman 1990). Thus in Taoist theory
the Tan T‘ien is the center for both meditation and movement. This
demonstrates that the T’ai Chi practitioners were not only aware of these
concepts, they also attempted to formally define them.
The Taoists believed that through the practice of T’ai Chi this central equilibrium could be kept despite external perturbations. Wu Yu-hsiang (1812-1880 A.D.) in his Expositions Into the Practice of the Thirteen Postures writes:

*The upright body must be stable and comfortable to be able to support (force from) the eight directions.*

*(Lo 1979, p. 55)*

Insights into the dynamic nature of stability, and the control of variability, can also be seen:

*Remember, when moving, there is no place that does not move.*
*When still, there is no place that isn’t still.* *(Lo 1979, p. 57)*

### 2.3.4 Observation of Animals

In an attempt to understand human balance, posture, and movement, past masters observed the posture, movement, and behavior of animals. Yu-hsiang notes:

*Walk like a cat.* *(Lo 1979, p. 56)*

*The form is like that of a falcon about to seize a rabbit, and the shen (spirit) is like that of a cat about to catch a rat.* *(Lo 1979, p. 59)*

Many martial art styles, postures, and movements are modeled after the nature, posture, and movement characteristics of specific animals. Examples can be seen in the formal exercises of the Chinese Five Form Fist. Four of these Chinese boxing styles are based on the study of the movement and behavioral characteristics of animals: tiger, leopard, snake, and crane. The fifth is based on the cultural tradition of the dragon.
Each of these styles is designed to develop specific mental, physical, and movement characteristics. For example the crane fist movements are practiced to improve concentration, stability, and accuracy (McCarthy 1987). Hsing-I, one of the three forms of Chinese Internal Boxing, contains the Twelve Animals Styles. Each of these “Styles” is a sequence of postures, steps, and movements that are modeled after the movement and fighting characteristics of a specific animal. The twelve animals represented are: the dragon, tiger, monkey, horse, water strider, cock, falcon, swallow, snake, t’ai (a mythical bird), eagle, and bear (Smith and Pittman 1989). Specific movement characteristics of animals were closely observed to determine the best methods of generating force during movement. Rapid rhythmic and quivering movements, and methods of deception and distraction, were observed in animals. From this approach specific styles of fighting were developed such as the Jumping Crane, Whooping Crane, Sleeping Crane, Feeding Crane, and Flying Crane styles (McCarthy 1995). The ancient Okinawan Karate masters also studied the posture and movement of animals in order to gain insights into balance and postural control. Three commonly used stances are: Neko Ashi Dachi (Cat Foot Stance), Tsuru Ashi Dachi (Crane Foot Stance), and Kagi Dachi (Hook Stance), a variant of both Neko Ashi and Tsuru Ashi (Figure 2.2).
Figure 2.2: One-legged Karate Stances Mimicking Animals

A) Neko Ashi (Cat Stance)
B) Tsuru Ashi (Crane Stance)
C) Kagi Dachi (Hook Leg Stance)

(Ôyama 1967)

The observation of animals is intended to provide insights into balance and movement, or the “Form” of the animal, the “External” characteristics. To “walk like a cat” means to mimic the balance, fluidity, and stealth of the cat. However, aspects of the “Internal”, are equally important, such as the Shen (Spirit, Awareness, or Consciousness). Thus one must also practice “internally” so that: “…the shen (spirit) is like that of a cat about to catch a rat.” The three primary arts within the Nei-Chia (Internal System) are T’ai Chi (Supreme Ultimate), Hsing-I (Form Mind), and Pa-Kua (Eight Trigrams).
2.3.5 Chinese Medicine

The blood circulating is similar to the moon and sun.

The origin of traditional Chinese medicine is credited to the legendary emperors Yao Wang and Shen Nong and dates to around 3,500 B.C. The first written record of herbal pharmacology is credited to the “Yellow Emperor” Huang Di (2,698-2,587 B.C.). The practice of herbal medicine (Zhong Yao) was systematized into a science during the Han dynasty by Zhang Zhongjing (160-200 A.D.). Zhang developed a system of diagnosis and treatment of illness based on the theories of Yin-Yang (complementary forces) from Taoism, and the Five Elements or Phases (Metal, Water, Wood, Fire, and Earth) of Chinese Cosmology. Formulae of herbal remedies were notated for each specific illness and injury. Hua Tuo (141-208 A.D.), a Han dynasty physician and martial artist, used herbs as anesthetics during surgery and during hydrotherapy for the treatment of injuries. Hua advocated the maintenance of “a healthy life” through a lifestyle that emphasized exercise and proper diet. Hua also developed a system of therapeutic exercises based on the behavior and movement characteristics of the crane, tiger, bear, deer, and monkey. The intent of this system was to improve physical fitness and physiological and mental health while practicing martial skills. The exercises were designed to stimulate specific organs and to improve the circulatory, respiratory, and digestive systems (McCarthy 1995).
Concurrent with herbal medicine a system of therapy involving acupuncture, moxibustion (cautery), massage, and breathing exercises (Qigong) was developed. Chinese physicians observed that specific points on the body were related to physiological processes and became hypersensitive in response to certain illnesses. These “vital points” were found to be aligned along fixed paths. Each series of vital points was thought to be linked to specific organs by routes known as meridians. These meridians were thought to be internal energy pathways along which Ch’i (life energy) flowed. During therapy specific vital points were stimulated by needles, heat, or massage.

By the Northern and Southern Dynasties Period (265-581 A.D.) the “Meridian Flow Theory” was developed. An Imperial family doctor and acupuncturist, Xu Wenbo, developed a system of treatment based on the body’s daily bio-rhythm. Xu found a correspondence between the changes in the flow of energy along the meridians and the body’s daily physiological cycle. He believed that the circulatory and respiratory systems followed a cyclic pattern much like the movement of the earth through the heavens.

By the start of the Song Dynasty (960 A.D.) 350 vital points were established. Prior to the Song Dynasty all representations of anatomy and the location of the vital points were through manuscripts. In 1026 A.D. the Emperor Renzong attempted to standardize the training of physicians. He instructed his imperial medical officer Wang Wei to construct models depicting the location of the vital points. Wang designed a three-dimensional model of the human body showing
the locations of the vital points, meridians, and the internal organs. He cast two models in bronze which became known as the Bronze Men. This system was improved by Gao Wu a physician during the reign of Emperor Jia Jing (1522-1567 A.D.). Gao Wu developed models showing the anatomical differences between men, women, and children.

The Taoist monk Chang San-feng (1279-1386 A.D.) experimented with striking the vital points of prisoners and animals while developing T'ai Chi Ch'uan (Supreme Ultimate Boxing). During the Ming dynasty (1366-1644) Feng Yiyuan further refined this system of vital point striking. Feng studied how one’s blood flow and physiology changed during the solar and lunar cycles and with the time of day. Feng then developed a self-defense system based on the striking of specific vital points during specific times of the day. Thirty-six of these vital points were found to be preferred targets on an opponent which, when struck with a martial technique, would cause maximum effect. Later, this system was further developed by the Southern Shaolin monks who identified a total of 108 vital points (McCarthy 1995). Martial techniques were defined for use on each of these points. The Quan, meaning “Fist”, a standardized boxing system, or a movement pattern, were established and named after the number of vital points being attacked. For example the Quan Seisan was developed to define attacks to thirteen vital points.
These Quan greatly influenced the development of Karate Kata (movement patterns) on Okinawa. Many traditional Okinawan Katas are named after this system of Quan. One example is the Isshinryu Kata Seisan (Thirteen). Feng’s original thirty-six vital points appear in the Bronze Man diagram in the Bubishi, the Chinese treatise on war. This system of combining the medical knowledge of vital points with the body’s daily bio-rhythm greatly influenced the development of the Martial Arts. The spread of this knowledge to Okinawa at the end of the Ming Dynasty was a major influence in the evolution of the indigenous Okinawan Ti into modern Karate. This influence can be seen in one of the eight aphorisms of the Okinawan Isshinryu Kenpo Gokui (Higher Knowledge):

_The blood circulating is similar to the moon and sun._

*(Dorow and Liskai 1969, p. 2)*

### 2.4 A Book of Five Rings

*Teach your body strategy*

Miyamoto Musashi (1584-1645), one of Japan’s most famous samurai, wrote his guide to martial strategy the Go Rin No Sho (A Book of Five Rings) while living in seclusion in a cave. In Buddhism the Go Rin (Five Rings) represent: the head, the left and right elbows, and the left and right knees. Musashi presents his guidance in the form of five books: Ground, Water, Fire, Wind, and Void. In Buddhism these are the Go Dai (Five Greats) that make up the Cosmos (Musashi 1982).
In Go Rin No Sho, his treatise on the Do (The Way) of Heiho (Soldier Method), he emphasizes timing, posture, and movement. He states that the five books are mainly concerned with timing:

*There is timing in everything….Timing is important in dancing and pipe or string music, for they are in rhythm only if timing is good. Timing and rhythm are also involved in the military arts, shooting bows and guns, and riding horses. In all skills and abilities there is timing.* (Musashi 1982, p. 48)

Musashi believed that in order to master timing and distance one must practice proper posture and footwork. He describes the proper body alignment and the correct position of the shoulders and hips. In addition, he describes the proper tensing of the abdomen and legs. He believed that one must study and improve natural posture and movement:

*In all forms of strategy, it is necessary to maintain the combat stance in everyday life and to make your everyday stance your combat stance.* (Musashi 1982, p. 54)

Many of these concepts predate Musashi, as several times he quotes “oral tradition”. For example:

*“Oral Tradition: “Teach your body strategy.””* (Musashi 1982, p. 66)

Equally important in the martial arts is the movement of the feet. The systematized study of Hokojutsu (walking techniques) is very old. This discipline
is believed to have evolved from the Amatsu Tatara (Heavenly Secret Teaching); a collection of scrolls which date from around 500 B.C. Musashi studied and compared the various systems of walking and advocates the use of In-Yo (Yin-Yang) stepping in which neither foot is favored. He describes various other methods of footwork that were commonly practiced in other martial arts systems: floating foot, jumping foot, springing foot, treading foot, crow’s foot, and various other walking methods. The existence of so many precisely defined systems of walking indicates that the study of posture and movement was widespread. These systems were studied earnestly since during Musashi’s lifetime duels were often fought to the death. However, Musashi found that these systems were unsatisfactory.

_In my strategy, the footwork does not change. I always walk as I usually do in the street. You must never lose control of your feet._ (Musashi 1982, p. 90)

Musashi believed that his mastery of timing, posture, and movement allowed him to maintain his balance while he took advantage of his enemy’s unbalance. This he did by winning more than sixty duels. He attributed his success to both his natural abilities and to his intense study of posture and movement. Throughout his lifelong study of the “Way of the Martial Arts”, Musashi sought to understand the “natural principles” underlying balance and movement.

_Please it was because of some natural talent in this pursuit or because I did not deviate from the natural principles._ (Funakoshi, Nakasone et al. 2003, p. 112)
2.5 Bubishi

*Distancing and posture dictates the outcome of the meeting.*

The Bubishi is a Chinese treatise on the art of war published in 1621 during the Ming dynasty (1366-1644) and is a compilation of many ancient documents (McCarthy 1995). This collection of works demonstrates that the search for the “Principles of Movement” is very ancient. The word Bubishi is composed of three ideograms: Bu (military), Bi (preparation), and Shi (record). In this text, many concepts relating to balance and movement are discussed. The control of balance is gained through training in Quanfa (Fist Way). One of The Eight Precepts of Quanfa states:

*Distancing and posture dictates the outcome of the meeting.
(McCarthy 1995, p. 160)*

The text states that “perfect balance” is required for proficiency in combat. By mastering balance, one can both recognize unbalance, and create unbalance, in an opponent’s posture. One’s posture must be “evenly balanced” so that the footwork and hand techniques support each other for both stability and mobility:

*The body generates the power and hands serve as the instruments of contact.* (McCarthy 1995, p. 66)

In addition to proper posture and balance, the Bubishi describes the correct way to move in order to maintain balance. These concepts are discussed in the section “Principles of Movement” and include the proper foot placement, length of
step, direction of foot movement, use of the legs, and proper breathing. The importance of balance in relation to external perturbations is also mentioned. The body must be “resilient like a willow branch” in a strong wind but then when the wind subsides “the bough spontaneously resumes its posture”. The Bubishi also mentions the use of posture for either increased mobility or increased stability. When the body is raised it “resembles a giant ocean wave knowing no resistance”. Also when necessary one can become immovable, “like a majestic mountain”, by assuming a stable posture, exhaling, and contracting the muscles (McCarthy 1995, p. 65). In addition to balance, movement, and skill development, the Bubishi also contains chapters concerning the maintenance of health. These articles include discussions on the preservation of health through exercise and the treatment of illness and injury. There are three major areas of study: herbal pharmacology (Zhong Yao), meridian channels, and vital points.

### 2.6 Karate-Do

*The body adapts to changes in time and situation.*

The version of the Bubishi that was transmitted to Okinawa is believed to have been produced sometime during the Qing dynasty (1644-1911), but no one knows for sure, as it contains neither a date nor an author’s name (McCarthy 1995). This document is very difficult to interpret as it is written in Fujianese, a Chinese dialect. It also contains local Okinawan idioms and some characters which are no longer in use. To compound the problem inaccuracies and
omissions are present due to the repeated hand-copying of the documents over many years (Funakoshi 2001). These writings were absorbed by the Okinawans who then reinterpreted and incorporated the techniques and philosophy into their indigenous martial art Ti (Hand). Since that time Ti has further developed to produce modern day Karate-Do (Empty Hand Way).

2.6.1 Karate and Fitness

From its beginnings Karate was practiced not just as a means of self-defense but as a lifestyle of health and fitness. However, the knowledge of this lifestyle was not well known outside of the secretive traditional martial arts systems until the beginning of the 20th century. Even considering the secrecy of the training, it is surprising that Karate was not well known given the geographic location of Okinawa. The Ryukyu Islands (Okinawa) are an archipelago of 55 islands that stretches 700 miles from the southernmost island of Japan southwest to Taiwan. As such, for centuries it played a central role in the maritime trade routes between Japan, China, and Southeast Asia. For most of this time, Okinawa paid tribute to China, and many Chinese immigrated to Okinawa as diplomats and traders. In 1609, Japan invaded and seized control of parts of the Ryukyu Kingdom. However, in an effort to ease tensions with China, the Japanese were prohibited from traveling to Okinawa unless they had special permission from the Shogun. The Okinawans were also considered inferior to the Japanese and it was forbidden for the Okinawans to learn Japanese. Thus, Japan was
essentially insulated from Okinawan culture and Karate. In 1879, Japan officially annexed the islands and abolished the Ryukyu Kingdom (Kerr 1958).

It was not until the Meiji period (1868-1912) that the value of Karate for improving physical and mental health was first officially recognized, even within Okinawa. During this time, both a formal educational system, and a military conscription system were instituted. Both of these systems required the candidates to undergo a physical examination. The examining physicians found that Karate practitioners were clearly more physically fit than the other candidates. The commissioner of public schools submitted a report to the Ministry of Education recommending that Karate be included in the physical education programs of the Okinawan public schools. This recommendation was instituted in 1902. In 1906, Gichin Funakoshi (1868-1957), an Okinawan school teacher, toured Okinawa giving public demonstrations. This was probably the first time that Karate was demonstrated in public (Funakoshi 1973).

Yasutsune Itosu (1813-1915) was also a strong proponent of the use of Karate for physical fitness and was the first to teach Karate in the Okinawan Dai Ichi junior high school. In 1908 he proposed that Karate training be incorporated into the curriculum of all school systems:

Karate masters have lived longer because it develops muscle and bone, helps the digestive organs, and improves the circulation of the blood. Therefore, karate should be practiced in physical education courses in elementary schools and up. (McCarthy 1987, p. 57)
In 1916, Gichin Funakoshi a student of Itosu’s, was asked to give a demonstration of Karate in Japan. This was the first time that Karate was publicly demonstrated outside of Okinawa. In 1922, Funakoshi again demonstrated Karate at the First National Athletic Exhibition in Tokyo held by the Ministry of Education. Soon afterward Karate was incorporated into the curriculum of many Japanese universities (Funakoshi 1973). Thus, Gichin Funakoshi is recognized as the “father of modern day Karate”. His efforts greatly assisted in Karate’s development from a secret system of self-defense into a recognized Japanese Budo (Stop Conflict Way). A true Budo is practiced as a means toward self-perfection and wisdom, and combines skill development with philosophy and mental and physical well-being. A fundamental concept in all Budo is the interrelationship of the physical form and the mind. Funakoshi emphasized the value of Karate for physical, mental, and spiritual development. He was also instrumental in changing the characters used to represent Karate. Initially the indigenous Okinawan martial art was called Ti or Te (Hand). Through centuries of influence from Chinese martial arts and philosophy the character for Ti was gradually replaced by characters representing Chinese Hand. At the time of Funakoshi the characters were changed to mean Empty Hand. In 1925, Gichin Funakoshi referred to the Bubishi’s Eight Precepts of Quanfa as “Eight Important Phrases of Karate” (Funakoshi 2001). This and many other similarities indicate that Funakoshi drew many of his ideas directly from the Bubishi. He too studied and understood the importance of posture and stability. He interpreted one of the Phrases as:
The body adapts to changes in time and situation.  
(Funakoshi 2001, p. 175)

2.6.2 Karate and Posture

The concept of proper Kamae (posture or position of preparedness) is taught throughout the Okinawan martial arts. In 1922 the first text on Karate was published and in it Funakoshi states the importance of a stable stance:

*We, the individuals of Okinawa, have innately observed this fact, even as children fighting, that by the posture and stance of the body can an outcome be altered.* (Funakoshi 1997, p. 10)

Funakoshi also defines seven stances and the necessity of mastering them:

*Since karate depends in a very real way on the stability of the hips and not just on the use of the arms, length of stride and positions of the feet must also be practiced with particular thoroughness.* (Funakoshi 1973, p. 41)

*As yin and yang have no beginning, and movement or non-movement do not appear, who can win but one who knows the Way?* (Funakoshi 1973, p. 212)

In addition to stationary Kamae, the Karate student must learn how to smoothly transition from one position to another. Series of Kamae, martial techniques, and footwork are combined to form standardized movement patterns known as Kata. When performing these Kata, the student must follow a strictly defined geometrical pattern of movement lines called an Embu (demonstration) Sen (line). There are over fifty such Kata in Okinawan Karate. Many of these Kata were derived from the indigenous Ti. Previously much of Ti was systematized
and practiced through traditional Okinawan folk dances (Funakoshi 2001). Some of the current Kata were developed from the earlier Chinese formal exercises of Five Form Fist with their insights from the study of animal movement. Other Okinawan Kata were influenced by the Southern Shaolin system of Quan based on the striking of vital points. An example of this is the Isshinryu Kata Seisan (Thirteen). Another great influence on Karate Kata was the Chinese system of Luohan Quan (Monk Fist). This form of Kung Fu (Gong Fu) emphasized the development of Qi, strength, and stance stability by focusing on the horse and Saam Chien (hourglass) stances. This type of training is demonstrated in the Isshinryu Kata Sanchin. Also each Kata has distinct breathing patterns that are practiced in coordination with the movements. The intent of this system of Kata is to develop mental concentration, reaction time, physical fitness, and the coordination necessary to maintain stability and to maximize the efficiency of movement.

In his Niju Kun (Twenty Precepts) Funakoshi advocates that beginners should practice low stance and posture. Once these are mastered, the advanced student can then better maintain “natural” body positions. Funakoshi’s seventeenth principle states:

*Kamae (ready stance) is for beginners; later, one stands in shizentai (natural stance).* (Funakoshi, Nakasone et al. 2003, p. 93)

In all facets of training Funakoshi stressed the importance of striving for the goal of “natural” movement and posture. One of his favorite sayings was:
Don’t go against nature.
(Funakoshi, Nakasone et al. 2003, p. 124)

When practicing Kamae one must not just focus on the position of the body; the proper state of mind is equally important. Even when in a resting posture, one remains alert and prepared to react by maintaining Zanshin (remaining mind) (Funakoshi 1973). The proper body posture is composed of three elements which are of equal importance: attitude, judgment, and skill. The posture chosen depends on the Ma-ai (distance and time harmony). The concept of Ma-ai also consists of three elements: time, space, and the psychological nature of the situation (Sakagami 1974).

The concept of Kamae, both physical and mental, is often compared to the characteristics of a pond’s surface. The 17th century Ryukyuan Confucian scholar Tei Junsoku describes the proper Kamae mental state as:

My mind, calm and clear, like water without ripples bearing a reflection. (Funakoshi, Nakasone et al. 2003, p. 98)

An unperturbed mind coupled with a stable position allows one to perceive the environment correctly and to respond instantly and effectively. However an agitated and confused mind resembles disturbed water. Ripples in the water’s surface will cause distorted reflections and multiple images. A perturbed Kamae prevents one from functioning effectively.
Confounded with multiplicity, one grows confused and freezes, unable to move the hands and feet in a coordinated effort. The confused mind is the cause of injury, the basis of error. (Funakoshi, Nakasone et al. 2003, p. 98)

The study of the physical and mental aspects of Kamae exists in all martial arts. The various Kamae are strictly defined and have been developed through the research and experiences of past masters. They have been chosen for their efficiency and effectiveness. A beginning Karate student is required to adhere to these strictly defined physical and mental concepts until they are mastered. However, this has a tendency to restrict the free execution of technique. As a student progresses they should become less concerned about the Kamae. This allows them to develop the ability to move and change position freely. Thus, a seemingly contradictory traditional precept of Karate states:

*In Karate there is no Kamae.*

(Funakoshi, Nakasone et al. 2003, p. 94)

This reinforces that the study of proper posture and movement evolves through stages until an adherence to strict form is no longer required. By mastering the strictly defined physical and mental forms one is eventually able to develop a free mind. Funakoshi’s sixth principle states:

*The mind must be set free.*

(Funakoshi, Nakasone et al. 2003, p. 43)

This free mind allows one to respond to an opponent’s movements without having to mentally prepare either for an opponent’s attack or one’s response. This developmental process towards a free mind is an important concept
underlying the study of Kamae and Kata and is referred to as Shuhari. Shu is the faithful practice of the traditional forms. Ha refers to the adaptation of the original forms to conform to the student’s particular physical characteristics. Ri is the eventual physical mastery and mental enlightenment (McCarthy 1987). This reflects the ultimate goal of Karate training. Through the careful study of proper body posture and mental state, one discovers the true meaning of the Way.

2.7 Kenpo Gokui

* A person’s unbalance is the same as weight. *

In Okinawa, insights into timing, posture, and movement have been passed down from master to student for many generations through a collection of aphorisms known as Kenpo Gokui or “Fist Way Higher Knowledge” (Uezu 2004). Gokui can also be interpreted as “Hidden Knowledge” which is only revealed to the most perceptive students. These aphorisms are meant to guide the physical and mental development of martial arts students. There are few written accounts of these precepts since at the time there was a tradition of strict secrecy in the martial arts. In addition, only a select few students were chosen to receive instruction which was usually through Kuden (traditional oral instruction).

Although the Kenpo Gokui exist in various forms, and can be interpreted in many ways, they all share a common origin in the Bubishi. Thus there is no way of determining the age or exact source of the Kenpo Gokui. In the Bubishi they are referred to as the Eight Precepts of Quanfa (Fist Way).
The great Okinawan Master Tatsuo Shimabuku (1908-1975) used concepts drawn directly from the Bubishi when he developed Isshinryu (One Heart Way) Karate. Master Shimabuku received instruction in the Bubishi from one of his instructors, Chojun Miyagi, who brought the Bubishi to Okinawa after studying in China. In 1960, Master Angi Uezu first recorded the Isshinryu Karate version of the Kenpo Gokui as taught to him by Master Tatsuo Shimabuku (Uezu 1960).

This document is written in Kanbun a terse classical Chinese literary form. The version of the Kenpo Gokui shown below (Figure 2.3) is Master Uezu’s reinterpretation using modern forms of the older characters that appear in Master Shimabuku’s original version. Master Uezu states that, in the “Original Form”, the characters are written in a “very old style” and that the document is considered “classify [sic] information” (Uezu 2005). Thus, Master Uezu has asked the author not to publish his in depth analysis of the Kanji. In addition, the documents are written in Uchinaguchi, the ancient Okinawan language. The specific Hogen (dialect) of Uchinaguchi spoken varies according to specific regions in Okinawa. The interpretation of the Kanji would thus vary depending on the region.

The Okinawan Master’s insights into balance, control of movement, and timing can be seen in the Kenpo Gokui aphorisms:

A person’s unbalance is the same as weight.
The body should be able to change direction at any time.
The time to strike is when the opportunity presents itself.

(Dorow and Liskai 1969)
These are three of the eight aphorisms of the Kenpo Gokui or “Code of Isshinryu Karate” as taught by the great Okinawan Karate master, Tatsuo Shimabuku (1908-1975) (Dorow and Liskai 1969; Armstrong and Alevizon 1984). Master Stuart A. Dorow learned Isshinryu Karate and this version of the precepts during the 1960's while he was serving with the U.S. Marine Corps in Vietnam. He discussed the true meaning of the Kenpo Gokui with Master Shimabuku while training with the master in Okinawa in 1970 (Dorow 2005).

![Figure 2.3: Kenpo Gokui: Fist Way Higher Knowledge.](image)

The exact meaning of some of the ideograms in the Original Form is unclear as some have either been modified or are no longer in use. In addition, there are no Furigana (phonetic characters) which are necessary to help establish the exact interpretation of the Chinese ideograms. Master Uezu notes that his interpretation is “Karate-Do Kun” (Uezu 1997). This is generally interpreted as “Karate Code”. However, the term Kun is also used to indicate that this is a native Okinawan rendering of Chinese characters. This further reinforces that this version of the Kenpo Gokui is an Okinawan Karate version of the precepts. Master Shimabuku taught only three people the correct interpretation and intricacies of the Kenpo Gokui (Uezu 1997). In turn, Master Uezu says that he has taught only a few students, “But never been questioned about it.”, until these discussions with the author (Uezu 2005).

The lines of Kanji of the Kenpo Gokui are normally read vertically from top to bottom, and from right to left; however they can be combined in various ways to produce other readings. The lines of Kanji are not sentences. These groups of Kanji are meant to elicit multiple concepts and associations in the mind of the student. For example, the fourth line of Kanji is presented below by two Okinawan Masters (Figure 2.4). One is intended to provide a basic understanding of the Kanji; the other represents an intermediate level.
Figure 2.4: Kenpo Gokui Fourth Line

A) Basic Level Reading. Calligraphy by Master Angi Uezu (Uezu 2004).

B) Intermediate Level Reading. Calligraphy by Master Kichiro Shimabuku (Shimabuku 2007).

The above basic level reading of the Kanji is based on the modern Japanese reading of the Kanji which are usually interpreted as:

\[
\text{Position Advance Pass Separate Meet} \\
\text{(Uezu 1973)}
\]

However, Master Tatsuo Shimabuku transliterated the fourth line of the "Original Form" Kenpo Gokui as:

\[
\text{A person’s unbalance is the same as weight.} \\
\text{(Dorow and Liskai 1969)}
\]
The discrepancy arises from several sources. First, there is a difference in the readings of the Kanji based on whether one is using a modern form of the Kanji or an older version. In addition, the Okinawan readings of the Kanji differ slightly from both the Japanese and Chinese. Also, there are various local dialects in Okinawa, thus each region of Okinawa has slightly different readings of the Kanji. The interpretation of the true meaning of the Kanji can also differ depending on one’s knowledge and insight. Thus, the meaning of the Kanji can differ depending on the individual Master and the level of the student being taught.

The concepts represented in the Kenpo Gokui are symbolized by the Go Shujin Sama (Protecting Goddess) of Karate, also referred to as Mizu Gami (Water Goddess). Mizu Gami symbolizes unity and balance despite perturbation (Figure 2.5).
Figure 2.5: Mizu Gami  Photograph of oil painting in Master Tatsuo Shimabuku’s Dojo in Agena Okinawa. (Dorow and Liskai 1970)
2.8 Summary

Throughout the history of the martial arts all cultures have demonstrated a common approach to the study of posture, movement, and skill development. The effectiveness of this approach can be seen in that it has survived basically unchanged for at least several thousand years. An obvious result of an effective martial system is that the culture is better able to withstand threats to its security. Another major reason for its longevity is that the martial arts have been systematized by each culture. Thus, standardized approaches to training were passed to succeeding generations through art, cryptic philosophical writings such as the Kenpo Gokui, and traditional oral teachings. An additional factor contributing to the longevity of this “physical culture” is that each culture considered physical skill to be only one facet of a holistic approach to both health and the perfection of the human character. Each culture recognized the importance of combining skill development with physical and mental health, fitness, and philosophy.

Perhaps the most important factor is that each culture emphasized that martial training is a lifestyle that should be practiced one’s entire life. Researchers wishing to study the effects of martial arts training on balance should consider these concepts. Such systems are potentially a very effective way to improve balance, control of movement, and health. However, short-term training programs may only produce very limited results. Martial arts training will be most
effective if one is willing to continue to practice the skills on a regular basis and to make long-term lifestyle adjustments.
CHAPTER 3

BALANCE: FROM PHILOSOPHY TO LAW

A person’s Heart is the same as Heaven and Earth.

3.1 Introduction: Cosmology of Complements

T’ai Chi (Great Ultimate) is a philosophical concept in Chinese cosmology referring to the evolution of the Universe from the Wu Chi (Void) into the complementary forces of Yin (passive) and Yang (active). The origin of the Yin-Yang theory dates to at least the beginning of the Xia Dynasty (2100 B.C.). By the start of the Zhou Dynasty (1066 B.C.) a fully developed theory was recorded in the first complete version of the I-Ching (Classic of Changes). It was further developed and refined by students of Confucius during the Warring States Period (475-221 B.C.) and recorded in the I-Zhuan (Commentary on the I-Ching). Thus, the cosmological concept of balance, despite continuous change and transformation, has an origin in the I-Ching.

The complementary forces of Yin and Yang interact to form a central balanced state. Within this system man interacts and maintains a balance, both philosophically and physically, with Heaven (Yang) and Earth (Yin). In this context Heaven represents the general environment or the macroscopic; Earth
represents the immediate environment or the microscopic. Man is affected by
the energies of both environments and thus represents a microcosm of the
Universe. This ternary system of Heaven, Man, and Earth forms the basis of
Chinese cosmology and defines many other sets of relationships. It has also
greatly influenced the study of balance, movement, and the development of the
martial arts. As the first aphorism of Karate’s Kenpo Gokui states:

A person’s Heart is the same as Heaven and Earth.
(Dorow and Liskai 1969, p. 2)

Since all things in the Universe interact, nothing exists independently. The
ancient Chinese knew that this has important implications for the study of
universal phenomena. Phenomena that cannot be perceived on the
macrocosmic level still affect the microscopic. Thus one must strive to “see” the
hidden harmony. As stated in the Kenpo Gokui:

The eye must see all sides.
The ear must listen in all directions.

Thus, through the development of the senses, and the study of posture and
movement, phenomena occurring at the microscopic level can then be perceived
by man. That which can be sensed can be better understood and controlled.
Thus, through the study of the inner workings of man, one can arrive at an
understanding of universal laws.

This chapter will explore the origin of philosophical concepts relating to balance,
order, and change. We will see a progression of growth and complexity, from a
simple binary system of divination based on “yes” and “no”, to the complementary interaction of the “elements”, to complex systems of postural control and movement. These beliefs eventually developed into what the ancients believed were “laws” of the cosmos. These systems formed the basis for what later gave rise to our current “laws of science” and the scientific method; with new ways of “seeing” the hidden truths. With these methods we can now explore the concepts of balance and change that fascinated the ancients.

3.2 Pa-Kua: Eight Trigrams

The I-Ching was originally a compilation of linear signs used as oracles to answer either “yes” or “no”. Yang (yes) is represented by a single unbroken line (——), and Yin (no) by a single broken line (— —). As the system further developed, these Yang and Yin signs were grouped in threes (trigrams) to provide more elaboration and discrimination in answers. This eventually led to the development of Pa-Kua (Eight Trigrams). The Pa-Kua diagram symbolically represents the T’ai Chi philosophy. The eight trigrams are positioned at the eight directions and encircle the T’ai Chi symbol of Yin and Yang. This center represents the ideal state of balance. The Pa-Kua symbol represents both the Cosmos and the inner workings of the body (Figure 3.1).
Time and space, represented by the four seasons and four cardinal directions, are included in this system. In addition, each trigram is assigned a name, an attribute, an image, and a body part. Concepts of movement, balance, and stability are also included in this system. For example, the trigram Chen

Figure 3.1: Pa-Kua: Eight Trigrams

*This is one possible arrangement of the eight trigrams surrounding the T’ai Chi symbol of Yin and Yang.*

(Smith and Pittman 1990)
(Arousing) has the attribute of “inciting movement and vibration”, is represented by the image of thunder, and is associated with the liver and the throat. The trigram Ken (Keeping Still) has the attribute of “resting”, the image of a mountain, and is associated with the back and the hands and feet. The trigram K’an (Abysmal) has the attribute of “dangerous”, is represented by water, and is associated with the kidneys and the ears (Smith and Pittman 1990).

3.3 The Five Crossroads

By 400 B.C., ancient Chinese cosmology had established the Five Element (or Phase) Theory. This theory expounds that there are five basic elements (Wu Hsing) which combine to form all matter and natural phenomena: metal, water, wood, fire, and earth. In the most ancient writings the expression “Wu Hsing” meant “Five Crossroads”, but it can also mean “five goings” or “five phases”. In this sense, the elements are used to describe interactions between phenomena. These five phases interact in cycles of generation and restraint or destruction (Figure 3.2). Through these interactions everything is maintained in kinetic balance. This theory is applied to all aspects of man and the environment. The earliest mention of the Five Elements occurred in Chinese texts on astrology, philosophy, and politics. The earliest of these texts was a political treatise written between the tenth and fifth century B.C. (Matsumoto and Birch 1983). The Five-Element Theory, in conjunction with the Yin-Yang Theory, formed the basis of ancient Chinese models of both nature and dialectics.
The fundamental principles of balance and the relationship of the body to the environment are set forth in the Yellow Emperor’s Internal Classic of Medicine (Huang Di Nei Jing). Known as the Nei Jing, it is the oldest Chinese medical text still in existence and forms the basis of Traditional Chinese Medicine (TCM). The Nei Jing, written sometime between 770 and 221 B.C., was compiled from...
several more ancient texts (Cheng 2000). The Nei Jing is the first known text to apply the principles of the Five Elements to the body and the study of medicine. During the second through fifth century, Buddhist monks from India greatly influenced Chinese concepts of health. These monks introduced the idea that health was based on an equilibrium of four components of the body: earth, water, fire, and wind (Draeger and Smith 1980). TCM absorbed the Indian concepts of health and modified them based on the Yin-Yang and Five-Phase theories.

In TCM, each of the five phases is correlated with specific organ systems, senses, emotions, symptoms, environmental stressors, body orientations, and therapies. The Jing Luo or meridian system is another important TCM concept formed during this period. According to TCM, the meridians connect the organ systems and transmit vital energy (Ch’i or Qi). Emphasis on disease prevention fostered the development of diet and exercise therapies to improve health. During the second century A.D., ancient meditation and physical exercise systems were combined to develop exercises based on the movement characteristics of five animals. This approach eventually led to the development of T’ai Chi Ch’uan. Thus, the ancient TCM practitioner sought to restore the body’s physiological and postural balance through treatments such as diet, simple surgery, drugs, acupuncture, hydrotherapy, and physical exercises (Hong 2004).
3.4 Thirteen Postures

T’ai Chi philosophy absorbed these concepts of body equilibrium and developed a theory for balance and movement based on matching the five basic elements of cosmology with five characteristics of movement. Chang San-feng (1279-1386 A.D.) wrote the earliest of the T’ai Chi Ch’uan Classics: T’ai Chi Ch’uan Ching. In this work, Chang defines the eight trigrams:

\[ P’eng \text{ (wardoff)}, \, lu \text{ (rollback)}, \, chi \text{ (press)}, \, an \text{ (push)}, \, ts’ai \text{ (pull)}, \, lieh \text{ (split)}, \, tsuo \text{ (elbow)}, \, k’ao \text{ (shoulder)}, \text{ are the eight trigrams.} \]

He then assigns each of the eight trigrams to one of the eight directions (four cardinal and four diagonal). To this system, he adds the five characteristics, or elements, of balance and movement:

\[ \text{Step forward, step back, look left, look right, and central equilibrium are metal, wood, water, fire, and earth.} \]

\[ \text{Together these comprise the thirteen postures. (Lo 1979, p. 27)} \]

These eight directions and the Five Elements thus comprise the thirteen basic concepts and movements of T’ai Chi.

Wu Yu-hsiang (1812-1880), in his classic “Expositions of Insights into the Practice of the Thirteen Postures”, expounds on these concepts. He indicates the importance of proper balance in resisting perturbations:

\[ \text{Be as still as a mountain, move like a great river.} \]

\[ \text{The upright body must be stable and comfortable to be able to support (force from) the eight directions. (Lo 1979, p. 55)} \]
These early classics also demonstrate insights into the variability inherent to postural stability. The Yin and Yang concept of balance despite continuous change influenced ideas of body weight distribution in posture and movement. During practice of forms in the Internal Arts a 50-50 weight distribution on the legs is not maintained. This is referred to as “double weighting”. Constantly shifting weight from one leg to the other allows one to distinguish Yang (full) from Yin (empty). This enhances balance and freedom of movement. Wang Tsung-yueh (1736-1795), in his classic “T’ai Chi Ch’uan Lun” states several of these principles:

- *Stand like a balance and rotate actively like a wheel.*
- *Sinking to one side is responsive; being double-weighted is sluggish (stagnant).*
- *Yin and Yang mutually aid and change each other.* (Lo 1979, p. 38)

The above examples illustrate how cosmological concepts such as T’ai Chi, Tao, Yin-Yang, Wu Hsing, and Ch’i, were absorbed into many aspects of Chinese culture. The fundamental cosmological principle is that the Universe and man are interconnected and are subject to the same laws. The internal workings of the human body are a microcosm of the Universe. According to the T’ai Chi philosophy, the I-Ching’s concept of Yin-Yang leads to the Tao (Way or Path) for the development of the mind, body, and spirit. By following the Tao, one harmonizes both internally and externally with the Universe, and thus one achieves T’ai Chi, the Great Ultimate. The body’s equilibrium is maintained
through the Wu Hsing cycles of generation and restraint. Both the internal and external parts of the body are interconnected through meridians and the flow of Ch’i. Thus, the T’ai Chi philosophical concept of balance, despite continuous change and transformation, greatly influenced the development of Confucian and Taoist thought, the natural sciences, Traditional Chinese Medicine (TCM), and the martial arts. In TCM and the martial arts, the I-Ching concept of balance encompasses three interconnected systems: the physiological, the psychological, and the postural.

3.5 Balance: Mind, Body, Spirit

*A person’s unbalance is the same as weight.*

The concept of balance lies at the core of all martial arts. Within these systems, a balance is sought between the physical, mental, and spiritual aspects of training. These components interact with each other to maintain homeodynamics. Balance is also sought within each component of the system. For example, physical balance is a key component of movement and skill development. The importance of this concept is demonstrated by the Kenpo Gokui aphorisms of Isshinryu Karate:

*A person’s unbalance is the same as weight.*  
*The body should be able to change direction at any time.*  
*{(Dorow and Liskai 1969, p. 2).}
Proficiency in the martial arts requires the control of balance, both in movement and in static posture. This reflects the concept that “Boxing requires movement but the Internal requires stillness.” (Smith 2003, p. 120).

All formal martial arts Katas begin and end with meditation while maintaining a balanced and relaxed standing posture. In Okinawan Karate, there are two such preparatory standing postures. The first stance assumed is Musubi Dachi (Union Stance); the heels are touching with the feet at a 45° angle. Here the practitioner concentrates on clearing the mind, relaxing the muscles, and maintaining postural stability. The Chinese martial arts contain similar postural stability training. Chan Chuang is the meditative process of clearing the mind and positioning the body to achieve a static posture while remaining internally dynamic. In Pa-Kua (Eight Trigrams), this posture is called Wu-Chih (Infinity Posture) (Figure 3.3).
According to ancient Chinese philosophy, the process of Chan Chuang allows one to develop both the mind and the body:

To stand still results in the mind’s settlement, mind’s settlement in tranquility, tranquility in a sense of security, security in wholesome thinking, and wholesome thinking in great accomplishment.

(Smith 2003, p. 114)

The next preparatory position that the Karate student assumes in performing Kata is Heiko Dachi (Balance or Equilibrium Stance), which is also referred to as Yoi Dachi (Prepared Stance). In the Heiko stance, the feet are shoulder width apart and the feet are parallel. The body is erect with the gaze directed straight ahead, the chin pulled in, the shoulders lowered, the abdomen slightly tensed, and the knees slightly flexed. Although the eyes are directed straight ahead, they are not focused on a single spot. Instead, the gaze is intended to provide
awareness of the entire environment. As stated in the Kenpo Gokui: “The eye must see all sides.” (Dorow and Liskai 1969, p. 2). The practitioner concentrates on balancing and awareness in preparation for quickly moving in any direction in response to an attack or perturbation. This alert and prepared mental state is known as Zanshin (Remaining Mind). This stance is one of the most important aspects of the Kata even though the practice of movement has not yet begun.

As the great Karate master Gichin Funakoshi states:

_The Yoi stance is an integral part of any Kata, and one’s level of ability is already clearly evident from this stance._
_(Funakoshi 1973, p. 43)._

Before starting Kata training, the student assumes the preparatory Kamae (Positions), practices breathing exercises, and maintains balance by focusing on an internal point below the navel that approximates their center of mass. In Karate, this point is known as the Tanden, in the Chinese martial arts, it is called the Tan-t’ien (Sea of Ch’i). In classical Chinese medical theory the Tan T’ien is precisely located at 1.3 inches below the navel and three-tenths of the distance from the navel to the spine (Smith 1990). While performing the Kata, the student concentrates on awareness of this center and on maintaining balance. Throughout the Kata, there are many such Kamae (Positions) of balance, preparedness, and awareness. These Kamae represent the unification of the body, mind, and spirit.
After achieving the preparatory balanced state, practitioners of the Chinese Internal martial arts perform movements designed to develop relaxed, balanced postures (Kung Chia). During practice of the forms, one seeks to maintain equilibrium between Yin and Yang, which are in a constant process of transformation. Yin represents stillness and softness, and Yang represents activity and hardness. Proper posture and movement requires concentrating on the principles of Nei-kuo (internally bound) and Wai-ch’eng (externally stretched). Internal binding refers to the sensation of linking the upper torso with the Tan-t’ien. External stretching refers to the extension of the arms during mild isometric contraction. The upper chest is relaxed, the shoulders and elbows are kept down, and the scapulae are held from moving forward (Smith 1990). One aspect of this type of arm movement is that the reach does not extend past the base of support. In all of the postures the gaze is directed forward, the head is erect, the neck and back straight, the sacrum vertical, the buttocks are relaxed, and the knees are slightly bent. The mind is relaxed but focused on the body’s center. The body segments stay coordinated in movement: shoulders with thighs, elbows with knees, and hands with feet (Smith and Pittman 1989).

T’ai Chi Ch’uan (Great Ultimate Boxing), Pa-Kua (Eight Trigrams), and Hsing-I (Form of Mind) are the three branches of the Nei-Chia (Internal System) of Chinese martial arts. The doctrine of the Nei-Chia is Wu-wei: only do what is natural or spontaneous. All three of the internal systems stress that all action comes from, and is controlled by, the I (Will or Mind). Mastery of action and body
movement requires one to remain mentally and physically “still” while the body moves. Only then can true balance, coordination, and natural movement occur. As a Taoist verse states:

*The stillness in stillness is not the real stillness; only when there is stillness in movement does the universal rhythm manifest itself.*  
*(Draeger and Smith 1980, p. 35)*

At a very rudimentary level, the Nei-Chia can be divided into soft (T’ai Chi), hard (Hsing-I), and change (Pa-Kua). However, they are all complementary aspects of one system. The hard and soft represent transitory states that are constantly in the process of change toward their opposite. T’ai Chi emphasizes deep breathing, slow relaxed movement, and subtle yielding; Pa-Kua focuses on remaining internally still and balanced while moving in circles and rotating; and Hsing-I stresses stillness while moving in a straight line and develops rapid movement.

The philosophy of Nei-Chia training is that one is interacting with both the external and internal environments. For example, while performing Pa-Kua, one is walking a circle that symbolizes moving through the Cosmos. At the same time, one is both internally affecting the body and being affected by it. Each of the eight Pa-Kua forms is designed to emphasize one of the principles of the eight trigrams. For example, the form Ta P’eng Chan Ch’ih (Giant Roc Spreads Wings) represents Ken (Stillness) and develops the ability to remain motionless. The Pa-Kua form Yao Fei Li T’ien (Hawk Soars up to Heaven) is correlated with
the Chen (Arousing) principle and develops the ability to move. The principle
K’an (Abysmal) is represented by the form Pai She T’u Shen (White Snake Sticks
Out Tongue). This form helps one remain centered, calm, and prevents
dizziness (Smith 2003). Thus, in just these three forms alone, one finds effective
training for the three main areas of concern in fall prevention: static postural
stability, balanced movement, and fear of falling.

3.6 Unity and Balance Despite Perpetual Change

*And some say that all existing things without exception are in
constant movement, but that this escapes our perception.*

The Chinese cosmological concept of balance, despite continuous change and
transformation, has an origin in the Yin –Yang Theory developed around 2,100
B.C. By 1,066 B.C., a fully developed theory was recorded in the first complete
version of the I-Ching (Classic of Changes). However, it was not until about 500
B.C. that similar theories began to develop in the West. Prior to this time, the
Greeks viewed the Universe as a static system. The principles of nature were
eternal and immutable, as reflected in the nature of their Olympic Gods; it was
only man’s knowledge of these laws that was limited and inconsistent.

The Greek philosopher Heraclitus (c.535-475 B.C.) forever changed the course
of Western philosophy and science when he proposed that the Universe was in a
constant state of flux. Later philosophers such as Plato attributed to him
statements such as:
You cannot step twice into the same river; for fresh waters are ever flowing in upon you.

The sun is new every day.
(Russell 1945, p. 45)

Heraclitus believed that there was unity in the world but that it is brought about by the interplay and synthesis of opposites which produce a harmony. Although he believed that everything is composed of four elements: water, earth, air, and fire; it is fire which is the primordial element; it is fire that serves to transform rather than destroy. Perpetual change is brought about by these transformations as Plato quotes:

…nothing ever is, everything is becoming…
(Russell 1945, p. 45)

Heraclitus believed that the laws of nature were controlled by Logos (λόγος), a principle or law based on reason, knowledge, and order. It is Logos that stabilizes and regulates the interaction of the opposites. Without Logos one cannot perceive the true nature of the Universe:

The hidden harmony is better than the obvious.
(Harris 2012)

The Greek philosopher Plato (c.427-347 B.C.) states that the true philosopher keeps his eye “fixed on the eternal order”. Thus, the structure of society as well as the pursuit of knowledge should be modeled after the “divine truth of nature” (Plato, Jowett et al. 1993). Knowledge and truth can be derived from both the world that can be sensed, and the world of the intelligible. However, in order to obtain this truth one must be able to perceive it through use of a medium. Plato
uses sight as an analogy and states that light is the bond between the eye and the object perceived. To reach the “divine truth of nature” one must have both “sight and light”:

*When the sun shines the eye sees, and in the intellectual world where truth is, there is sight and light.*  
(*Plato, Jowett et al. 1993*)

For Plato, “sight” is provided by Logos (reason), and “light” is obtained through science:

*And will the blindness and crookedness of opinion content you when you might have the light and certainty of science?*  
(*Plato, Jowett et al. 1993*)

### 3.7 Natural Order: Movement and Stability Through Laws

At a time when the sciences are at an early stage of development, Plato already recognizes that they are related. Plato believes that they are connected through a natural order:

*All these sciences are the prelude of the strain, and are profitable if they are regarded in their natural relations to one another.*  
(*Plato, Jowett et al. 1993*)

Plato suggests that the formal educational system should provide training in mathematics, gymnastics, and music. In Plato’s opinion, the “universal or primary science” is mathematics, which he considers to be “a conductor to thought and being” which will lead to truth (*Plato, Jowett et al. 1993*). The essential branches of mathematical education should be arithmetic, geometry,
and “astronomy or the motion of solids” (Plato, Jowett et al. 1993). In addition, other applications should be studied such as the “sister science of harmonical motion” (Plato, Jowett et al. 1993).

3.7.1 The Law of Motion

By the time of Plato, the origin of the theory of constant movement and change is attributed to Heraclitus. Plato summarizes the idea of constant change as proposed by Heraclitus:

Heraclitus is supposed to say that all things are in motion and nothing at rest; he compares them to the stream of a river, and says that you cannot go into the same water twice.

(Plato, Jowett et al. 1993, p. 439)

Plato even proposes that the intent of Homer’s tragedies is to show that “all things are the offspring of a flowing stream of change” (Plato, Jowett et al. 1993, p. 857). Thus at the time of Plato the basis of Greek cosmology is the idea that all things are produced by motion and that anything at rest will perish. Plato states that the greatest masters of philosophy and poetry agree:

Their doctrine that ‘being’, so called, and ‘becoming’ are produced by motion, ‘not-being’ and perishing by rest, is well supported by such proofs as these.

(Plato, Jowett et al. 1993, p. 858)

Like Heraclitus, Plato believes that this basic principle of movement is essential for the maintenance of the heavens, the sun, the earth, and one’s body. However, unlike the constant chaos of the Heraclitian flux, Plato believes that the
principle of system pervades the world. He contends that there are universal and regular characteristics of motion that provide symmetry and balance to the Universe: “the belief that sun, moon, and other heavenly bodies are ‘wandering stars’ of any sort is not true” and “each of these bodies always revolves in the same orbit” (Plato, Jowett et al. 1993, p. 1391). To maintain balance and harmony in both the Cosmos and one’s body, all things must follow the laws of motion:

And again, motion which is never regular or uniform, never in the same compass, nor about the same center, or in one place, motion which has no order, plan, or law, will have kinship with folly of every kind. (Plato, Jowett et al. 1993, p. 1454)

Plato contends that his principle of motion can explain such diverse phenomena as the fall of the thunderbolt, the flowing of water, the projection of bodies, the swallowing of drink, and the effect of medical cupping glasses. Plato believes that they can all be investigated by a similar principle. To explain, he draws an analogy between movement and the qualities and interactions of different sounds: high or low, discordant or harmonic. When a balance in different sounds is achieved, “producing a single mixed expression”, this produces pleasure “being an imitation of divine harmony in mortal motions” (Plato, Jowett et al. 1993, p. 1201). Plato states that all phenomena result from the same basic principles of movement and the combination of certain conditions:

the nonexistence of a vacuum, the fact that objects push one another around, and that they change places, passing severally into their proper positions as they are divided or combined (Plato, Jowett et al. 1993, p. 1201)
3.7.2 The Law of Movement and Health

Plato believes that man is affected by the same principles that produce the “harmonies and revolutions of the Universe” (Plato, Jowett et al. 1993, p. 1209). By learning and imitating these harmonies and movements, one can achieve health, fitness, and the “best life”. According to Plato, this principle of movement affects the health of both the body and the mind:

*Again, the healthy condition of the body is undermined by inactivity and indolence, and to a great extent preserved by exercise and motion, isn’t it?*

*And so with the condition of the soul. The soul requires knowledge and is kept going and improved by learning and practice, which are the nature of movements. By inactivity, dullness, and neglect of exercise, it learns nothing and forgets what it has learned.*

(Plato, Jowett et al. 1993, p. 858)

According to Plato, to be healthy and balanced in both body and soul, one must practice exercise and intellectual pursuit in equal proportion. This balance is produced by movement “in imitation of the pattern of the Universe”. One can imitate this pattern of movement in three ways. The best method of “purifying and reuniting the body” is through gymnastics. The next best is “surging motion” as in sailing. The third method, which should only be used as a last resort, is treatment by a physician. Plato extends this idea of movement and balance to include postural stability. Through exercise and gymnastics the body “is always producing motions and agitations through its whole extent, which form the natural
defense against other motions both internal and external” (Plato, Jowett et al. 1993, p. 1209).

Plato also attempts to explain physiological functions, such as blood circulation and respiration, in terms of the universal properties of movement. For example, although his explanation of the cause of respiration is in error, he demonstrates insight into the effects of respiratory movements: “a circulatory motion swaying to and fro is produced by the double process, which we call inspiration and expiration” (Plato, Jowett et al. 1993, p. 1200). Plato demonstrates another insight into postural stability: “But to speak generally, no man who is using his vocal organs, whether for song or for speech, can keep his body perfectly still.” (Plato, Jowett et al. 1993, p. 1385).

In addition to following the universal laws of movement, Plato believes that a balanced system must contain the proper amounts of the Four Natures: earth, fire, water, and air. In order to function properly, the body must not contain an “unnatural excess or deficit” of these elements nor can any of them change from “its own natural place”. Any “violation of these laws” will produce “disorders and diseases” (Plato, Jowett et al. 1993, p. 1202). Plato summarizes the effect of change on a balanced system such as the body: “When more is taken away than flows in, then we decay, and when less, we grow and increase.” (Plato, Jowett et al. 1993, p. 1202). Plato believes that the most important symmetry is the balance between the mind and body. If the proportion of the two is not correct, or
if either of these are unsymmetrical, then neither can function properly. The unbalanced body becomes “much distressed and makes convulsive efforts, and often stumbles through awkwardness” and the unbalanced mind “convulses and fills with disorders the whole inner nature of man” (Plato, Jowett et al. 1993, p. 1207).

3.7.3 The Unwritten Law: Ancestral Tradition

Plato states that the basis of his ideas for the development of the mind and body is the “unwritten law” of “ancestral and primitive tradition” (Plato, Jowett et al. 1993, p. 1365). To maintain this tradition, Plato proposes the establishment of schools to foster intellectual development and physical culture with training beginning for both sexes after the age of six. Here Plato notes a practical error in early training that puts emphasis on the development of skill by using only one side of the body. Since “nature made all things to balance” (Plato, Jowett et al. 1993), instruction in skill development should not favor one side of the body “so that all of our boys and girls may grow up ambicrural and ambidextrous” (Plato, Jowett et al. 1993, p. 1366). This is especially true in the training of martial skills as it promotes agility and balance:

*A man who has practiced the pancratium, or boxing, or wrestling to perfection does not find himself incapable of fighting with his left; he does not halt or make ungainly lunges if his opponent drives him to shift his position and bring that side of his body into play.*

(Plato, Jowett et al. 1993, p. 1366)
Thus, Plato believes that everyone should train as a warrior and “should be a skilled gymnast and able to fight and balance himself in any position” (Plato, Jowett et al. 1993). The training should be compulsory and “the girls must be trained exactly like the boys” (Plato, Jowett et al. 1993, p. 1375). This training should be of two types the first of which is dance that is intended for physical fitness and which mimics the movements of martial skills. The Pyrrhic (war dance) “depicts the motions of eluding blows and shots of every kind”; contains movements for swerving, leaping, crouching, retreating, and postures for attacking; and mimics the “reproduction of the shooting of arrows, casting of darts, and dealing of all kinds of blows” (Plato, Jowett et al. 1993, p. 1385). The basis of Pyrrhic performance is a focus on maintaining balanced posture:

In these dances the upright, well-balanced posture which represents the good body and good mind, and in which the bodily members are in the main kept straight, is the kind of attitude we pronounce right, that which depicts their contrary, wrong. (Plato, Jowett et al. 1993, p. 1385)

The second type of physical training proposed by Plato is practice in all forms of martial skills both armed and unarmed. Part of this training should be in “stand up wrestling” composed of “exercises in the disengaging of neck, arms, and ribs” (Plato, Jowett et al. 1993, p. 1367). Such physical training benefits both the individual and society whether in war or peacetime.

In addition to advocating the development of physical balance through martial training, Plato espouses many of the same philosophical concepts of balance
that are contained in Karate’s Kenpo Gokui. For example, Plato discusses the process of absorbing and excreting: “the process of repletion and evacuation is effected after the manner of the universal motion” (Plato, Jowett et al. 1993, p. 1202). The third Kenpo Gokui precept states: “The manner of drinking and spitting is either hard or soft.” (Dorow and Liskai 1969, p. 2). Plato also believes that the “universal motion” is found in the functioning of the body’s physiological systems. Plato believes that the body is a microcosm of the Universe and states that the components of blood “which are divided and contained within the frame of the animal as in a sort of heaven, are compelled to imitate the motion of the Universe” (Plato, Jowett et al. 1993, p. 1202). A similar concept appears in Karate as the second aphorism of the Kenpo Gokui states:

*The blood circulating is similar to the moon and sun.*
*(Dorow and Liskai 1969, p. 2).*

Plato contributed greatly to the development of modern western science. Plato’s insight is that the world is both orderly and organic. The living whole is composed of interacting members. According to Plato, systematic processes control the world. Laws control phenomena and these principles are intelligible through reason. True knowledge is obtained through logic and exists in the form of permanent “Forms” or “Ideas”. Plato’s student Aristotle (384-322 B.C.) continued the pursuit of knowledge through logical inquiry and further developed the concepts of movement and balance. He established the world’s first university, the Lyceum, in which he taught a wide range of subjects including
logic, physics, astronomy, biology, anatomy, philosophy, and ethics. Aristotle also believed in the concept of universal motion:

> And some say that all existing things without exception are in constant movement, but that this escapes our perception. (Kirk 1951, p. 41)

### 3.8 Summary: The New Cosmology

The present day understanding of stability, movement, and change has its origins in man’s first attempts to understand his place in the Cosmos. Our present day “laws” of science have evolved from ancient philosophical systems such as the simple “yes/no” binary system of divination found in the origins of the I-Ching. The concepts of Yin and Yang brought forth the complementary nature of the forces that act to produce stability. From this there evolved the idea of fundamental “elements” that interact to both create and destroy. The Kenpo Gokui places man within a complementary ternary system; in a balanced state with the Heaven and the Earth: “A person’s Heart is the same as Heaven and Earth.” In addition, since man is a sentient being he must find a balanced inner state of mind, body, and spirit. A fundamental concept of Karate is that man’s response to his environment is determined by space, time, and the psychological nature of the situation.

Heraclitus also proposed that all things in the Universe interact, and are in a constant state of flux; coming into and out of “being”, creating a harmony. To
discover these “hidden harmonies” one must learn to “see”. The Kenpo Gokui also advises: “The eye must see all sides.” Today, we are gaining a new appreciation of these ancient insights as our model of the Cosmos continues to evolve. Much like the first ancient binary “yes” versus “no” oracle system, the present model of the universe proposes that there is a state of conflict between opposites. In the current “Big Bang” cosmology, Lambda, the dark energy of the vacuum, opposes gravity. It is believed that the expansive force of Lambda dominates the combined gravity of both visible matter, and dark matter. Thus, the Universe is expanding; and at an accelerating rate.

Likewise, Heraclitus believed that the Universe was composed of opposites, and that everything was in flux. However, although he saw the Universe as a dynamic system, he also believed that these opposites interacted to produce a steady state. Instead of opposites that opposed each other, where one may win out over the other, he saw that these opposites were fundamentally interrelated. Recently a new cosmological theory has emerged; the “Dynamic Steady State Universe”, also known as “Cellular Universe” (Ranzan 2010). This theory is much like that proposed by Heraclitus. In a cellular universe, expansion exits only within vast cellular structures where expansion is balanced by eventual contraction. In this model, overall the Universe is nonexpanding: it is in a harmonious steady state.
In this chapter, we have seen how ancient philosophical beliefs eventually developed into what we now consider “laws” of the cosmos. These systems formed the basis of what would later become the “scientific method”: a method of “seeing” the “hidden harmonies” that control the Cosmos. With our new sight we can now gain a better understanding of the concepts of balance and change. In the next chapter we will explore the history and evolution of the scientific method and the development of systems for exploring the forces acting on balance, posture, and movement.
CHAPTER 4

ORIGINS OF BIOMECHANICS

Now it is worthwhile to pause and consider what has been said; for it involves a speculation which extends beyond animals even to the motion and march of the Universe.

4.1 Introduction: What is Biomechanics?

The origin of the relatively new scientific discipline of biomechanics coincides with ancient man’s first attempts to understand skill development and the biological functioning of organisms. In order to understand how organisms control movement the principles that govern the mechanics of inanimate objects were adapted for use in biological systems by early researchers. The study of the internal and external forces acting on an organism can provide insights into the control of movement. In addition, it provides knowledge concerning the mechanical and biological changes in the tissue that result from this movement. This understanding can lead to improvements in the efficiency of movement for work and sport, the reduction of movement related injuries, and for improvements in physical rehabilitation. The following is one current definition of biomechanics:

*Biomechanics is the science that examines forces acting upon and within a biological structure and effects produced by such forces.*

*(Nigg and Herzog 1999, p. 2)*
In this chapter we will explore the history of biomechanics. We start with the earliest forms of posture and movement annotation, many of which are still in use today not only by primitive cultures, but also by many researchers; archeologists, anthropologists, and historians to name a few. We will explore how cultural values have both influenced and preserved posture and movement traditions from symbolism, to dance, ritual, competition, and martial arts. Associated with these traditions is an evolution from movement philosophies to “laws”, that not only determine man’s movements, but influence everything around us “even to the motion and march of the Universe” (Aristotle, Barnes et al. 1996). By the end of this chapter we will have a better understanding of this evolution of science and technology that can assist us in finding the Hidden Harmonies of the ancients, and provide insights into postural control.

4.2 Prehistoric Symbolism: Posture and Movement

The defining symbols of man, hand, foot, and upright posture, can all be found in the cave art of cultures worldwide and extending back for many thousands of years. The oldest figurative art found so far dates to at least 35,000 BP (Conard 2009). Ancient peoples did not just leave pictures; they left individually and culturally meaningful symbols of identity, valued resources, and self-preservation. In close association with the symbols of man, there are depictions of animals that he valued as a resource, or that symbolized special qualities. Also, from the earliest times there are scenes of hunting and of warfare. At many rock art sites
there is evidence of ritual practices. The art served as a tool to teach the young and as a record for future generations. This symbolism depicted both animals and humans in various positions and associations suggesting movement (Figure 4.1).
Figure 4.1: Ancient Art Movement Sequence, Animals
Figure 4.1: Image Sources and Notes

A) 7,000-4,000 BP: Rendering of a cave art painting, Hares. Paleolithic, Tassili n' Ajjer Period of the Hunter. Tassili n' Ajjer Caves, in the Algerian section of the Sahara Desert. (Lhote 2012) This fresco was found in a sheltered spot, painted directly on the stone.

B) 32,000-30,000 BP: Cave art painting, Panel of Lions. Chauvet Cave, Ardeche, France. (AHDVRC 2012e) Cool and damp, the Chauvet Cave's steady interior climate, 56 degrees Fahrenheit, with 99 percent humidity year-round, contributed to the French cave's remarkable state of preservation.

C) 32,000-30,000 BP: Cave art painting, Bison. Chauvet Cave, Ardeche, France. (AHDVRC 2012c) This bison was drawn with multiple outlines and given seven or eight legs to suggest movement.

D) 15,000 BP: Cave art painting, Boar. Culture: Upper Paleolithic, Magdalenian. Altamira Cave, Cantabria, Spain. (PBS 2012) This image of an eight legged boar depicts the illusion of movement. This and other animal paintings were drawn on the ceiling of Altamira Cave, giving it the reputation of "Sistine Chapel of Stone Age Art." The paintings at Altamira are unique, because they are composed of many different colors (polychrome), more than is common in most other examples of parietal art. Additionally, the Magdalenian artists took full advantage of the facets and angles of the rock surface to give their figures maximum impact.

E) 32,000-30,000 BP: Cave art painting, Horses. Chauvet Cave, Ardeche, France. (AHDVRC 2012d) These images are not drawn on top of each other. They were intentionally drawn in sequence from top to bottom.

F) 5,500-4,500 BP. Petroglyph, giraffes. Air Mountains, near Tiguidit Cliffs, Southern Sahara, Niger, Africa. (Wikipedia 2012) A depiction of a line of giraffes, or a depiction on one giraffe, that walks forward and then kicks.

G) 32,000-30,000 BP: Cave art painting, Rhinoceros. Culture: French. Chauvet Cave, Ardeche, France. (AHDVRC 2012g) The multiple horns and outlines of the rhinoceros' body, shown at the top of the painting, suggest movement.
In the depiction above of hares (Figure 4.1 A), does the series of images represent “hares bounding”, or “a hare bounding”? Animals depicted in the cave paintings of France, are often drawn in overlapping sequence and sometimes with multiple images of legs, as if the animals were in motion. If a cultural tradition exists of representing animals in movement, there exists a great potential that other depictions would attempt to document human movement; for example aspects of physical culture such as ritual, dance, or warfare. In the ancient rock art of all cultures multiple human figures in various postures are often depicted in close association. These depictions can be interpreted as a group of individuals engaged in common activities; such as ritual activities, hunting, fighting, or dancing. A linear series of figures, with each in a different pose, could represent a group of individuals, with each person performing completely independent movements. However, they could also be designed to depict sequences of postures and movements that are to be imitated by others. If so, this would be the earliest form of posture and movement annotation (Figure 4.2).
Figure 4.2: Ancient Art Movement Sequence, Humans
Figure 4.2: Image Sources and Notes

A) 6,500-5,500 BP: Rock Art Painting, “Soldiers celebrate victory”. Chalcolithic Period (Copper Age). Pachmarhi Hills, Madhya Pradesh, India. (Pathak 2012b) Do the three figures on the right represent three soldiers, or one soldier running up to greet the other?

B) 2,400 BP: Rendition of rock art painting. San Trance Dance, “Dance scene with men using sticks and wearing dancing rattles.” Culture: South African San Bushmen. Fetcani Glen, Barkly East, Drakensburg Mountains, Eastern Cape Province, South Africa. (AHDVRC 2012k) This is a series of images representing movements in the San Trance Dance. The Drakensberg region is one of the most important archaeological areas in South Africa. Archaeological sites indicate that human occupation in this mountain region may extend over the last 1 million years.

C) 3,700-3,450 BP: Representation of a wall painting of The Sacred Grove Dance. Agean Bronze Age. Culture: Minoan. Palace of Knossos, Crete, Greece. (German 2007) At least six different dance positions are depicted. These positions are also found on other ancient art objects forms in this area of Crete.

D) 4,000 BP: Representation of dance or ritual scenes painted on a pottery vessel. Culture: Predynastic Egyptian, Abydos, Egypt. (Garfinkel 2001) In Garfinkel’s description of this scene he notes: “It is even possible that the scene represents four stages in a sequence of movement. If so, it is one of the earliest movement notation documents preserved from antiquity.”

Another example of basic movement annotation can be seen in the above San Trance Dance ritual sequence (Figure 4.2 B). This can be interpreted as a sequence with each of the figures depicting a separate individual demonstrating a specific move of a trance dance. Alternatively, it could represent the same individual arising from a rock, or symbolically arising from a mountain or some state of being, and then performing specific movements until a state of altered
consciousness is reached. These figures represent actual postures and stages of the Trance Dance that is still practiced by the San.

The sequences depicted below in the “Mantis Dance” (Figure 4.3 A and C) demonstrate again that such artwork can serve to maintain a tradition of specific movement or dance over thousands of years. This type of dance is still performed by the San and related peoples in the region where this artwork occurs.
Figure 4.3: San Bushmen Trance Dance
Figure 4.3: Image Sources and Notes

A) circa 2,400 BP: Rock art painting. Dancing figures with sticks. Culture: San Bushmen, Eastern Free State, South Africa. (BradshawFDN 2012b) Images of dance are a common theme in South African San rock art. This is a depiction of the San Bushmen "Mantis Dance". These dances can last many hours until the dancer enters a trance. The central figures are dancing using dancing sticks to support their weight. The images show the bent over position that the dancers eventually assume as their "potency" begins to 'boil' in their stomachs. The women depicted on the left hand side of the painting are chanting and clapping out a beat.

B) 1970 AD: Photograph. Dance of the Tyi Wara by a Bamana man. Central Mali, Africa. (Imperato 1970) Tyi Wara is a name which means, "an excellent farmer." Imperato notes: "The characteristics of such a person in their terms are those embodied in a man who spends his entire day, from sunrise to sunset, bending over his Daba (hoe), never straightening up, not even for a moment, either to rest, drink or eat, and hoeing with joy, perseverance and pride. This then is a man who possesses not only the physical strength to be an excellent farmer, but also the abstract virtues of determination, conscientiousness and perseverance. His harvest is the best, his fields free of weeds, the quality of his millet and corn the best in the village. He is a champion farmer. He is Tyi Wara."

C) circa 2400 BP: Representation of rock art painting depicting a group of dancing men and clapping women. Culture: South African, Orange Springs, Ladybrand, Free State, South Africa. (AHDVRC 2012h) It is thought that this dance is the trance dance with the participants wearing mantis masks. The most important southern Bushmen spiritual being was /Kaggen, the trickster-deity. The word '/Kaggen' can be translated as 'mantis', this led to the belief that the Bushmen worshipped the praying mantis. However, the mantis is only one of the deity's manifestations. He can also turn into an eland, a hare, a snake or a vulture. When he is not in one of his animal forms, /Kaggen lives his life of an ordinary Bushman.

D) and F) 1911 AD: Photographs. The person dancing in the photographs is in a stooped position with two sticks (D) or in a crouched position (F). Culture: San Bushmen, South African, Prieska, Northern Cape, South Africa. (Jolly 2006) The posture adopted by dancers in some of these photographs, stooped and supported by two sticks, is represented in many San rock paintings. It is suggested that the sticks were used to support San shamans while they are in a trance.

E) 1950 A.D: Photograph. San Bushmen of the Kalahari Desert: Naron Eland Bull dance. Botswana, South Africa. (AHDVRC 1950b) The Bushmen believed that the eland was the favorite animal of the African deity /Kaggen.
G) 1950 A.D.: Photograph. San (Bushmen) of the Kalahari Desert: !Kung Medicine dance. Culture: Kung. Namibia, South Africa. (AHDVRC 1950a) The role of 'Medicine People' or shamans is to protect the village from evil spirits and sickness. This is done by undergoing a trance through ritual dance.

H) circa 2,400 BP: Representation of a rock art painting. Lonyana Rock, Kwazulu-Natal: Circular trance dance: a sick person lying with knees drawn up. Mooi River District, KwaZulu-Natal Province, South Africa. (AHDVRC 1988) This is a depiction of the “Curing” or “Trance Dance” showing figures dancing around a seated shaman who kneels and lays his hands on a supine patient.

4.3 Cultural Values

There is nothing that does anyone so much credit all his life as the showing himself a proper man with his hands and feet.

Systemized training in physical fitness and martial arts has its origins in ancient cultures who maintained standing armies. Maintaining physically fit and skilled warriors has obvious benefits for the defense of a society. The pursuit of health and skill was valued by these societies in general, as it became a facet of their philosophical beliefs. In addition to the training provided by the military, these skills were maintained through preparation for contests. The societies of India, China, Okinawa, and Greece all shared these values. The legendary Greek poet Homer (c. 700 B.C.), in Book VIII of his epic poem The Odyssey, describes organized athletic games (Athloi) of the time. Such games were an integral part of Greek culture and existed well before the time of Homer. Most scholars believe that The Odyssey is a compilation and standardization of ancient oral traditions established well before the 8th century B.C.
The myths related through these oral traditions preserve the ancient Greek’s philosophical concepts and reflect their view of the Cosmos since its origin. The underlying cosmic force, represented by the archaic Greek concept of Dikê, dictates both the proper functioning of nature and of society. The heroes of these tales serve as models to convey cultural values. In ancient Greek culture, the ideal of heroic performance binds the fame of the father with that of the son. The son was compelled to equal or better the father’s fame. The father in turn promoted the son’s accomplishments and spread their fame. The myths and stories entwined in The Odyssey also serve to compare and contrast the Greek’s cultural ideal with the values of other cultures. The Kuklops who have no laws or assemblies and the Lotus-eaters who have no cultural memory represent negative examples. As the hero of The Odyssey, Odysseus serves not only as a model for athletic accomplishment but also as the restorer of the proper natural order. By reinforcing cultural values, the ancient oral traditions help to maintain the stability and identity of the society. Thus, The Odyssey defines what it is to be Greek and to be human.

The writings of Homer and other ancient Greek authors had a great influence on succeeding generations of Greek scholars. By 150 B.C., a standardized text of the Homeric works was established. Subsequently, a tradition of scholarship developed centered on learning of the epics. In his works, Plato (427-347 B.C.) cites many Homeric lines and believes the epics hold encyclopedic knowledge. Plato no doubt valued the concepts of physical training and skill development
expressed in the Homeric epics. In Greek, Plato means “Broad” and some scholars believe that this refers to his style of wrestling. Plato’s student Aristotle (384-322 B.C.) in his work Poetics also discusses literary theory and the works of Homer.

4.4 Standardized Athletic Training

In The Odyssey, Homer describes the ancient Greek athletic games as highly organized competitions with nine stewards assigned to oversee them. The competitors received prizes and thousands of spectators attended the contests. The organizers of the games took pride in showing that their competitors surpassed those of other nations. This indicates that such games were widespread and that the qualities of strength and skill were highly valued by the cultures:

There is nothing that does any one so much credit all his life as the showing himself a proper man with his hands and feet.  
(Homer 1968, p. 67)

Homer describes many such contests in both of his epic poems The Iliad and The Odyssey. These games consisted of various athletic sports (Athlos) including running, jumping, wrestling, boxing, fighting, archery, and throwing of the disc, and javelin. Homer describes wrestling as “the painful art” indicating that it was a combative form. Boxing is also described as a “painful art” and was
considered a noble sport with its own mythical hero “the mighty boxer” Pollux (Homer 1948).

It is apparent that in order to field teams of expert competitors these societies must have studied movement and had standardized training in skill development. Ancient Greek societies highly valued strength, endurance, and skill. They held competitions for health, entertainment, religious, and philosophical purposes. The Greeks established training institutions called Gymnasion (place for exercising) and employed Gymnastēs (trainers). Some competitions were a part of funeral rites to honor deceased heroes. Gymnastika is the ancient Greek goddess of the morning hour that is devoted to fitness. Physical training and competition also reflects the Greek philosophical concept of Pathos. One could gain heroic fame (Kleos), and sometimes immortality, by undergoing virtuous struggle and suffering while trying to attain any goal. The Greeks used the term Athlētēs to describe anyone who is struggling toward a goal, not just sports competitors. They referred to both the competitions of sport and to the struggles of life as Athloi (competitions). Thus, physical competitions were valued for both health purposes and for philosophical reasons, as they provide a model of how to succeed in the struggles of life.
4.5 The Ancient Greeks: Natural Philosophy

*All men by nature desire to know.*

In Western culture the origins of the science of biomechanics can be traced to the ancient Greeks who around 600 B.C. developed a scientific system of inquiry in an attempt to separate knowledge from myth. Through this system of rational thought, the Greeks developed the basic elements of mathematics, mechanics, and medicine. In ancient Greece the study of philosophy, medicine, mathematics, and science were interrelated. The Greek’s philosophical goal of the harmony of mind and body necessitated that the search for knowledge must be coupled with athletic development. Ancient Greek art reflects this emphasis as it frequently depicts athletes in poses which represent both knowledge of anatomy and the kinematics of movement (Nigg and Herzog 1999).

The exact origin of Greek philosophy and science is unknown. Prior to about 600 B.C. the Greeks either did not systematically record their cultural history or these records have been lost. Around 600 B.C. the “Natural Philosophers” began to develop theories of natural science that were detached from religion. Thales of Miletus (c. 624-547 B.C.), a philosopher, mathematician, and engineer, was the first known Greek scientist. He attempted to explain natural phenomena through rational thought rather than ascribing them to supernatural sources. Through logic, Thales developed suppositions and mathematical statements to explain his observations of natural processes. His major contribution to scientific thought is
the concept that natural phenomena are caused by matter interacting through natural laws.

This process of deductive scientific thought produced many insights into the true nature of the world. For example, around the time of Thales the Greeks developed the theory of the elemental structure of matter; that all matter is composed of a few basic elements. Anaximander (c. 610-546 B.C.), a student or companion of Thales, believed that all forms of matter are in a constant process of transformation. He proposed that the basic elements of air, water, earth, and fire were in opposition to each other and thus produced constant change. However, since there is a natural law, which governs the process, no one element can dominate, and thus a natural balance is maintained. A third Milesian philosopher Anaximenes (c. 585-525 B.C.) further refined the theory of elements and proposed a theory of aggregates. In this theory, the primary element air can be condensed to form liquids and solids. Thus, the differences between the various types of matter are quantitative and depend on the degree of condensation.

Pythagoras (c. 582-496 B.C.), a contemporary of Anaximenes, believed that perception of the world through use of the senses produced uncertainties; however numbers were a form of universal and eternal truth. He believed that although they were imperceptible to the senses, the divine principles of the Cosmos could be determined through deductive reasoning and critical analysis of
observable phenomena. Pythagoras established the connection between music and mathematics. He believed that both the Universe and the human body have properties similar to musical instruments. Harmony results when these properties are in balance and have the proper tension (Nigg and Herzog 1999).

About 180 years after the time of Thales the quest to understand the true nature of matter culminated in the theory of atoms. The concept of the atom as the most basic form of matter is credited to Leucippus (c. 440 B.C.) and his student Democritus (460-370 B.C.). They held that atoms were indestructible and they moved at random. When atoms with matching shapes interlocked, they accumulated in clusters to form specific substances. The Milesians contributed greatly to the development of the scientific method by attempting to explain nature through a systematized study of observations, deductive reasoning, and by critically debating the merits of each theory. Hippocrates (460-370 B.C.) extended this system of deductive reasoning to medicine. He believed in the principle of causality: there is no chance and a reason exists for anything that occurs. His rational scientific approach produced a method for disease diagnosis that was free of religious and supernatural constraints. Hippocrates emphasized both the curative and the preservative aspects of medicine.

Aristotle (384-322 B.C.) believed that mathematics provided the best model for science and that the role of science should be to explain nature. Aristotle believed that the search for knowledge is a fundamental human characteristic:
“All men by nature desire to know.” (Aristotle, Barnes et al. 1996, p. 1552). He believed that a true knowledge of nature can only be gained by careful observation and perception. However, since observation cannot explain why perceived phenomena occur, Aristotle developed theoretical explanations.

*Again, we do not regard any of the senses as wisdom; yet surely these give the most knowledge of particulars. But they do not tell us the ‘why’ of anything—e.g. why fire is hot; they only say that it is hot.*

(Aristotle, Barnes et al. 1996, p. 1553)

Aristotle held that theories must be in harmony with both observation and with other theories.

*And we must grasp this not only generally in theory, but also by reference to individuals in the world of sense; for with these in view we seek general theories, and with these we believe that general theories ought to harmonize.*

(Aristotle, Barnes et al. 1996, p. 1087)

Aristotle developed a model of the Universe based on the four elements of earth, water, air, and fire. He paired these with the qualities of dryness, humidity, cold, and heat. In his model, the elements are arranged in concentric spheres extending outward from the center of the world. The concepts of movement and change are fundamental aspects of his model. The natural movements of objects depend on where they are located. In the terrestrial zone, the natural movement of falling objects is a straight line. Objects in the celestial zone move in circular motions. Aristotle also believed that the elements and their qualities combine in the body to form four main humors. He thought that pneuma (breath)
passes through the heart, which is the center of one’s intellect. This pneuma is also the impetus behind all muscular movement. In his treatise Movement of Animals, Aristotle presented the first scientific analysis of muscular action and gait (Nigg and Herzog 1999). He believed that animal movement could be modeled after mechanical objects:

The movements of animals may be compared with those of automatic puppets which are set forth on the occasion of a tiny movement…
(Aristotle, Barnes et al. 1996, p. 1092)

However, Aristotle noted that animal movement differed from the movement of mechanical devices because the parts of animals had the ability to change length and shape. In order to study movement Aristotle developed a geometric analysis of body segment motion to describe the role of the tendons and joints in movement. He may have understood the role of muscles in movement as he states that the animal’s “organs” change shape. When describing the “sinewy tendons” he states, “…for when these are slackened or released movement begins”. In contrasting parts of a mechanical device with an animal’s parts, he states, “In an animal the same part has the power of becoming now larger and now smaller…” (Aristotle, Barnes et al. 1996, p. 1092). He thought that sensations could cause these changes of “quality”. He also hinted at insights into postural stability when discussing the effect of sensations on the body. He believed that sensations could cause “tremblings and shivers and their opposites”: 
And it is not hard to see that a small change occurring at the centre makes great and numerous changes at the circumference, just as by shifting the rudder a hair’s breath you get a wide deviation at the prow.
(Aristotle, Barnes et al. 1996, p. 1092)

Aristotle’s general theory of motion requires that anything that moves must be resisted by, or moved by, something else. Thus, he demonstrated an understanding of reaction forces that are necessary for movement:

For were that something always to give way (as it does for tortoises walking on mud or persons walking in sand) advance would be impossible, and neither would there be any walking unless the ground were to remain still, nor any flying or swimming were not the air and the sea to resist.
(Aristotle, Barnes et al. 1996, p. 1087)

For as the pusher pushes so is the pushed pushed, and with equal force.
(Aristotle, Barnes et al. 1996, p. 1088)

Aristotle further believed that these forces were universal and were in harmony with the Cosmos:

Now it is worthwhile to pause and consider what has been said; for it involves a speculation which extends beyond animals even to the motion and march of the Universe.
(Aristotle, Barnes et al. 1996, p. 1087)

By the third century B.C. Alexandria became the center of scientific study in anatomy and physiology. The origin of the systematic study of anatomy is credited to Herophilos (c. 300 B.C.) who was the first to identify the role of nerves. In addition, he believed that the brain was the center of one’s intelligence. Also during this time, Erasistratis (c. 280 B.C.) was the first to
identify with certainty muscles and their role in movement. Archimedes (287-212 B.C.) was also interested in movement and mechanics. He developed methods to determine the center of gravity of objects and the force necessary to move an object of known mass.

4.6 The Roman Influence

The scientific progress of the early Greeks was somewhat diminished during the first century B.C. due to the influence of the Roman Empire. The Romans placed more importance on the development of systems of ethics and warfare. They did however adopt the Greek idea of maintaining health through exercise. The Romans also made some progress in both mechanics and medicine. Hero of Alexandria (c. 62 A.D.), an inventor and instructor of physics, documented the principles behind his mechanical inventions that included a crude steam engine and mechanical birds. Galen (129-201 A.D.), physician to the College of Gladiators, gained in-depth knowledge of movement, anatomy, and surgery. Galen believed that the study of medicine should include research in both anatomy and physiology. He subsequently produced over 500 manuscripts documenting his research and wrote the first textbook on physiology: De Usu Partium.

Galen was perhaps also the first to publish works on exercise from a medical standpoint. He wrote two short treatises on this subject and he discussed it in his
principle work on regimen: De ingenio sanitatis. Galen notes that exercise must be of the correct type, intensity, and duration. He does not consider the life style of an athlete to be healthy as it is too excessive (Siraisi 2003). In addition, he produced De Motu Musculorum (On the Movement of Muscles). In this treatise, he proposed that muscular movement is stimulated by spiritus animalius that originates in the brain and is transmitted by the nerves. Galen believed that the arteries included both blood and Aristotle's pneuma (breath). Perhaps his most important contribution to the advancement of science is his observation that injuries to specific parts of the nervous system produced corresponding paralysis in specific muscles and organs (Nigg and Herzog 1999).

4.7 The Middle Ages

In the Early Middle Ages (410 A.D.-1066 A.D.), often referred to as the Dark Ages, many historians believe that scientific development was minimal; as during this time religious doctrines discouraged scientific investigation. Some feel that there was no true scientific tradition, as only Aristotelian natural philosophy existed during this time (French and Cunningham 1996). However, it was during this period that the imaginative thinking required in the development of theories of natural philosophy was preserved. The science of the Dark Ages consisted of two major elements. The first was the science of natural philosophy and the second was the study of the exact sciences: math, astronomy, optics, and statics. Some significant advances were made in the exact sciences that were
inherited from Greco-Arabic sources. The major contribution however, was in the preservation and the study of the exact sciences. This made it possible for later pioneers of science to establish early modern science (Grant 2005).

4.8 The Renaissance

There was little further change in the development of biomechanics until the time of the Italian Renaissance (c.1450-1527 A.D.). During this period, there was a renewed interest in the work of the natural philosophers of ancient Greece. During this period, Leonardo da Vinci (1452-1519 A.D.) used his artistic skills to document human anatomy accurately. To his study of anatomy, da Vinci applied his knowledge of mechanics in an attempt to understand movement. He performed the first comprehensive mechanical analysis on the structures of movement including the bones, muscles, tendons, and ligaments. In his drawings, Da Vinci represented the forces acting along the muscles. He also replaced Aristotle's theory of pneuma with the concept of spiritual force. He believed that a form of energy travels through the nerves and changes the shape of muscles thus producing movement. Although Da Vinci did contribute greatly to the development of biomechanics, this was not until several hundred years later when his work was first published.

During the Renaissance, a more immediate influence on the understanding of movement was the work of Vesalius (1514-1564 A.D.). In 1543, he published
research on the anatomy of nerves and muscle that established the basis for modern anatomy. This work was revolutionary as it challenged and revised views held since the time of Galen (129-201 A.D.). A major contribution to the study of human movement and the health benefits of exercise was the work of the Italian physician Girolamo Mercuriale (1530-1606 A.D.). Mercuriale believed that medieval and Renaissance preservative medical regimens ignored the importance of exercise and placed too much emphasis on diet. In 1569, Mercuriale published his six-book treatise De arte gymnastica; the first book on sports medicine, massage, and physical culture. In this work, he drew on all available sources and compiled a history of structured physical exercise. He describes the varieties of exercises, venues, and equipment used since the time of ancient Rome and Greece. In addition, he discusses the effects of these exercises on health. Mercuriale notes that the ancient cultures practiced three forms of exercise: Gymnastica Bellica (exercise to develop martial skills), Gymnastica Medica (exercise for health), and athletic games for competition or entertainment.

Mercuriale was the first Renaissance author to link sport and health. He also understood that exercise could be both beneficial and detrimental and thus he makes recommendations on the intensity and duration of activity. He provides advice and precautions for many types of exercise and states that walking is beneficial for anyone (Siraisi 2003).
This is so especially because if any physical exercises are found that preserve health, drive away weakness acquired from disease, and strengthen a good habitus of body that are in frequent use among all men and all nations, one is certainly walking. (Siraisi 2003, p. 244)

Mercuriale gained many ideas from the works of Galen, who 1,400 years earlier had written about the health benefits of exercise in his treatise De ingenio sanitatis. According to Mercuriale, exercising for health purposes is the only "pure" form of exercise. Whereas activity during competition is unhealthy, thus it is Gymnastica Vitiosa (exercise full of vice). In this, he followed the ideas of Galen believing that the lifestyle of an athlete involves excessive strenuous activity, exposure to the sun for long periods, an excess of meat in the diet, too much sleep, and it produces unbalanced emotions. He also drew from the medical works of Hippocrates in correlating the origin of medicine with the origin of structured exercise for health. In his work, Hippocrates emphasized both the curative and the preservative aspects of medicine. Mercuriale believed that the supervision of physical exercise was part of the preservative role of medicine as exercise is necessary for maintaining health, preventing disease, and for assisting in rehabilitation. Mercuriale’s work was a major contributor to a general Renaissance interest in all aspects of physical culture. During this time there were various treatises written by educators advocating physical exercise and the development of skills such as dancing, horsemanship, and swordsmanship (Siraisi 2003).
4.9 The Scientific Revolution

Needles, Cat’s Whiskers, and Cocaine

In the 17th century, wealthy political and educational institutions provided support for scientific research and thus initiated a revolution in scientific thought. It is during this time that the modern science of biomechanics has its origins. Two figures are recognized as the founders of biomechanics: Galileo Galilei (1564-1642) and Giovanni Borelli (1608-1679). In an unpublished manuscript, De Animaliam Motibus (The Movement of Animals), Galilei wrote an analysis of the mechanics of animal movement. The topics covered included an analysis of humans jumping and the gait of horses. Also in 1638, he published Discourses on Two New Sciences that included an analysis of the structural properties of solids. He related this to biological material, particularly the dynamics of bone fracture. He also wrote treatises of his theories on uniform motion, the properties of falling objects, the motion of projectiles, and momentum. This work laid the foundation for much of the scientific progress for the next few centuries including Isaac Newton’s laws of mechanics.

The other recognized founder of biomechanics is the Italian physician and mathematician Giovanni Borelli (1608-1680). A student and associate of Galileo, he had many of the same interests and may have collaborated with Galileo on the study of animal movement. De Motu Animalium (The Movement of Animals), published posthumously in 1680, describes Borelli’s investigations of animal and
human movement. The subjects of his analysis include gait, jumping, flying, and swimming. He presented theories on muscle physiology and force production, and included illustrations of mechanical models for muscular contraction.

Since the time of Galen (129-201 A.D.), physicians had believed that muscle contraction was due to elements of breath called *pneuma* or vital spirits, which entered the muscles and caused swelling. In 1664, William Croone (1633-1684), English physician and one of the original Fellows of the Royal Society, published De Ratione Motus Musculorum (The Reason of the Movement of Muscles). In this work he attempted to describe muscle contraction using mechanical and chemical concepts. Croone later commented on this work:

…*the motion of a muscle is performed only by the carnous fibres, and that each distinct carnous fibre had a power of contracting itself; I offered an hypothesis of the structure of one carnous fibre, since the force of the whole muscle is but an aggregate of the contractions of each particular fibre*…(Croone 1674)

In addition to describing the structure of muscle fibers, Croone postulated that muscular contraction could be the result of a chemical process. He also hypothesized that an impulse was transmitted along the nerve just as vibrations are transmitted along the string of a musical instrument (Maquet, Nayler et al. 2000). The year following his publication, Croone met with Niels Stensen (1638-1686) a Danish anatomist, whose experiments demonstrated that muscles do not swell during contraction. Stensen, also known as Nicolaus Stenonis or Nicolas Steno, published “Elementorum Myologiae Specimen” (Elements of Mycology) in
1667. In this work he rejected the view of many of his contemporaries who believed that muscle contraction was caused by a “spirit” filling the muscle. Stensen’s study of muscle function was almost entirely from a mechanical and mathematical perspective and modeled the muscle as a parallelepiped, a three-dimensional figure formed by parallelograms (Kardel 1994).

The 18th century saw advancements that helped lay the foundations of electrophysiology. Luigi Galvani (1737-1798) performed his famous experiments on the contractions of a frog’s limbs elicited through an electrical spark. In 1791, Galvani published the results of his frog experiments in his famous work “De Viribus Electricitatis in Motu Musculari Commentatius” (Bresadola 1998). There was not much further progress in the study of human posture and movement through the 18th and early part of the 19th centuries. Several theories were published but they were not validated through experimental work. In addition, the authors had expertise in either physiology or in mechanics, but no one used a combined approach (Baker 2007).

Meaningful advances in biomechanics have usually occurred through the coordinated efforts of teams of researchers composed of individuals with expertise in both the life sciences and mechanics. Thus, significant progress in human posture and movement was not made until a team of brothers, Willhelm Weber (1804-1891), a professor of physics, and Eduard Weber (1806-1871) a professor of physiology, began to study the biomechanics of walking. In 1836,
they published “Mechanics of the Human Walking Apparatus” (Weber and Weber 1992). Their work was productive and innovative, but they used very simple measuring devices: a measuring tape, a stop watch, and a telescope. Although the data recorded was limited, they produced fairly accurate estimates of walking speed, step length, and the timing of changes in cadence. Through their research, they were also able to illustrate the limb positions during several phases of the gait cycle. During this same period, another advance was achieved through the work of French physician Guillaume Duchenne (1806-1875) who did pioneering research in electrophysiology (Clarac, Massion et al. 2009). During his research in 1850, he used an induction coil to stimulate muscles in his patients which provided unique insights into the in vivo functional anatomy of skeletal muscles. Thus, he is considered by many to be the founder of electrophysiology. Duchenne’s work was significant as one of the major issues in neurology in the 19th century was concerned with the mechanism of motor control and its relation to posture and movement.

The 1880’s saw continued interest in determining nerve pathways through experimentation on animals. This was done in an attempt to determine if there was a “localization of functions in the brain” and if there was a “motor area”. Portions of the brain were removed and the animal was then studied to determine the effects this had on their motor control. The animals were then dissected and the nerve tracts were examined for signs of degeneration (Langley and Sherrington 1884). The 1880’s also saw extensive work on determining the
nature of the “rhythms” of muscles. Prior to 1881, muscle contractions were thought to be “sounds” that corresponded to the vibrations of a vibrating metallic reed or a tuning-fork. In 1881, Otto Christian Lovén produced tracings of muscle activity and concluded that the “note” of a voluntarily contracting muscle is not constant; instead it varies with the tension of the muscle. Thus, he drew the conclusion that the variations in the tracings represented the rate of nerve impulses passing to the muscles (Schäfer 1886). This prompted further investigations to prove that muscle activity was not caused by vibration waves.

Lovén’s findings were verified by Sir Edward Albert Sharpley Schafer (1850-1935) who produced similar tracings of voluntary muscle contractions using a mechanical device. Schafer believed that the tracings gave a “conclusive indication of the character of the muscular contraction”. He found that the “rhythm of muscular response” to voluntary muscle contractions was about 10 nerve impulses per second (Schäfer 1886). Schafer was so intent on investigating motor tracts that he performed an experimental section of a nerve in his own arm. During his career Schafer also developed the method of giving artificial respirations in the prone position that has since been adopted by all emergency response personnel. From his search for the hidden rhythms within man he extrapolated his insights to include the origins of life. In 1912, in an address to the British Association for the Advancement of Science, Schafer created quite a stir by suggesting that living matter had its origin in colloidal
Schafer further stated that vital life processes could be explained solely by chemico-physical activity, without the aid of any special “vital force” (Hill 1935).

At the same time that Schafer was performing his experiments on the “rhythm of muscular response”, Wilmot P. Herringham (1855-1936) independently arrived at the same conclusions. Herringham recorded myograms of his own muscles by using a mechanical device:

*I selected the muscle, ran the needles about half an inch into my forearm and tested them when in position to see in what muscle they were sticking.* (Herringham 1890)

He then ran a thread through the eye of a needle and attached it to a lever. A cat’s whisker at the end of the lever then recorded tracings on a revolving drum. Herringham did not use the method of recording myograms that was common at the time. The commonly used methods relied on a tambour which was placed in contact with the skin lying over top of the muscle. Herringham preferred to insert needles directly into the muscle as he could then be assured that he was isolating specific muscles. However, in Herringham’s words this method was a “…more laborious, and, even with the help of cocaine, considerably painful method…” (Herringham 1890). Through his experiments Herringham found that the amplitude of the recorded curves increased both with effort and with fatigue. In 1890, Etienne-Jules Marey (1830-1904) produced similar tracings by recording the electrical activity produced by skeletal muscles and gave the technique the name “electromyography” (EMG).
Another major issue during this period, debated since the time of Newton, was whether or not human movement was subject to the same laws as the rest of nature. Etienne-Jules Marey (1830-1904), a physician, believed that it was. Marey set out to demonstrate how these laws operated by taking careful measurements of human posture and movement. Thus, today he is considered to be the first modern gait analyst. In his book, “The Graphic Methods in Experimental Sciences”, published in 1878, he describes how science can overcome obstacles to progress in human posture and movement:

Science has two obstacles which block its advance: first, the defective capacity of our senses for discovering truths and then, the insufficiency of language for expressing and transmitting those we have acquired. The aim of scientific methods is to remove these obstacles.

(Laporte 1998)

Marey worked closely with his student Gaston Carlet (1849-1892) on gait analysis. In 1872, Carlet developed a pressure registering shoe for use in gait analysis (Blanksby, Wood et al. 1981). Through using three pressure transducers attached to the sole of the shoe, he recorded the forces exerted by the foot during gait. Also for the first time, Carlet published a graph showing the characteristic double humped nature of the vertical component of the ground reaction force during the human gait cycle (Baker 2007). Marey and Carlet also developed a pneumatic force plate which they combined with photographic equipment to investigate the energetics of gait.
Marey continued his work on gait, but this time he studied horses. In 1872, by adapting Carlet’s device for measuring the pressures exerted by the human foot, Marey developed a device to detect the pressure of the horse’s legs during a canter and a gallop. He was thus able to prove that there is a suspension phase in these gaits where all four hoofs are off the ground. In 1878, Eadweard Muybridge (1830-1904) proved this photographically. Marey modified this photographic equipment and developed a shutter system that could capture multiple sequential images on the same photographic plate. With this device, Marey was now able to take accurate measurements of gait. He and another student, Georges Demeny (1859-1918), experimented with the placement of various markers on body segments to produce accurate photographic images of the entire gait cycle. Marey went on to use this technique to analyze pathological gait in his patients.

The next evolution in the study of gait was three-dimensional analysis. Otto Fischer (1861-1917), a mathematician, and Willhelm Braune (1831-1892), a professor of anatomy, used light emitting tubes strapped to a subject’s body to record movement. Three dimensional reconstructions were possible by comparing the images of two systems of cameras. Fischer continued this work and eventually was able to calculate the trajectory of the center of mass of each body segment as well as the entire body. Jules Amar (1879-1935) improved on Marey and Demeny’s pneumatic force plate and created the first three-component plate in 1916. The next major advance in force plate technology
occurred during the 1940’s at the University of California. This was the
development of a full six-component force plate utilizing strain gauges (Baker
2007). Beginning in the 1970’s, with the advent of computerized monitoring,
imaging, and data analysis equipment, we have entered a new age in the study
of posture and movement. In the next chapter we will explore the use of some of
these systems for the study of fall prevention.

4.10 Summary

Most researchers believe that biomechanics had its origins in the work of
Leonardo da Vinci’s on human anatomy and structure, and with Giovanni
Borelli’s mathematical analysis of human motion during the Renaissance.
However, as can be seen in ancient rock art, mankind has been fascinated by
posture and movement for thousands of years, and attempted to symbolically
record their ideas. As a basic form of movement annotation, these images have
been used by primitive cultures for thousands of years to transmit ritual, dance,
and martial arts. In order to develop systems of martial arts, such as in India,
China, and Okinawa, it was necessary to develop standardized training methods.
This also required methods of transmitting knowledge of posture and movement,
as these systems are thousands of years old. In the west, standardized athletic
training began with the Greeks. Ancient Greek philosophers, from Heraclitus, to
Hippocrates, to Aristotle and Plato, believed that through rational thought,
mathematics, and with the proper “sight” one could discover the natural laws and
hidden harmonies within man, and the Cosmos. Even the words of pioneers in biomechanics, such as Marey, “…defective capacity of our senses for discovering truths…”, echo the ancient writings of the Kenpo Gokui, Heraclitus, and Plato. Both “sight and light” are needed to discover the hidden truths and harmonies. Modern biomechanics can provide this “sight and light”. In the next chapter we will explore the current literature on the use of biomechanics in the search for effective fall prevention programs.
CHAPTER 5
LITERATURE REVIEW

5.1 Introduction: Focus of Current Research

Injuries incurred from slips, trips, and falls are a major public health concern. During 2004-2007, falls in the U.S. were the leading cause of injury (CDC 2010). The morbidity and mortality rates increase dramatically for the segment of the population over the age of 65 (CDC 2005). Various studies have been initiated to first define the scope of the problem and then to formulate effective preventive strategies. The maintenance of postural equilibrium requires both a keen sense of proprioception and exact neuromuscular control. Researchers have thus investigated various forms of exercise for their potential to improve postural stability. One fall prevention strategy that has received much attention recently is the use of martial arts training, such as T’ai Chi to improve balance.

For centuries, T’ai Chi has been practiced in China by people of all ages to maintain health. The benefits of this traditional exercise form are purported to include improvements in cardiac function, respiratory efficiency, muscle strength, muscle endurance, flexibility, and balance control. The following sections will summarize the current research on the impact of falls on our society and will
identify those who are most at risk. Also discussed is the recent interest in the use of exercise, complementary and alternative medical (CAM) therapies, and martial arts for reducing the risk of falls. The Martial Arts philosophy of balance, and how it relates to the modern concept of Homeostasis, is explored. Finally, the results of recent research on the effectiveness of various therapies for improving postural stability are presented.

5.2 The Impact of Falls on Society

A recent survey in the U.S. showed that during 2004-2007, falls were the leading cause of injury and accounted for almost 40% of all injuries (Figure 5.1). Indeed, falls were twice the number of injuries than any other causes (CDC 2010).
Annually, falls accounted for one-third of those hospitalized or 783,000 persons and one-fifth of the non-hospitalized injured or 11.5 million persons. For 1985, a typical year, the total economic loss due to falls was estimated at $37.3 billion. The average cost of hospitalization for a fall injury was $38,174, and for a non-hospitalized fall injury, $499 (Rice and MacKenzie 1989). Most of the deaths due to falls involve head and lower extremity injuries (Anderson, Minino et al. 2004).

The number of injuries from falls and the economic cost to society continues to rise. In 2000, falls were the leading cause of medically attended injury with 6.9 million episodes (Schoenborn, Adams et al. 2003). In 2001, falling was the

Figure 5.1: Falls, the leading cause of injury during 2004-2007. (CDC 2010)
second leading mechanism of unintentional injury and resulted in 14.8% of all injuries. In the same year, falling was the fourth leading mechanism of injury death accounting for 10% of deaths. From 2001 to 2002 the age-adjusted death rate for falls increased by nearly 10% (Anderson, Minino et al. 2004). In 2002 it was estimated that falls account for 25% of all injury related emergency department visits annually which equates to an estimated 7.43 million emergency department visits (CDC 2002). In 2003, the National Center for Health Statistics found that falls were the leading external cause of medically attended injury. With 8.0 million episodes, falls far exceeded the next two leading causes of such injury: transportation with 3.8 million episodes, and overexertion with 3.4 million episodes (Schiller, Adams et al. 2005).

In 2003, the rate of non-fatal injuries for all ages due to unintentional falls for the entire U.S. population was 2,715 per 100,000. The rate of death for all ages due to unintentional falls was 5.65 per 100,000 (CDC 2005). This now positions falling as the third leading cause of injury-related death in the U.S. Falls are the leading cause of both non-fatal and fatal injuries in the home. In 2000, the cost of fall-related injuries in the home was 90.5 billion or 42% of the total cost for all unintentional home injuries (Zaloshnja, Miller et al. 2005). Among children and adolescents, injuries due to falls are the leading reason for hospital emergency department visits, producing an estimated 3 million visits annually. The annual direct medical cost to treat these children is $958 million (CDC 2002).
5.3 Risk Factors Associated With Falls

Gender, ethnicity, occupation, physical fitness, and age are important contributing factors to the risk of injury from falls. Recent statistics show that, after adjusting for age, the injury rate for falls was 17% higher in women than in men (Figure 5.1) (CDC 2010). Based on ethnicity alone, the age adjusted rate for falls is highest for the non-Hispanic white population at 5.8 per 100,000 U.S. standard population (Anderson, Minino et al. 2004). Non-Hispanic whites also have the highest risk of injury with a fall injury rate of 488 per 100,000 per year. This is more than double the rate of 233 per 100,000 for Blacks. Native Americans have the lowest rate with 96 per 100,000 (Ellis and Trent 2001).

When fall incidents are grouped according to gender and ethnicity, falls are the second leading mechanism of injury death for non-Hispanic white females and the third leading mechanism for Asian or Pacific Islander females. In contrast, it is the fourth leading mechanism for non-Hispanic white and Asian or Pacific Islander males. There is an exponential increase in fall rates with age for both men and woman. Starting at age 55 there is a 2.5 to 3-fold increase in fall rate with each decade (Ellis and Trent 2001).

The three main types of falls are falls on the same level, falls from one level to another, and falls on or from stairs. These represent the mechanism of nearly 91% of all fall injuries. The most common type of fall for adults aged 20 years and older is slipping, tripping, or stumbling on the same level. This accounts for
65% of all fall injuries with a known cause. The second most common cause of fall injuries are falls from one level to another with 18%. In this category, falls from a bed or chair are very common. The next most common type of fall is from stairs or steps with 7% followed by falls from ladders or scaffolding, which cause 5% of injuries. In a study of 242,166 adults aged 20 years and older hospitalized due to a fall, it was found that 63% of the falls occur in the home. More than two thirds of the falls in the home are due to slipping, tripping, or stumbling. One-half of the falls from one level to another occur in the home. The second most common place for falls is in residential institutions, which account for 14% of fall injuries (Ellis and Trent 2001).

5.4 Workplace Injuries Due to Falls

Occupational related injuries from falls are another area of great concern. Each year the National Institute for Occupational Safety and Health (NIOSH) investigates traumatic injuries in the workplace as part of the Fatality Assessment and Control Evaluation (FACE) program. Although the data collected included incidents involving equipment failure, the most common causes of fall-related injury were loss of balance, tripping, or slipping. NIOSH classifies falls into two general categories: falls on the same level and falls from elevation. Falls from elevation include incidents ranging from falling on stairs or falling a few feet from a stepladder up to falling hundreds of feet from a building under construction.
During the period 1980 through 1994, falls on the same level resulted in less than 3% of the total fall-related fatalities. However, falls from elevations accounted for 10% of all work-related fatalities, which placed it as the fourth leading cause of occupational fatalities (NIOSH 2000). This trend was still observed in 2009-2010 (BLS 2011).

The construction industry leads all industries in the total number of reported deaths from all causes with falls being the leading cause of death (CDC 2001a). More than one third of the fatal incidents were fall related (Dong, Wang et al. 2012). This is disproportionally high since construction makes up less than 8% of the total workforce. Other industries have significant rates of fall injuries. The incidence rate of lost-workday slips, trips, and falls for hospitals was 90% greater than the average rate for all other private industries combined (NIOSH 2010). However, the greatest contributing factor is age. While workers 25 to 34 years of age experienced the greatest number of fall incidents, the rate of fatalities was greatest after age 45. These rates increased slowly up to age 55 and then increased rapidly until at age 65, there was a dramatic increase (Table 5.1) (NIOSH 2011).
When the two factors of gender and age are combined the risk of injury greatly increases. For adults 65 years or older, the injury rate due to falls is twice as high for females as for males (Schoenborn, Adams et al. 2003). In most industries, the fatality rate for workers aged 65 and older is five to ten times higher than that of workers below age 25. Workers aged 55 and over account for 42% of fatal falls from ladders and they are involved in 27% of all fatal falls (NIOSH 2000). Workers at elevation rely on balance and coordination to keep from falling. Factors that challenge one’s balance when at elevation include lack of close visual references, decreased surface firmness, increased slope, and improper footwear. This increased instability is not adequately perceived by workers and thus the risk of loss of balance is increased (NIOSH 2003). The risk of falling increases with age related declines in balance, coordination, and reaction times. Thus, when at elevation even minor perturbations to balance can

<table>
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<th>Age Group (Years)</th>
<th>Risk Index</th>
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<tr>
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result in a fall. With increase in age, morbidity and mortality rates increase, but the height required to produce an injury decreases.

5.5 The Impact of Falls on the Elderly

The need for effective fall prevention programs is especially obvious when one considers the morbidity and mortality rates due to falls involving the elderly. Approximately one third of those aged 65 and older fall at least once a year (CDC 2002). In 2010, this equated to 2.3 million elderly being treated in emergency departments for non-fatal fall-related injuries. Moreover, the medical costs of these emergency room visits totaled $30 Billion (CDC 2012a). Most of the falls experienced by the elderly involve tripping or falling while on a level plane (Rice and MacKenzie 1989). Even though the elderly usually do not fall from a great height, moderate to severe injuries occur in 20% to 30% of these falls, which include 300,000 hip fractures annually. The annual cost of such fractures exceeds $10 billion. For people aged 65 and older falls are also the leading cause of injury related deaths. In total, falls account for 29% of the injury deaths for this age group or nearly 10,000 deaths per year (CDC 2001b). The total cost of fatal fall-related injuries involving the elderly was $349 million in 2005 (CDC 2011).

Factors that increase the risk of falling in the elderly include impaired vision, balance, and gait, the use of multiple medications, and sedentary lifestyles (CDC
Other risk factors that have a statistically significant effect are: fear of falling, occurrence of a fall within the past year, and difficulty in falling asleep at night (Wolf, Barnhart et al. 1996). Adults of any age who are not physically fit exhibit impaired muscle strength, endurance, and control of movement. The resulting balance and mobility problems lead them to be twice as likely to fall as healthier adults of the same age. In addition, when frail or physically unfit adults fall their injuries are more severe (CDC 2001b). The above statistics indicate that all segments of the population could benefit from effective balance and fall prevention training.

### 5.6 Traditional Medicine and Balance

In an attempt to develop effective balance training programs and fall prevention strategies, researchers are now exploring neuromuscular therapies used in traditional medicine. According to the World Health Organization (WHO) traditional medicine (TM) refers to various indigenous medical systems that utilize health practices incorporating manual techniques and exercises; plant, animal, and mineral-based medicines; and spiritual therapies. These traditional therapies are applied singularly or in combination to treat, diagnose, and prevent illnesses or maintain well-being (WHO 2001).

Although there are many traditional medical systems, they share some common characteristics. First, they focus on the holistic treatment of an individual and
seek to maintain equilibrium between the mind, body, and environment. Second, they emphasize the body’s natural healing processes. Third, they use naturally occurring medicinal substances derived from plant, animal, and mineral sources. By contrast, Allopathic medicine often referred to as Western or conventional medicine emphasizes the scientific approach and tends to focus on a specific pathogenic process. Within conventional medicine, the traditional medical systems and therapies are referred to as complementary and alternative medicine (CAM) (WHO 2002). These CAM systems and therapies are an integral part of the health care systems of many countries.

5.6.1 Asian Traditional Medical Systems

For centuries, many cultures have used traditional medical systems that utilize therapies such as T’ai Chi, Yoga, acupuncture, massage, manual and exercise techniques, and herbal remedies for the maintenance of health and well-being and the treatment of injury and illness. For example, one of the world’s oldest medical systems is the Indian system of Ayur (life) Veda (science or knowledge). The first texts on Ayurveda, written more than 2,000 years ago, are based on ancient oral traditions drawn from Hinduism and ancient Persian systems of health and healing. “Balance” is the core principle and aim of Ayurveda. Practitioners of this system seek to integrate and balance the body, mind, and spirit. Traditional therapies include massage, exercise, Yoga, breathing
techniques, meditation, proper diet, herbs, and metal and mineral preparations. This system is practiced at a national level as part of the federal health system.

Almost half of India’s population uses Ayurvedic medicine to meet their primary health care needs (NCCAM 2005). Variations of Ayurveda are practiced in Pakistan, Nepal, Bangladesh, Sri Lanka, and Tibet. There have been very few controlled scientific studies on Ayurvedic treatments. Most of the clinical trials have been small and poorly designed. Currently the CDC is supporting several studies on Ayurvedic practices including the use of a medicinal compound derived from the plant cowhage (Mucuna pruriens). This research is investigating the compound’s potential to prevent or lessen the debilitating side effects of drugs that are used to treat Parkinson’s disease (NCCAM 2005).

Traditional Chinese Medicine (TCM) is another system of health maintenance and medicine that utilizes therapies not commonly found in western medicine: herbal medicine, acupressure, acupuncture, T’ai Chi, and Qigong. In many Chinese hospitals, TCM is often practiced in conjunction with conventional medicine (Barnes, Powell-Griner et al. 2004). Many recent studies have focused on the use of T’ai Chi as an aid to improve balance and to reduce the risk of falls (Wolf, Barnhart et al. 1997). Another area of interest is the use of TCM herbal remedies for neuromuscular disorders such as tremor, movement difficulties, and loss of balance. For example, Xiao-Yao a TCM medication containing 10 herbs is prescribed for such disorders (Ishikawa, Funahashi et al. 2000). Such
medications combined with physical and exercise therapies such as T’ai Chi are used to improve balance.

Kampo, a Japanese traditional medicine, also utilizes herbal preparations. The Shin-no-honzō-kyō, an ancient medical text, lists 365 drugs derived from herbal, animal, and mineral substances for use in Kampo prescriptions (Sugaya, Sugaya et al. 1997). The Kampo (Chinese Way) system is a modification of TCM therapies introduced to Japan in the 5th century. Many Japanese physicians practice this system and treatment is covered by national health insurance. In a recent survey of Japanese doctors, it was found that 73% practice some form of CAM and 70% indicated that they practice Kampo. In addition, 19% practice other CAM including acupuncture, moxibustion, Yoga, Qigong, and Ayurveda (Watanabe, Imanishi et al. 2001).

In oriental TM, various therapies combining exercise, acupuncture, and herbal medication are used to treat neuromuscular disorders and to improve balance. Kampo utilizes several herbs that have been used for centuries to treat neuromuscular and balance disorders. For example, Kami-Shoyo-San, a mixture of several herbs, is traditionally used to treat Parkinson’s disease and convulsions. Other neuromuscular disorders can be caused by the side effects of anti-psychotic drugs: Parkinsonism (tremors and slowing down of movements) and Tardive Dyskinesia (random movements of the extremities and swaying movements). These symptoms greatly affect movements, walking, and balance.
A recent study found that Kami-Shoyo-San is effective in treating the tremors of antipsychotic-induced Parkinsonism (Ishikawa, Funahashi et al. 2000).

### 5.6.2 Asian Traditional Medicine Treatment Philosophy

In traditional Asian medicine, disease is classified by stage of progression and strength. The maintenance of health and well-being is believed to be a battle between the natural healing force and any factor that reduces this force such as bacteria, injury, or stress. The period during which the natural healing force is greater than the disease-causing factors is called Yo in Japanese TM (Yang in Chinese). The period when the healing force is less than the disease factors is called the In period in Japanese (Yin in Chinese). Both of these periods are further subdivided into three periods. The natural healing force is also divided into two grades: Jitsu (strong) and Kyo (weak). The specific physical therapy, diet, and medication are prescribed according to the disease period and the grade of the natural healing force. Various therapies are combined to produce the desired effect.

An example of this approach is seen in the system for administering medications. Substances derived from plant, animal, and mineral substances are divided into three categories: superior, middle, and inferior. The superior drugs are used for health maintenance, have no toxicity, and can be taken in large quantities and for long periods. The middle category of drugs are effective for improving poor
preventive therapy is another important principle in traditional Asian medicine. Therapies are prescribed against diseases or disabilities that are most likely to occur in the future. Such therapies begin during pregnancy or at birth with the administration of herbal drugs to aid in the healthy development of the child. Later in life, in addition to the continued use of preventive herbal drugs, other therapies are added such as T’ai Chi, acupuncture, massage, and Qigong. An example of a preventive drug is the Kampo herbal mixture Saiko-Keishi-To-Ka-Shakuyaku (SK, TJ-960). In China and Japan, this has been administered to newborn children since ancient times to guard against neuromuscular disorders. Studies on the effect of this drug on rats and mice indicate that it may have some benefit. Some of the reported beneficial effects are protection against neuron damage, normalizing effects on developmental defects, and regulation of the pathological expression of genes (Sugaya, Sugaya et al. 1997).
T'ai Chi is another commonly used preventive therapy. Recently it has gained much attention as researchers attempt to develop effective balance improvement therapies. However, results of many these studies have been inconsistent (Wu 2002). When one looks at the design and subject population of these studies such results may be expected. Many of the inconsistencies are due to differences in subject populations, the type of balance measurement used, and variations in the duration and style of T’ai Chi used. Many of the longitudinal studies were of relatively short duration ranging from 8 to 16 weeks and the subjects practiced once to three times per week. An analysis of 24 studies indicates that it takes 40 or more practice sessions before significant improvements develop in most balance measures (Wu 2002). In addition to minimal exposure to T’ai Chi training, the subjects in most studies did not experience the preventive benefits of the holistic TCM system of synergistic therapies.

5.7 Traditional Medicine Use in the U.S.

Traditional medical systems and therapies, known as Complementary and Alternative Medicine (CAM), have not been commonly available within the U.S. health care system. However, data from the 2007 National Health Interview Survey conducted by the CDC indicates that the use of these alternative therapies has recently become more popular. The statistics in this report show that 36% of adults used some form of CAM therapy (other than prayer) in the
past 12 months (NCHS 2008). The majority of the 10 most popular therapies are mind-body interventions (Figure 5.2).

![10 Most Common CAM Therapies—2002](image)


**Figure 5.2: 10 Most Common CAM Therapies—2002**

Percentage of U.S. adults who used the specific CAM therapy within the past 12 months. (Barnes, Powell-Griner et al. 2004)

Many of the therapies included in the National Health Interview Survey are part of traditional Asian medical and martial arts systems: acupuncture, Ayurveda (traditional Indian medicine), meditation, massage, guided imagery, deep breathing exercises, Yoga, T’ai Chi, Qigong (vital energy development), and
Reiki (energy healing). These CAM therapies were used at some time in their lives by 53% of U.S. adults (Barnes, Powell-Griner et al. 2004). In 2007, it was estimated that U.S. adults paid $33.9 billion out of pocket for CAM therapies (NCHS 2009). Between 1990 and 1997, there was a 47.3% increase in the total visits to alternative medicine practitioners. This exceeds the total visits to all U.S. primary care physicians for 1997 (Eisenberg, Davis et al. 1998). Interestingly, the number of adults who sought care from a CAM practitioner decreased from 1997 to 2007. However, the billions of dollars in CAM expenditures, while a fraction of the total health care spending, constituted a substantial part of out-of-pocket health-care costs and were comparable to out-of-pocket costs for conventional physician services and prescription drug use (NCHS 2009).

In response to the growing interest in CAM, in 1991 the U.S. Congress passed legislation to establish the Office of Alternative Medicine (OAM) within the National Institutes of Health (NIH). The role of the OAM was to investigate the efficacy of unconventional medical practices. The OAM was designated a World Health Organization Collaborating Center in Traditional Medicine in 1996. In 1999, by congressional mandate the NIH established the National Center for Complementary and Alternative Medicine (NCCAM) in order to evaluate the effectiveness of these therapies. Thus, the status of the OAM was elevated from that of an office to an independent NIH Center.
The mission of the NCCAM is to explore complementary and alternative healing practices through rigorous science. NCCAM conducts and supports basic and clinical research studies in the four domains of CAM: mind-body medicine, manipulative and body-based therapies, energy medicine, and biologically based practices (NIH 2005). In 2006, there were 305 on-going clinical trials of CAM or TCM therapies registered with the NIH. The NIH or another federal agency funded 293 of these studies (NIH 2006b). Since 2006 the number of on-going trials involving CAM or TCM therapies has increased dramatically. As of October 2012 there were 1,672 open studies with 542 studies still recruiting subjects (NIH 2012).

5.8 U.S. Government Disability and Fall Prevention Research

The NIH, the nation’s medical research agency, is composed of 27 Institutes and Centers. The NIH provides funding and leadership to medical researchers in every state. In 2006, there were 54 NIH registered clinical studies on balance or falls currently in process; 15 of these specifically explored the effects of exercise on balance and fall prevention (NIH 2006b). Since 2006, the number of NIH trials examining balance and falls has increased dramatically. As of October 2012, the number of trials listed has grown to 208; of these 92 trials are still recruiting subjects (NIH 2012). The Research on Aging Act of 1974 established the National Institute on Aging (NIA) as an NIH Institution. The NIA’s mission is to conduct and support biomedical, social, and behavioral research on the aging
process, age-related diseases, and the special problems and needs of the elderly. The central focus of this research is to understand age-related changes in physiology and the ability to adapt to environmental stress (NIA 2004b).

The NIA’s Clinical Research Branch supports two major longitudinal studies: Healthy Aging across the Life Span (HANDLS) and the Baltimore Longitudinal Study of Aging (BLSA). The primary objective of HANDLS is to conduct a study of minority health focused on the relationships among race, socioeconomic status, and health outcomes. The baseline sample will consist of approximately 4,000 adults aged 34-69. HANDLS began in 2004 and will examine physical, genetic, demographic, psychosocial, and psychophysiological parameters over a 20-year period. Part of the study will focus on age-associated functional decline in strength and balance (NIA 2004a). The BLSA is the most comprehensive study of aging in the world. BLSA began in 1957 and will be completed in 2016. This is a multidisciplinary study of the physiological and psychological aspects of aging intended to improve quality of life and to prevent or delay loss of independence. A major goal of the BLSA is to define the anatomical, physiological, and functional changes that occur during the aging process and then to identify the biological, behavioral, and environmental factors that contribute to these changes. The BLSA seeks to develop interventions to strengthen multiple physiological systems including those that support mobility and cognitive function (NIH 2006a). More than 1,100 subjects, ranging in age from 20 to over 90, undergo over 100 physiological assessments every two years.
throughout their lives (BLSA 2006). Current research projects are evaluating osteoarthritis and the neuromuscular/strength changes that contribute to disability.

### 5.8.1 A Multi-systems Model for Disability

Balance and efficient mobility have been an important factor in natural selection throughout human evolution. Highly redundant physiological systems have thus developed that are able to function and interact in a variety of ways to assist in balance and mobility. Frailty is a condition characterized by instability and a decline in physiologic reserve. The CRB’s Longitudinal Studies Section (LSS) has taken the approach that disability and frailty are parts of a dynamic process that starts early in life. Interventions to improve stability and mobility are more likely to be effective if initiated early in this process. Since frailty is detectable before severe disability develops, it is a reliable predictor of various negative outcomes such as falls. The LSS studies have found that subjects can use a number of compensatory strategies to maintain mobility. Problems in balance and mobility are clinically detectable only after the functional reserve of the redundant physiological systems is depleted (NIA 2004b).

The LSS is studying the relationship between aging, morbidity, and disability.
The LSS is examining this relationship by analyzing data from the Established Population for Epidemiological Studies of the Elderly (EPESE) and the Women’s
Health and Aging Study (WHAS). Both of these studies were established to investigate the preclinical characteristics and progression of disability. The LSS is using data from these longitudinal studies to investigate the compensatory strategies that subjects use to maintain mobility even though they have damage to multiple physiological systems (NIA 2004b).

An analysis of the EPESE data indicates that in the non-disabled elderly, poor performance in balance and mobility tests is an independent and reliable predictor of disability, morbidity, and mortality. LSS studies found that 50% of the elderly develop disability rapidly due to an acute pathological event that results in a decline from full function to severe disability. However, the other 50% of the elderly experience frailty-associated progressive disability, whereby balance and mobility problems develop slowly and are not due to acute events. This progressive disability is typically exhibited by the oldest of the elderly. Analysis of data from WHAS has demonstrated for the first time the existence of a large functional reserve. The findings show that muscular strength is the basic compensatory mechanism for counteracting disability caused by balance problems. Reduced muscle strength and balance problems synergistically interact to cause severe difficulty in mobility. However, it is only below a specific threshold of strength that leg strength is associated with walking speed (NIA 2004b).
The LSS has analyzed data from InCHIANTI (Invecchiare Chianti, or aging in Chianti), a population-based study of factors contributing to balance and mobility problems of persons living in the Chianti area of Italy. From the results of this study, the LSS developed a model that defines balance and mobility as a product of a sequence of events:

- the brain receives a motivational clue and then creates a motor program
- this motor program is transported by peripheral nerves that activate muscles in a proper sequence
- the muscles transform chemical energy into physical energy
- the muscles apply forces to the skeleton and move the joints

This process produces forces, that when applied to the floor through the feet, act to balance the body and produce mobility. Individual impairments that can cause disability occur in one of six main subsystems: central nervous system, peripheral nervous system, perceptual system, the muscles, energy production and delivery, and the skeleton and joints. To continue activity, the circulatory system must deliver oxygen and nutrients to the muscles, and continuous feedback is necessary through the vestibular, proprioceptive, and visual systems. Minor impairments to balance and mobility do not usually cause disability since the supporting subsystems have a certain amount of functional reserve (Ferrucci, Bandinelli et al. 2000).
5.8.2 Subsystem Thresholds and Balance

Impairments to a subsystem cause disability only when the amount of damage reaches a certain threshold (Ferrucci, Bandinelli et al. 2000). Refinement in the design of other research studies such as the BLSA now includes a search for such thresholds. The ultimate goal is to define the biological pathways that lead to disabilities in balance and mobility. This task involves the unraveling of multiple interconnected biological mechanisms. The most readily apparent aspect is a person’s behavior within the environment. Behavior is greatly influenced by physical and cognitive function, which in turn requires the efficient functioning of multiple physiological systems. Reduction in the efficiency of physiological function results when the body cannot maintain homeostasis or supply sufficient energy to react appropriately to environmental demands. Thus, a main goal of the new BLSA design is to identify the multiple adaptive responses to physical activity and their effect on disabilities in balance and mobility (NIA 2004b).

Identifying the limits, within which each subsystem functions efficiently, will assist in the development of effective disability interventions. For example, strength programs are often employed to improve balance and mobility. However, clinical studies have shown that leg muscle strength is not related to walking speed above a critical threshold (Ferrucci, Guralnik et al. 1997). Strength is not a significant factor in walking disability when lower extremity muscle strength is
above this critical threshold. Thus, strength-training programs for stronger individuals will improve strength and physiologic reserve, but they will have no effect on gait speed.

A similar analysis was performed to determine if there is a critical threshold in the relationship between muscular strength and the maintenance of standing balance. Since difficulty in balance may result from multiple impairments in several subsystems, it is difficult to identify the specific sources of impairment. However, the results of this study show that increasing strength is associated with a progressively higher percentage of subjects who can successfully complete balance tests. A given difference in strength produced a similar effect on the probability of success in maintaining balance. Unlike the strength and mobility relationship, there is no critical threshold in the relationship between strength and balance. The goal of current LSS research is to develop such reference values to assist in measuring the functionality of all the various subsystems. Knowing these critical thresholds will help to identify the damaged subsystems. This will indicate the specific interventions to prescribe in order to strengthen the damaged subsystems and thus improve balance and mobility (NIA 2004b).


5.8.3 Fall Prevention Research

Prior to 1985, falls were thought to be caused by unavoidable accidents or due to discrete disease or impairment. The results of subsequent studies indicate that there are multiple factors involved in the risk of falls including impaired balance/gait, lower extremity impairment, cognitive impairment, central nervous system dysfunction, two or more chronic conditions, and sedative use. As the number of risk factors increases from 0 to 4 or more, the percentage of subjects who fall increases from 8 to 78%. These studies resulted in the development of a Multi-factorial Geriatric Syndrome Model for falls. This model predicts the risk of falls based on a subject’s risk factors. It also predicts a reduction in the number of falls if effective interventions are used (NIA 2003).

In 1990, both the NIA and the National Center of Nursing Research recognized the need for a major research effort to find effective fall prevention interventions. To test the validity of the multi-factorial model they jointly sponsored a series of research studies: The Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT). This effort involved more than 2,500 elderly subjects and encompassed eight independent clinical trials designed to assess the efficacy of various intervention strategies. The interventions assessed included behavioral modification, changes in types and amount of medications, education about fall prevention, functional activities, nutritional supplements, and exercise. Seven of the trials utilized exercise as at least one component of the intervention.
Exercise programs lasted from 10 to 36 weeks and varied as to frequency, intensity, time, and type of exercise. The specific activity employed in each program contained various combinations of training types: strength, endurance, flexibility, static balance training on a balance platform, or dynamic balance training through T’ai Chi (Province, Hadley et al. 1995).

The NIA’s Geriatrics and Clinical Gerontology Program is currently funding research on multifactorial geriatric syndromes such as falls and the effects of physical activity on disease and disability in older persons. Other government sponsored research programs focus on reducing falls in the workplace. In 1996, NIOSH instituted the National Occupational Research Agenda as a guide for occupational safety and health research. In an attempt to identify the factors that contribute to the risk of falling, NIOSH is using virtual reality technology to simulate elevated work environments (NIOSH 2003).

**5.8.4 Effects of Exercise on Risk of Falls**

A preplanned meta-analysis of the FICSIT clinical trials indicated that exercise programs in general reduced the risk of falls (Province, Hadley et al. 1995). The programs that included balance training significantly reduced falls. Grouping of the interventions according to the predominant focus (strength, endurance, or balance) indicated that the programs emphasizing balance had the greatest effect on delaying the onset of first falls (Wolf, Barnhart et al. 1997). However, in
addition to exercise the FICSIT trials contained various non-exercise treatment components. Thus, it is very difficult to define the exact role of exercise in the reduction of the risk of falls seen in these trials. In addition, since the trials that included balance training included other types of exercise, it cannot be concluded that balance training by itself would produce the same effect. However, the FICSIT trials did demonstrate that interventions that include exercise produce a significant reduction in falls and those that include balance training have the greatest effect.

Monitoring of the FICSIT subjects for falls and injuries continued for 2 to 4 years after the end of the intervention programs. Although the treatment duration of the FICSIT trials was relatively short, lasting from only 10 weeks to 9 months, the beneficial effects of exercise on the reduction of falls persisted for a median time of 1.5 years after the end of the supervised interventions (Province, Hadley et al. 1995). In addition to a reduction in the risk of falls, exercise programs also produced improvements in the emotional health score. In general, those subjects who followed an exercise program perceived less interference from emotional problems in their daily activities (Schechtman and Ory 2001). An added benefit is the $2,000 per person reduction in health care costs for the intervention group compared to the control group (NIA 2003).
5.9 Overview of Research on T’ai Chi

In recent years, there has been a tremendous increase in attention toward the use of the martial arts and especially T’ai Chi for prevention and rehabilitation therapy for maintaining health, improving balance, and for preventing falls. The U.S. National Library of Medicine PubMed Bibliographic Database contains over 22 million bibliographic citations from more than 5,600 biomedical and life sciences journals published in the U.S. and 70 other countries. A search of PubMed for the period 1950 through November 2012 for published journal articles relating to T’ai Chi and other martial arts produced 2,638 citations. The earliest publication date is 1955. The majority of the research articles (72%) were published in the past 10 years. When the total martial arts results are narrowed to those relating to balance, 288 articles are cited (NCBI 2012).

5.9.1 Systematic Reviews of T’ai Chi Research

A recent comprehensive systematic review of published articles relating to the health effects of T’ai Chi searched 11 computerized English and Chinese bibliographic data bases (Wang, Collet et al. 2004). This search covered articles published from January 1966 through April 2002. A total of 743 abstracts were found however only 47 original studies met all of the quality requirements for inclusion in the review. Of the 47 acceptable articles, 39 were published after 1990. Inclusion requirements included: treatment of a chronic condition, well
defined study question, explicit eligibility criteria, valid outcome measurements and statistical methods, and conclusions supported by the findings.

The acceptable studies were of three types: randomized controlled trials, nonrandomized controlled studies, and observational studies. In randomized controlled trials (RCT) subjects are randomly assigned to groups. One group of subjects (the exposed group) is given training and the other group (the control group) is given some other training, a placebo, or nothing. In nonrandomized controlled studies (NRS) the subjects are not randomly assigned to groups. Some subjects are given training and undergo a before and after comparison. These subjects are then compared with an unexposed group. In observational studies (OS) the use of training is not manipulated and the researcher simply observes and interprets the outcomes. Of the 47 selected studies there are 9 RCT, 23 NRS, and 15 OS.

The studies selected for examination in the above review all evaluate the effectiveness of T’ai Chi in improving the health of patients with chronic problems. The focus of the studies include: balance and fall reduction, cardiovascular and respiratory function, blood pressure, musculoskeletal changes, psychological effects, and effects on the immune and endocrine systems. The effects of T’ai Chi on balance are reported in 11 studies. Overall, these balance studies indicate that long-term practice produces favorable effects by improving balance, flexibility, and cardiovascular fitness, and by reducing the
risk of falls. Three of these are cross-sectional studies of individuals with from 1 to 35 years of practice. These studies indicate that the T’ai Chi practitioners have greater lower extremity flexibility and that T’ai Chi training improved normal and maximal gait velocity. Seven of the balance studies are clinical trials that evaluate the effects of T’ai Chi on fall reduction in community-dwelling older adults.

The 11 balance related T’ai Chi studies indicate that training programs lasting 8 to 16 weeks significantly reduce the risk of falls and improve balance, flexibility, and knee extension strength. However there are several limitations to these balance oriented studies, as many (5) are nonrandomized studies, some have no comparison group, and others have small sample sizes. The three cross-sectional studies are too limited to explain the cause-effect relationship. In addition, the subjects selected for the 11 balance studies exhibit a wide range of T’ai Chi exercise experience ranging from 8 weeks to 35 years. Further, some studies did not control for exercise time during the training sessions. Thus, it is difficult to compare the duration of exercise sessions or total training time to the resulting benefits. Another problem is that the style of T’ai Chi and the individual exercises are not standardized. The forms of T’ai Chi used vary significantly between studies and include Chen, Beijing, Pa-Kua, Wu, and Yang.

In general, the 47 selected studies on the effects of T’ai Chi training indicate that long-term practice of T’ai Chi produces many benefits. Improvements are
demonstrated in balance, fall prevention, strength, flexibility, cardiovascular and respiratory function, symptoms of arthritis, and psychological effects. However, it is difficult to evaluate the true effectiveness of T’ai Chi, as limitations and biases existed in many studies. In addition, these studies did not present a well-defined theoretical foundation concerning the mechanism of benefit (Wang, Collet et al. 2004).

A similar critical review of articles published from 1985 through 2003 found over 300 T’ai Chi related articles. Over 200 of these were original scholarly or scientific reports however only 17 met strict methodological standards and the following inclusion criteria: 1) controlled clinical research, 2) methodology free of major threats to internal validity, and 3) T’ai Chi intervention defined as an independent variable. The 17 studies evaluated a total of 1,035 subjects with 70% of them being elderly adults. Over 22 outcome areas were examined and over 60% of these demonstrated a statistically significant improvement. Positive trends were also reported another 15% of the time. None of the studies reported harmful effects. Although all of the studies demonstrated a positive effect due to T’ai Chi training, it is difficult to determine the mode and dose effect as the training regimen varied significantly. The style of T’ai Chi taught varied between studies, the lengths of T’ai Chi training ranged from 6 weeks to 12 months, sessions ranged from one to three times a week, and the time of each session varied from less than 15 minutes to over one hour. The evidence from these studies provide support for the proposed benefits of T’ai Chi training which
include improvements in: overall quality of life, cardiovascular function, immune response, strength, flexibility, kinesthetic sense, and balance (Klein and Adams 2004). Furthermore, in a current survey collected by the CDC, it was found that T’ai Chi and Qigong practitioners have significantly better health status than average exercising and non-exercising U.S. adults. After controlling for income, education, and exercise group membership, older practitioners were found to have the best average health trajectory (Komelski, Miyazaki et al. 2012).

5.9.2 Research on Specific Health Effects of T’ai Chi Training

Those who practice T’ai Chi believe that it improves quality of life by promoting mental and physical health, concentration, balance, strength, endurance, flexibility, and cardiovascular and respiratory functioning. Many clinical trials have been initiated in an attempt to verify the benefits of training in T’ai Chi and related arts. In 2006, there were 15 clinical trials of T’ai Chi, 4 trials of Qigong, and 17 trials of Yoga registered with the NIH. Of these, 20 trials were completed or were no longer recruiting subjects, and 16 were in the process of recruiting. Of the total 36 clinical trials, 26 are funded by either NIH or another federal agency. These studies examined the beneficial effects of T’ai Chi and related arts on all age groups (NIH 2006b).

The results of recently completed research indicate that T’ai Chi does appear to have beneficial physiological, psychosocial, and neuromuscular effects. If for no
other reason, T’ai Chi has beneficial health effects as it is a form of moderate exercise that almost everyone can participate in. The average energy cost for healthy adults is equivalent to that expended during a brisk walk at a rate of 6 km/hr. With a peak heart rate of 134 beats/min the intensity does not exceed 50% of an individual’s maximum oxygen uptake (Zhuo, Shephard et al. 1984). Such physical activity has been shown to protect against age-related cognitive decline and all-cause mortality. Exercise is now prescribed as a component of treatment in many chronic diseases and disorders: metabolic syndrome related disorders, heart and pulmonary diseases, muscle, bone, and joint diseases, and cancer, depression, asthma, and diabetes (Pedersen and Saltin 2006). Adults with coronary heart disease and hypertension have significant reduction in blood pressure and improvement in aerobic endurance after 12 weeks of T’ai Chi exercise (Taylor-Piliae, Haskell et al. 2006a). Significant improvements in muscle strength, muscle endurance, and flexibility occur with as little as 6 weeks of T’ai Chi training (Taylor-Piliae, Haskell et al. 2006b).

Recent studies indicate that moderate exercise also mediates the anti-inflammatory response of the immune system. Systemic low-level inflammation is produced in the pathological processes of chronic conditions and diseases such as functional disability, cognitive decline, cardiovascular disease, stroke, Alzheimer’s disease, and cancer. Contracting skeletal muscle acts as an endocrine organ by releasing cytokines into the circulation which act as important regulators of metabolism, the immune system, endocrine system, and brain
Interleukin-6 (IL-6) is the first identified “myokine”: a cytokine released from muscle cells (Febbraio and Pedersen 2005). Muscle-derived IL-6 is thought to play a major role in the health benefits and anti-inflammatory effects of physical exercise (Bruunsgaard 2005).

Exercise intensity is an important factor in determining plasma concentrations of IL-6. Marathon runners show a 100-fold increase in IL-6 and demonstrate a positive correlation between running intensity and peak IL-6 concentration. Recent studies suggest that IL-6 is important in maintaining homeostasis. Greater levels of IL-6 are produced during high intensity exercise as it creates a greater stress on homeostasis (Ostrowski, Schjerling et al. 2000). Even moderate exercise has a significant effect on IL-6 levels. In young healthy subjects, a 50% maximal knee extensor exercise produces an increase in heart rate of 113-122 beats per minute. This level of heart rate is equivalent to a brisk walk, yet during extended periods of exercise this produces a 20-fold increase in plasma IL-6 (Fischer, Hiscock et al. 2004). Healthy elderly adults produce similar amounts of muscle-derived IL-6 during moderate exercise (Pedersen, Steensberg et al. 2004).

Current research is attempting to identify interventions to help preserve thymic function and increase the production of T cells. The primary lymphatic organ responsible for generating T lymphocytes is the thymus. The thymus begins to involute in childhood and becomes progressively smaller with age. This
produces a progressive loss of immune response against disease, infections, and tumors (NIA 2003). T’ai Chi appears to improve immune response by increasing T cells, which have an important role in mucosal defense and inflammatory disease (Yeh, Chuang et al. 2009). T’ai Chi practice also has a beneficial effect on psychosocial functioning as it improves quality of life and reduces psychological stress. This reduction in stress may be a critical factor in improving neuroendocrine-immune responses and subsequent health outcomes (Robins, McCain et al. 2006).

The practice of T’ai Chi involves the coordination of various breathing patterns, postures, and body movements. Advanced T’ai Chi training contains the practice of specific stability, breathing, and relaxation exercises known as Qigong (Breath Technique). Known as “guiding” in ancient China, it is a form of Traditional Chinese Medicine practiced for health maintenance and as a therapeutic intervention. Recent research indicates that it may have beneficial effects. Patients who undergo chemotherapy experience a decrease in their white blood cell count. Those who receive Qigong therapy demonstrate significant increases in white blood cells compared to the control group (Yeh, Lee et al. 2006). Additionally, Qigong has shown to improve the antibody response to influenza vaccine in older adults (Yang, Verkuilen et al. 2008).
5.10 Effects of T’ai Chi on Balance

Much of the early research on postural stability examined general balance abilities but did not identify the specific body system responsible for a decline in the control of balance. More recently, postural stability research has taken a dynamic systems approach that examines the various neuromuscular factors that interact to contribute to postural control. These multiple factors include: 1) inputs from the vestibular, visual, and somatosensory systems; 2) the adaptive capacity to shift the dominant sensory input for the control of posture; and 3) the strength and organization of the response of the postural control muscles during perturbations to balance (Woollacott 1993).

Despite the fact that there are multiple factors that contribute to postural control, most interventions aimed at reducing the risk of falls have focused on developing either a single or a limited number of variables such as strength, endurance, gait, or balance. These training programs have demonstrated improvements in the particular area of focus but they have not been effective at reducing the risk of falls (Wu 2002). By contrast, dynamic balance training such as T’ai Chi focuses on the functioning of the body and mind as a whole. The practice of T’ai Chi follows the same basic principles of all traditional Chinese medical therapies. The intent is to balance the Ch’i by strengthening the body and relaxing the mind. To achieve this T’ai Chi incorporates training in three basic areas: movement, breathing, and cognition. T’ai Chi practice combines training in strength,
endurance, flexibility, posture, balance, gait, and concentration (imagery, internal awareness, and awareness of the environment).

T'ai Chi training emphasizes whole body dynamic movements and progresses through stages of increasing difficulty that continue to challenge postural stability. As greater proficiency is achieved the magnitude of trunk and arm rotation increases, there is a gradual narrowing of the base of support, and the emphasis of weight bearing shifts from bilateral to unilateral support. The postures are performed with knees slightly flexed so that the quadriceps muscles support the body weight. This improves postural stability by lowering the body's center of mass and by permitting quick adjustments in response to perturbations. All of the other muscles are relaxed allowing the body to maintain a relaxed postural alignment. The movements are performed slowly with emphasis on full body awareness and full mental concentration. This leads to better control of whole body displacements.

The implications of this type of dynamic balance training are greatest for the elderly. With increasing age, there is a general decline in resilience in the musculoskeletal, cardiovascular, immune, and central nervous systems. This decline in adaptive capacity leads to an increase in risk of disease, balance and mobility problems, and declines in cognitive ability (Hogan 2005). These age-related impairments have been identified at all levels of the postural control system: muscle strength and control at the ankle, knee, and hip; the peripheral
sensory system involving vision, proprioception, and the vestibular; and the central nervous system’s integrative processes (Lord, Stephen et al. 2003). These multiple-system declines in turn lead to an increase in the risk of falls, which especially for the elderly, can be life threatening. Thus, there has been increased interest in training programs such as T’ai Chi, which combine physical and cognitive exercises, skill development, and relaxation.

5.10.1 T’ai Chi and Fall Reduction

The FICSIT trials demonstrated that the balance interventions which emphasized T’ai Chi had the greatest effect on reducing falls (Wolf, Barnhart et al. 1997). The specific FICSIT trial held in Atlanta Georgia evaluated the efficacy of two exercise interventions, T’ai Chi and computerized balance training (CBT), on reducing the risk of falls. This study evaluated the effects of 15 weeks of training on 200 subjects over the age of 70. The total instructor contact time for each group was approximately one hour every week. The T’ai Chi group practiced 10 movement patterns synthesized from the 108 patterns contained in traditional T’ai Chi. The CBT group received balance training on a force platform. In CBT, the force platform outputs representing the subject’s center of pressure are displayed on a monitor. Through the shifting of their weight, the CBT subjects learn to move a cursor toward targets displayed on the screen. The incidence of falls in both groups was monitored throughout the study and for four months afterward.
The results obtained indicated that T’ai Chi was more effective than CBT in reducing the risk of falls. With T’ai Chi, there was a reduction of the risk of multiple falls by 47.5%. By contrast, CBT did not reduce the rate of falls. Other beneficial effects of T’ai Chi are a reduction in blood pressure both before and after a 12-minute walk, and a reduction in fear of falling (Wolf, Barnhart et al. 1996). The reduction in the fear of falling though returned to pre-intervention levels within four months (Wolf, Barnhart et al. 1997). The reduction in the risk of falls due to exercise programs however lasts for a median of 1.5 years after supervised intervention (Province, Hadley et al. 1995). This may indicate that reduction in the fear of falling is not a significant factor in the long-term reduction of the risk of falls.

5.10.2  T’ai Chi and Postural Sway

The major goals of fall prevention programs are to reduce injury and to encourage functional independence by improving balance. What constitutes “balance” however is not clear. Much research has thus focused on the analysis of the characteristics of postural stability. The FICSIT trials held in Atlanta employed two types of balance training: T’ai Chi and CBT. In an effort to understand how balance training affects characteristics of stability, researchers analyzed the postural sway of the Atlanta FICSIT subjects. The aim was to determine which type of balance training improved the ability to minimize postural sway against defined perturbations.
Subject testing involved standing on a force plate under four conditions: 1) quiet standing, eyes open; 2) quiet standing, eyes closed; 3) toes up, eyes open (with angular perturbation of 4° over 4 seconds); and 4) toes up, eyes closed. Postural stability data was recorded for 20 seconds and each condition was repeated three times. This data provides three measures of balance: measurement of anterior-posterior displacement of the center of pressure (y-axis), lateral displacement (x-axis), and dispersion. The dispersion index describes the variability of the x and y coordinates of the center of pressure data. It is based on how far the data points deviate from the mean center of pressure. Larger values of any of these three measures indicate greater postural sway. Subjects were evaluated before balance training, immediately after completion of training, and at four months after training (Wolf, Barnhart et al. 1997).

The analysis of this data indicates that CBT improved postural stability as measured by reduced postural sway whereas T’ai Chi practice did not. In fact, the T’ai Chi group demonstrated increased sway in the sagittal or frontal planes for several conditions, particularly those involving angular perturbation (Wolf, Barnhart et al. 1997). However, the increased sway of the T’ai Chi group did not adversely affect balance. This is demonstrated by the fact that the FICSIT interventions that included T’ai Chi had the greatest reduction in the risk of falls. This indicates that training to increase postural stability by reducing sway is not an effective strategy for improving balance to reduce falls or for coping with real-life situations involving unexpected perturbations.
5.11 Effects of T’ai Chi on Perturbations to Postural Stability

The conclusion from the FICSIT study demonstrated that T’ai Chi practice did not improve postural stability as measured by reduced postural sway. However, since then, a comprehensive, randomized controlled trial published in the New England Journal of Medicine (Li, Harmer et al. 2012) found that T’ai Chi did improve postural stability and additionally, was consistent with FICSIT results in reducing the number of falls. This study examined whether T’ai Chi could improve postural stability in 195 patients with mild to moderate Parkinson’s Disease and assigned the participants to: a T’ai Chi program, a resistance training program, or to a stretching program. Measurements were assessed at four time points, baseline, 3mo, 6mo, and 3mo after the completion of the program. Maximum excursion and directional control were selected as the primary outcomes and were measured using computerized dynamic posturography using the Balance Master System from NeuroCom.

At the conclusion of the study, the participants in the T’ai Chi group performed significantly better on the primary outcomes than those in the resistance-training (maximum excursion, P=.01; directional control, P=.002) and stretching groups (P<.001 for both comparisons). Analyses of the secondary outcomes demonstrated that the T’ai Chi group had significantly better performance on the measurements of gait and strength, better scores on the functional-reach and timed up-and-go tests, and better UPDRS III scores, as compared with the
stretching group (P<0.001 for all comparisons). The T’ai Chi group also outperformed the resistance training group on stride length and functional reach (P = 0.01 for both comparisons). Finally, the incidence rate of falls was lower in the T’ai Chi group (0.22 per participant/month) than in the other two groups. Moreover, three months after the study conclusion, the T’ai Chi group maintained their health improvements in both the primary and secondary outcomes and furthermore, they had fewer falls than those in the stretching group (P = 0.003) and those in the resistance training group (P = 0.02). These results supported the efficacy of T’ai Chi in alleviating the bradykinetic movements associated with Parkinson’s disease and indicated that the inherent movements found in T’ai Chi can improve postural control and walking ability (Li, Harmer et al. 2012).

While it is important that T’ai Chi can improve static postural stability and reduce the number of falls, T’ai Chi has also been found to improve dynamic balance. In Wong et al. 2011, T’ai Chi was evaluated against swimming because of its similar nature as a low impact activity yet still required coordination of the trunk, arms, legs, and feet in combination with mental concentration. Thirty two participants were chosen from a local T’ai Chi club and 20 participants from a local swimming group. All volunteers had practiced regularly in their corresponding activity for at least three years before the study and trained at least three sessions a week. The average ages were 67 and 65 years for the T’ai Chi group and swimming group, respectively. The control group consisted of 34 healthy, active adults matched for age and sex.
Postural stability was measured using the SMART Balance Master instrument and was evaluated by asking the participants to have: (1) eyes open and fixed support; (2) eyes closed and fixed support; (3) sway-referenced vision and fixed support; (4) eyes open and sway-referenced support; (5) eyes closed and sway-referenced support; and (6) sway referenced vision and support. Each participant practiced two trials (1-2) or three trials (3-6) prior to the formal experiment.

The results from the study showed that in the tasks that were simple and non-challenging, all three groups were similar in performance when the eyes were open or closed with fixed support. However, in more challenging balance conditions such as sway-referenced vision and fixed support, eyes closed and sway-referenced support, and sway referenced vision and support, the T’ai Chi group exhibited significantly greater maximal stability, compared with the swimming and control groups (p < 0.05). Additionally, in the latter two challenging balance conditions, in which the proprioception and vestibular functions are disturbed under the sway ground support condition and, at the same time, vision could not provide reliable information, the T’ai Chi group demonstrated significantly smaller center-of-pressure velocity, and greater use of ankle strategy, (p < 0.05). Thus, the T’ai Chi group overall had less posture sway and better posture control indicating that T’ai Chi can be effective in improving the balance reaction in more complicated and unstable balance situations (Wong, Chou et al. 2011).
5.12 Summary

In 2005, it was estimated that every 17 seconds, an older adult will be treated in an emergency room for injuries related to a fall, and tragically, every 30 minutes, an older adult will die from injuries sustained in a fall (CDC 2011). Fortunately, the risk of falls can be reduced. Indeed, the CDC recommends the use of regular exercise, and specifically T’ai Chi, in programs designed to help reduce the risks of falling (CDC 2012a). In this chapter, the tremendous socioeconomic impact of falls on society was discussed. The results of recent data examining T’ai Chi therapies for improving health status, postural stability in dynamic situations, and reduction in the risk of falls support the value of T’ai Chi training. Thus, these studies validate the importance of using martial arts training to develop approaches to improve balance control and well-being. In the next chapter, the methods used in this research study to examine the effects of both Karate training and strength training on postural stability are presented.
CHAPTER 6

METHODS

And some say that all existing things without exception are in constant movement, but that this escapes our perception.

6.1 Introduction: Chasing Shadows

The ancient T'ai Chi texts say that there is “motion in stillness”. But how does one discern this motion? How does one learn to be still? The Kenpo Gokui provides hints as to how we can improve our perception. For example: “The eye must see all sides.” If one can sense change one can control it. But how can we “see” minute changes in movement? How can we perceive the “Hidden Harmonies” of Heraclitus? As Plato advises, in addition to “sight” we need “light”.

The ancient T'ai Chi masters relied on insights gained from a lifetime of study. Aristotle attempted to find hidden patterns by tracing the movement of shadows on a wall. Michael of Ephesus suggested that this could be improved upon by using a brush attached to the head. By the 1880’s things had progressed to where researchers were exploring the “rhythm of muscular response” through the use of cat’s whiskers attached to needles inserted into their own muscles; supplemented of course by ample doses of cocaine. Fortunately, today we have computerized instruments that provide new ways of “seeing”. One can now more
easily explore the “hidden knowledge” of the mechanisms behind stability and movement. This chapter outlines which “shadow” I have chosen to chase and the “light” that I used. This is my approach to gaining insights into the mysteries of postural stability.

6.2 Center of Pressure

The “shadow” that we are chasing is called the center of pressure (COP). This corresponds approximately to the vertical projection of the subject’s center of gravity on to the surface upon which they are standing. A simple analogy is demonstrated by fixing a yard stick to your upper body and suspending it vertically to the floor. Unlike Michael of Ephesus, I chose not to tie a brush to the stick and attempt to obtain a drawing of the subject’s center of gravity on the floor as their balance shifted. Fortunately, I had access to more advanced technology, a force plate, which I will describe further below.

6.3 Research Study Description

The purpose of this study was to examine the postural characteristics of two groups of subjects in a variety of upright postures. Karate students were compared with a control group of strength training students during tasks of standing on two feet and one foot, both with and without perturbations. Strength training was chosen as a comparison since it is one of the interventions
commonly investigated for use in fall prevention programs (Clemson, Fiatarone Singh et al. 2012). The changes in the center of pressure were recorded for each subject. The COP roughly corresponds to the point about which they were balancing. Variability of the patterns of movement between subjects was determined in order to provide insight into the characteristics and mechanisms of postural control. The hypothesis is that the Karate students will show more improvement in balance as training progresses, compared with the control group, as the Karate students underwent a more posturally dynamic training program. The insights gained will help in designing programs to assist in fall prevention. Below are brief outlines of the study and the potential benefits.

6.3.1 Study Outline

**Purpose:** The study examined the potential differences in postural characteristics between karate students and a control group while standing on one and two feet with and without a perturbation.

**Hypothesis:** Karate students will show more improvement in balance as their training progresses compared to the control group.

**Methods:**
- 40 subjects, age 18-26, : 20 Karate students and 20 control group strength training students.
- Questionnaire used to ascertain physical activity levels and experience in Karate or strength training.
• Anthropometric measures recorded: height, mass, limb lengths, circumferences.
• Subjects stood barefoot on a force plate in various positions for 30 seconds each.
  The positions were standing upright:
  ○ On both feet
  ○ On one foot
  ○ On one foot with eyes closed
  The tasks were to maintain these positions:
  ○ Without perturbation.
    ○ After a destabilizing movement is applied to the hips.
• Both Karate and Strength students completed 15 weeks of training with a qualified University Instructor.
• Subjects were tested twice: at the start of the 15 week period and at the end
• The center of pressure motion was computed from force plate data. This will permit quantification of the nature of each subject’s balance in each of the tasks.

6.3.2 Benefits of the Study

The students were informed that their participation had the potential to benefit both themselves and society in general:

• Subjects could benefit by understanding how their balance changes during physical training.
• Subjects would become more educated as to current biomechanics research aims and methods.
• Society may benefit by a greater understanding of how balance is influenced by Karate training.
Society may benefit by gaining insights to improve programs to assist in fall prevention.

The following sections provide a description of the subjects, the training they received during this study, and the analysis of their postural stability. These subjects performed a series of tasks designed to assess their postural stability; both before and after participation in physical training programs. Outlined below are the tasks, the equipment, and the statistical analysis used to discover if there are any differences in postural stability between the groups.

**6.4 Subject Recruitment**

The recruitment of subjects followed the Kinesiology Department and University policies for the protection of research subjects. Human subject protection regulations were first issued by the U.S. Department of Health and Human Services (HHS) in 1974. Subsequently, the HHS established the Office for Human Research Protections (OHRP) to assist the research community in conducting ethical research that is in compliance with the HHS regulations (OHRP 1993). In compliance with these regulations, the Pennsylvania State University’s Office for Research Protections (ORP) has established an Institutional Review Board (IRB) which is responsible for reviewing research involving human participants (OVPR 2009). Before this study was initiated, approval for the use of subjects was obtained from the IRB. This study carefully
followed the guidelines for the use of human subjects, specifically for the use of
students (ORP 2003).

Subsequently, two groups of volunteer subjects were recruited to participate in
this research study. Both groups were composed of full-time undergraduate
students at the Pennsylvania State University who were enrolled in classes
offered through the Penn State Kinesiology Department: Exercise and Sport
Activity (ESACT) and Kinesiology (KINES). The Karate subjects were recruited
from ESACT 183, Introduction to Karate. The strength-training subjects were
recruited from KINES 68, Strength Training; an introductory course in strength-
training. Students were recruited from these courses through the use of flyers
and a verbal presentation by the principle investigator (PI). No monetary
compensation was offered for the subject’s participation in this research study.
However, as an incentive to participate in this study, the subjects earned credit to
substitute for three activity class absences. So as to be fair to all students, each
student had an option to make up missed classes by performing a substitute
activity.

The goals of the study and the testing procedures were explained to all potential
subjects. Those who were willing to participate then signed an Informed Consent
Form (see Appendix A), indicating that they understood the purpose of the study,
and the tasks which they would perform. Subjects were excluded if they were
not in the 18 to 26 year old age group, if they reported that they had any physical
or medical condition, or if they were taking any substances, which would affect their balance. Also, prior to beginning the study, all subjects completed a questionnaire designed to access their physical activity levels (Appendix B). Subjects were excluded if they had any previous training in Karate, T’ai Chi, strength training, or any similar activity. A total of 40 subjects participated in the study of which 18 were females and 22 were males. Both testing groups were equal in size and consisted of 20 Karate students and 20 Strength Training students. None of these subjects had any known injuries or disorders that would affect their ability to maintain a stable upright posture.

6.5 Physical Training Programs

The 15 week physical training programs that each group participated in during the study were not part of the research study. The subjects were advised that if they did not complete the 15 week physical training program, they would be dropped from the research study. The subjects were informed that participation in this study was completely voluntary, and that they were free to withdraw from the project at any time, and for any reason, without penalty.

To be eligible for this study, each subject was required to participate in a 15 week undergraduate physical training program offered through the Penn State Kinesiology Department at the University Park campus. These courses are taught by qualified Penn State Kinesiology faculty members and they meet the
uniform departmental course standards for developing physical fitness, skill
development, and a healthy lifestyle. As per Department policy, these courses
require a minimum of 37.5 hours of in-class participation. The Penn State
Kinesiology Department offers over 30 physical activity courses. The following
courses were chosen for subject recruitment as they teach activities which are
currently being explored in research studies on stability and fall prevention
(Clemson, Fiatarone Singh et al. 2012).

6.5.1 Karate Training Program

Introduction to Karate (ESACT 183)

This course was first established by the author at Penn State in 1985. This is a
beginning course in Karate designed to improve physical fitness, skill
development, and mental well-being. The intent is to encourage the student to
use Karate training to contribute to a life-long program of fitness, and a healthy
lifestyle. An added benefit is that the student learns skills that will assist them to
maintain self-determination, whether it be through physical self-defense, or
through the ability to adapt to other life stressors.

The training is progressive and it is a non-contact activity course. This 15 week
course meets twice a week for 1.25 hours per class. A typical training session
consists of a short period of meditation followed by 15 minutes of flexibility and
conditioning exercises. The remainder of the class consists of one hour of
practice in skill development: various two and one-legged postures, movement
from posture to posture, and practice of arm and leg skills. The course
description is presented in Appendix C.

6.5.2 Strength Training Program

Strength Training (KINES 68)
This is an introductory course in strength training taught by Coach Mike Morse
who has taught physical activity courses at Penn State for over 25 years. This
15 week course meets three times a week for 50 minutes per class. This course
is designed to introduce students to the acquisition of muscular strength through
different methods. The course requires each student to develop personal goals
and to implement those goals into a practical personal fitness program. The
intent is that the student will gain an understanding of key concepts such as:
muscular strength versus muscular endurance, proper training technique,
development of balance through proper training of antagonist muscles, and the
concurrent development of flexibility. The course description is presented in
Appendix D.

6.6 Test Procedures and Protocol

Subject testing was performed in the Penn State Biomechanics Lab at the
University Park campus. The pulley and weight apparatus used to apply
perturbations was manufactured in the Biomechanics Lab machine shop by the principle investigator. The apparatus and surrounding area was padded for subject safety. In addition, a research assistant acted as a spotter to assist the subject in case of a loss of balance. Each subject was tested both before and after completion of a physical training program, either Karate or Strength Training.

6.6.1 The Study Protocol

A total of 40 subjects participated in the first test sessions of which 18 were females and 22 were males. Both testing groups were equal in size and consisted of 20 Karate students and 20 Strength Training students. For the second test session a total of 35 subjects participated: 18 Karate subjects and 17 strength training subjects.

During the initial session, the subjects first signed the Informed Consent Form and then the subject’s anthropometric data was recorded. The subjects then performed tasks to assess their postural stability. Each testing session lasted approximately one hour. Table 6.1 describes the order in which the subjects performed the procedures in this study.
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed Consent</td>
<td>Explanation of goals and objectives, subject signs Informed Consent.</td>
<td>Pre-training Session only</td>
</tr>
<tr>
<td>Introduction to Biomechanics Lab and Study Equipment</td>
<td>Explanation of test procedures and equipment. Tasks demonstrated. Subject's questions answered.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Anthropometry Data</td>
<td>Subject measured with anthropometer at pre-determined sites on all segments.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Placement of Markers</td>
<td>Subject asked to assume a comfortable stance on force plate, markers were then placed around feet to assure consistent foot placement.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Quiet Standing Trials, 2-Legged, Eyes Open</td>
<td>Subject asked to stand quietly for 40s, staring at a marker placed on the wall at eye level 3m away.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Quiet Standing Trials, 2-Legged, Eyes Closed</td>
<td>Subject asked to stand quietly for 40s with eyes closed.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Quiet Standing Trials, 1-Legged, Eyes Open</td>
<td>Subject asked to stand quietly on one leg for 40s, staring at a marker placed on the wall at eye level 3m away.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Quiet Standing Trials, 1-Legged, Eyes Closed</td>
<td>Subject asked to stand quietly for 40s with eyes closed.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Perturbation Trials, 2-Legged, Eyes Open</td>
<td>Subject asked to recover from a perturbation and then stand quietly for 40s, staring at a marker placed on the wall at eye level 3m away.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Perturbation Trials, 2-Legged, Eyes Closed</td>
<td>Subject asked to recover from a perturbation and stand quietly for 40s with eyes closed.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Perturbation Trials, 1-Legged, Eyes Open</td>
<td>Subject asked to recover from a perturbation and stand quietly on one leg for 40s, staring at a marker placed on the wall at eye level 3m away.</td>
<td>Both sessions</td>
</tr>
<tr>
<td>Perturbation Trials, 1-Legged, Eyes Closed</td>
<td>Subject asked to recover from a perturbation and stand quietly for 40s with eyes closed.</td>
<td>Both sessions</td>
</tr>
</tbody>
</table>
6.6.2 Subject Anthropometry

At the start of the study, anthropometric data were obtained from each subject. The body dimensions recorded were height, mass, limb lengths, and the circumferences of all body segments. These measurements are summarized in Table 6.2, in which values are given as the mean ± standard deviation. Data were obtained prior to the start of the study (Pre) and after the study ended (Post). Five subjects did not complete the second testing session and these values were not included in the Post measurement data.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yrs)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>Foot Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Karate</td>
<td>20.1 ± 1.3</td>
<td>20 ± 1</td>
<td>1.68 ± .1</td>
<td>1.69 ± .09</td>
</tr>
<tr>
<td>Strength</td>
<td>21.5 ± 1.6</td>
<td>21.4 ± 1.7</td>
<td>1.66 ± .1</td>
<td>1.65 ± .1</td>
</tr>
</tbody>
</table>

Anthropometric data were obtained via measurements of segment lengths, widths, and perimeters. The segment boundaries were identified by the author as defined in the literature (Dempster 1955). The author performed all measurements on all of the subjects. The subjects were measured using an anthropometric measuring tape and calipers, and all measurements were made to the nearest millimeter. Measurements were performed on both sides of the
subject’s body with the subject standing upright. A copy of the form used for acquisition of these data can be found in Appendix E.

For each segment, a system of axes was defined with its origin at the center of mass of the segment. The axes were aligned with approximate body axes: sagittal (x), frontal (y) and longitudinal (z). Thus, for each segment the principal axes were defined such that the z-axis coincided with the segment’s longitudinal axis, the x-axis with the anterior-posterior direction, and the y-axis with the medial-lateral direction of the segments; with all axes passing through the center of mass. As the thigh, shank, upper arm, and forearm segments were modeled as truncated cones, which are symmetrical about the x and y axes, a “transverse” moment of inertia was used to represent the moments of inertia about these axes ($I_T$).

The inertial properties of the segments were determined via modeling (Challis 2004). The body segments were modeled as follows:

- Foot: as a series of three stadium solids, with separation at the mid-arch and the ball of the foot.
- Shank, thigh, forearm, and upper arm: each is modeled as two equal length truncated cones.
- Hand: divided into a series of three stadium solids, with separation at the base of the thumb, and at the knuckles.
- Trunk: a series of four stadium solids, with separations at the naval, base of rib cage, and nipple levels.
- Head: modeled as two truncated cones, with an ellipsoid at the top, and separations occurring at the bottom of the ear lobe, and at the eye brow level.

The density values for these solids were taken from data published in the literature (Challis, Winter et al. 2012). These density values were assumed to be uniform throughout a given segment for both male and female. Prior to comparisons of the inertial properties of the two groups the inertial properties of each segment were normalized. The segmental masses were normalized with respect to total body mass, segmental center of mass locations were measured from the proximal end of the segment and expressed as a percentage of segment length, and segmental moments of inertia about the center of mass were converted to radii of gyration and normalized with respect to subject height.

### 6.6.3 Posture Descriptions

At each testing session, all subjects were asked to stand upright and barefooted on the force plate, with arms crossed at the chest. For the duration of each trial, the subject was required to keep their arms crossed and in contact with their chest so as not to use the arms to assist in balancing. For all eyes open trials, the subjects stared at an “X” at eye level placed on a wall 3 meters away. For the two-legged positions, the subjects assumed a comfortable stance with their feet placed approximately shoulder width apart. During the one-legged trials the subjects stood with their preferred foot positioned at the center of the force
platform. In the one-legged stance the subject was required to keep their raised foot in contact with their support leg at the level of mid-calf.

For consistency of foot placement over all trials and conditions, markers were placed on the surface of the force plate to indicate the exact location to place the feet. During all tasks the subjects were required to maintain their feet within the marked footprint, and flat on the force plate surface, otherwise the trial was terminated. A spotter was standing beside the subject to catch them if they should lose balance during the trials.

6.6.4 Postural Stability Trial Conditions

For this study the subjects were tested twice, once before training began and once after completing the 15-week training. During each test, the subjects performed a total of three trials for each condition. There was a total of six conditions: two stance, two sight, and two perturbation. Thus, there were a total of 24 trials per subject per test. Trials lasted a total of 40 seconds which included a data collection period of 30s. The recording of data was started a few seconds after the subject had acquired a stable stance. To record a minimum usable set of data for each trial, the subjects had to maintain their support foot in the initial footprint for at least 10 seconds. Thus, each trial lasted for a maximum of 40 seconds, with the intent of obtaining a maximum of 30 seconds of usable data. An acceptable trial was considered to be one in which the subject was able to
maintain the required position for at least 10 seconds. The subjects could repeat
the trials up to five times per condition if they failed to reach 10 seconds.
However some subjects could not complete three acceptable trials for some
conditions such as one-legged with eyes closed.

For the quiet standing trials, the subjects were asked to stand quietly and hold
the postures for 40 seconds. The goal of this trial was to remain as still as
possible, thus allowing the investigator to determine baseline quiet standing
levels. They performed this task in both a natural two footed stance and when
balancing on one foot. The subjects then attempted these postures with eyes
closed. Lastly, the perturbation trials required the subjects to repeat these
postures but after a few seconds a destabilizing force was applied to their hips.
The subjects were asked to attempt to regain their balance and continue to hold
the posture for the remaining 30 seconds of the trial.

Each test that the subjects performed during the two testing sessions consisted
of attempting to maintain their balance under the conditions listed below:

**Conditions:**

1) Two stance: a) two-legged b) one-legged
2) Two sight: a) eyes open b) eyes closed
3) Two perturbation: a) without perturbation b) with perturbation
**Perturbations:**

1) Two-legged stances: 10% of body weight
2) One-legged stances: 5% of body weight

**Order of Trials:**

Without perturbation:
1) Two-legged, eyes open
2) Two-legged, eyes closed
3) One-legged, eyes open
4) One-legged, eyes closed

With perturbation:
5) Two-legged, eyes open
6) Two-legged, eyes closed
7) One-legged, eyes open
8) One-legged, eyes closed

**Number of Trials:**

There were a total of 24 trials per subject per test:

\[(2 \text{ stance}) \times (2 \text{ sight}) \times (2 \text{ perturbation}) \times (3 \text{ trials}) = 24 \text{ trials}\]

Thus, for the 35 subjects who completed both tests there are a total of 48 trials per subject.
6.7 Data Collection and Analysis

The PI collected the minimum data necessary to achieve the goals of the research. The following provisions were made to maintain the confidentiality of data. All subjects were identified by a unique code known only to the PI. Personal identifiers were not associated with the data. All force plate and anthropometry data was stored on the Biomechanics Lab server which is kept in a locked and secure location designated for data storage in the Biomechanics Lab. Below is a description of the equipment that was used for data acquisition, the process of data collection, and the subsequent analysis of the data.

6.7.1 Equipment used for Data Collection

Force plate data were collected using a Bertec force plate (model N50601, Type 4080s, Bertec Corporation, Worthington, OH). In general terms this instrument is just a thin platform that the subject stands upon which measures the ground reaction forces. This force plate, or force platform, is designed specifically for use in balance and gait research and measures ground reaction forces: the forces generated by a subject as they stand or move across the platform. It measures the three dimensional components of the force applied to the surface, as well as the vertical moment of force. The moment is the horizontal or shear components of the applied force. The three dimensional components of the forces measured by the force plate are the anterior-posterior direction or X-axis
(forward and backward), the medial-lateral direction or Y-axis (side to side), and the vertical direction or Z-axis. The plate also captures the moments about these three axes. The point on the plate at which this force acts is called the center of pressure (COP). This is the location of the intersection of the plate and a vertical line projected from a subject's center of gravity.

The strain gauges within the plate react by deforming due to the forces applied. The change in shape of the gauge causes its electrical resistance to change, which can then be quantified. The force plate consists of strain gauged load transducers with a built-in pre-amplifier for signal conditioning. The six-component load transducers measure the three orthogonal components of the resultant force acting on the force plate. It also measures the three components of the resultant moment. Signal acquisition and conditioning is obtained by 16-bit digital technology (Bertec 2012). The force plate is secured to the Biomechanics Lab floor so as to insulate it from extraneous vibrations, such as people walking throughout the building or passing vehicles. The force plate is connected through cables to an external amplifier and computer.

During the perturbation trials the subjects were connected to a pulley and weight apparatus by a padded waist belt (Figure 6.1). A cable was attached to this belt and weights were then applied to the end of the cable. The subject thus had to maintain postural stability while resisting the pull of the weight. The weight was released by pulling a pin, and thus causing the subject’s balance to be disturbed.
The subject then had to attempt to regain their balance. This is analogous to the effect one feels when standing upright on a bus, subway, or moving walkway such as in an airport, and then having to recover one’s balance after a sudden deceleration.

Figure 6.1: Weight and Pulley Apparatus
The subjects stood on a force plate wearing a padded belt. The belt was attached to a weight and pulley apparatus via a cable.
6.7.2 Data Analysis

In brief, the data were sampled with a time interval of 0.01 seconds (100 Hz). Ground reaction force data were obtained with a sample duration of 30 seconds. From the force plate records, the COP obtained during the trials was computed in the anterior-posterior and medial lateral directions. The data was pre-processed by filtering in forward and reverse directions using a 2\textsuperscript{nd} order low-pass Butterworth filter with a cutoff frequency of 5 Hz to eliminate high frequency measurement noise.

Data analysis was achieved by using the computer program \textit{COP Analysis} designed to examine COP data collected during quiet standing on a force plate (Challis 2003). This program contains the following sub routines for processing COP:

- \texttt{<Center of Pressure>} contains main routines for analyzing center of pressure data
- \texttt{<DFA>} contains routines for performing detrended fluctuation analysis
- \texttt{<Random Walk>} contains routines for performing random walk analysis
- \texttt{<Filtering>} contains routines for filtering the data

COP can be quantified through the use of various metrics (Challis 2003). Table 6.3 presents an outline of all descriptors that were used to quantitatively assess the COP motion.
Table 6.3. Parameters Used to Quantify COP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units or Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP Path Length</td>
<td>Total length of the COP motion.</td>
<td>millimeters</td>
</tr>
<tr>
<td>Standard Deviation of the COP</td>
<td>The standard deviation of the COP motion.</td>
<td>millimeters</td>
</tr>
<tr>
<td>COP Sway Velocity</td>
<td>Mean velocity of the COP motion during the time interval.</td>
<td>millimeters / second</td>
</tr>
<tr>
<td>Range of the COP</td>
<td>Distance, from maximum to minimum values, of the anterior/posterior COP motion.</td>
<td>millimeters</td>
</tr>
<tr>
<td>COP Area</td>
<td>Principal component analysis was used to compute an ellipse that contained 85.35% of the path of the COP in both AP and ML directions.</td>
<td>millimeters²</td>
</tr>
<tr>
<td>Fractal Dimension</td>
<td>A measure of self-similarity</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Detrended Fluctuation Analysis</td>
<td>A method for determining statistical self-affinity</td>
<td>Alpha values</td>
</tr>
</tbody>
</table>

6.7.3 COP Parameter Descriptions

In order to quantify measures of postural sway the following parameters were examined. There are two main groupings of COP analyses:

- Normal time-based analyses:
  - COP Path Length
  - Standard Deviation
  - COP Sway Velocity
  - Range of COP
  - COP Area

- Non-linear analyses:
  - Fractal Dimension (FD)
  - Detrended Fluctuation Analysis (DFA)
1) COP Path Length

The COP path length is computed by calculating the total distance traveled by
the COP during each trial. This measures the amount of meandering of the COP
trajectory. Units are in mm.

2) Standard Deviation (SD)

The standard deviation of the COP motion is used to quantify the variability or
amount of postural sway. It computes the standard deviation of the motion of the
COP in two directions, anterior-posterior and medial-lateral. Units are in mm.

3) COP Sway Velocity

This is the mean velocity of the COP path which is computed by dividing the
COP path length by the sample duration. To minimize noise that may
inadvertently inflate measures such as the mean velocity, the COP time series
are filtered to the frequency range of interest. COP velocity results are in mm/s.

4) Range of the COP

The range or excursion of the COP is the maximum displacement of the COP,
i.e., it is the distance between the furthest points in the Anterior-Posterior, and
the Mediolateral directions. The units of measurement are in mm.
5) COP Area

This is calculated by applying the best fitting ellipse to the area described by the motion of the COP. To obtain the area of the best fitting ellipse principle component analysis is used to determine the ellipse that contains 85.35% of COP path in both the anterior-posterior and the medial-lateral directions (Oliveira, Simpson et al. 1996). The area is expressed in mm².

6) Fractal Dimension (FD)

This is a measure of statistical self-similarity. If the COP is stationary, that is it forms a point, the fractal dimension is zero since a point has no dimension. If the COP moves on a straight line forwards and backwards the dimension is one. If the COP forms a solid surface the dimension is two. The units of measurement are dimensionless. The algorithm used is based on methods developed to measure biological movement, such as the paths of wondering animals (Katz and George 1985). This approach is used to determine the probability that these COP movement patterns are random walks. It can also be used to compare the straightness of the patterns before experimental intervention with that observed after intervention.

7) Detrended Fluctuation Analysis (DFA)

This is a method for determining statistical self-affinity. It is useful in revealing the extent of long-range correlation in time series and avoids the spurious detection of apparent long-range correlations that are caused by artifacts (Peng,
Buldyrev et al. 1994). This is a modified root mean square analysis of a random walk. DFA permits the detection of intrinsic self-similarity embedded in a seemingly non-stationary time series, especially slowly varying trends. While this parameter is used in this study, it should be noted that some researchers believe that it can introduce artifacts and bias (Bryce and Sprague 2012). Results are reported in terms of alpha (\(\alpha\)) values which measure the degree of long-range correlation (Theiler, Eubank et al. 1992; Schiff and Sauer 1994).

- alpha greater than 0 and less than 0.5 indicates long-range anti-correlations
- alpha of 0.5 indicates completely uncorrelated or white noise
- alpha greater than 0.5 and less than 1.0 indicates long-range correlations
- alpha of 1.0 indicates 1/f noise
- alpha of 1.5 indicates brown noise

### 6.7.4 Inertial Properties

Comparisons were made of the inertial properties between the two groups. These data were normalized to remove the influence of one group having different inertial properties compared with the other; i.e. the values of one group could be systematically larger or smaller than the other.

- Segment masses were normalized with respect to subject mass
- Segment center of mass locations were normalized with respect to segment length
- Segmental transverse moment of inertia was normalized with respect to the product of subject mass and the square of subject height.
The COP metrics were compared between the two groups and between pre- and post-training. It should be noted that the segmental inertial parameters differ between males and females. The differences are relatively small but when the inertial parameters are used to determine limb swing times, as in walking, the difference between the two groups is large (Challis, Winter et al. 2012). This most likely was not a factor in this study as the subjects were tested only in stationary stances.

6.8 Statistics

The following section describes the statistics that were performed on the data. The force plate data from the one-footed perturbation conditions were not usable due to a hardware malfunction; therefore these data were excluded from further analysis.

Descriptive Statistics: The data obtained through the above parameters was analyzed to compute the means and standard deviations of all variables across subjects, and subject groups.

ANOVA: A repeated measures analysis of variance (ANOVA) was performed in MINITAB (version 12.1, Minitab Inc.) on the pre- and post-training, and the subject group data.
6.9 Summary of Methods

Since first assuming an upright stance, humans have struggled with the problem of how to stay there, of how to maintain balance, despite the movement of the Universe both without and within. As we have seen, the ancient philosophers pondered this question and attempted to find how man maintains this harmony with the Universe. As Plato instructed we need “light” to “see”. This chapter has outlined my approach to “see all sides” and the “light” that I used.

In summary, this study is an attempt to examine the postural stability characteristics of a group of subjects and to determine how these characteristics change with training. This chapter outlined the methods used to obtain data and how they were analyzed. The logistical problems of obtaining sufficient subjects were presented. Fortunately, I was able to recruit a large group of physically fit and intellectually motivated subjects. This provided an excellent source from which to gain data.

As a summary of the parameters measured in this study, there are two groups of COP analyses:

- Normal time-based analyses:
  - COP Path Length
  - Standard Deviation
  - COP Sway Velocity
  - Range of COP
COP Area

- Non-linear analyses:
  - Fractal Dimension (FD)
  - Detrended Fluctuation Analysis (DFA)

Some researchers believe that an alternative should be sought for the Detrended Fluctuation Analysis (DFA). They believe that DFA can introduce artifacts and bias when used for examining nonlinear trends. They believe that this method induces an empirically observed curvature which is a serious finite-size effect, that will always be present (Bryce and Sprague 2012). However, since this has not been proven, for this study DFA was used.

By choosing an interesting and comprehensive range of balance tasks, this study has created a complicated data and statistical analysis problem. The following chapter will present the results, and then perhaps we can determine if they reveal any of the Rhythms and Hidden Harmonies of the Universe.
CHAPTER 7

RESULTS

7.1 Introduction

In the following sub-sections the experimental results are presented. The results of the determination of the body segment inertial parameters for all subjects are presented first; along with a comparison of these parameters between the two experimental groups: Karate and Strength Training. The two groups performed six experimental tasks, both before and after a 15-week period of training. The subsequent sub-sections compare the results of the analyses of these tasks before and after physical training. The Chapter ends with a summary of the results.

7.2 Segmental Inertial Parameters

The segmental inertial parameters were determined for all subjects by modeling the body segments as series of geometric solids. Postural stability is influenced by the segmental inertias, but a statistical comparison of the two groups indicated no statistically significant differences between the two groups for any of the inertial parameters (Table 7.1).
Table 7.1: The means (± standard deviations) of the normalized segmental inertias for the body segments of the two experimental groups.

<table>
<thead>
<tr>
<th>Body Segment</th>
<th>Inertial Parameters</th>
<th>Experimental Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Karate</td>
</tr>
<tr>
<td>Foot</td>
<td>Mass (% mass)</td>
<td>1.15 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>43.26 ± 0.99</td>
</tr>
<tr>
<td></td>
<td>$R_{xx}$ ($10^2 x / \text{segment length}$)</td>
<td>27.81 ± 0.65</td>
</tr>
<tr>
<td></td>
<td>$R_{yy}$ ($10^3 x I_{yy} / \text{mass.height}^2$)</td>
<td>29.01 ± 0.77</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^3 x I_{zz} / \text{mass.height}^2$)</td>
<td>14.84 ± 0.72</td>
</tr>
<tr>
<td>Shank</td>
<td>Mass (% mass)</td>
<td>5.05 ± 0.73</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>43.92 ± 1.47</td>
</tr>
<tr>
<td></td>
<td>$R_T$ ($10^2 x / \text{segment length}$)</td>
<td>28.60 ± 0.43</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>9.70 ± 0.99</td>
</tr>
<tr>
<td>Thigh</td>
<td>Mass (% mass)</td>
<td>11.03 ± 1.07</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>42.92 ± 1.65</td>
</tr>
<tr>
<td></td>
<td>$R_T$ ($10^2 x / \text{segment length}$)</td>
<td>29.73 ± 0.68</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>14.18 ± 1.32</td>
</tr>
<tr>
<td>Hand</td>
<td>Mass (% mass)</td>
<td>0.66 ± 0.10</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>44.59 ± 1.64</td>
</tr>
<tr>
<td></td>
<td>$R_{xx}$ ($10^2 x / \text{segment length}$)</td>
<td>25.80 ± 0.65</td>
</tr>
<tr>
<td></td>
<td>$R_{yy}$ ($10^2 x / \text{segment length}$)</td>
<td>27.89 ± 0.73</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>14.38 ± 0.72</td>
</tr>
<tr>
<td>Forearm</td>
<td>Mass (% mass)</td>
<td>1.51 ± 0.17</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>43.06 ± 0.59</td>
</tr>
<tr>
<td></td>
<td>$R_T$ ($10^2 x / \text{segment length}$)</td>
<td>28.65 ± 0.29</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>10.42 ± 0.84</td>
</tr>
<tr>
<td>Upper Arm</td>
<td>Mass (% mass)</td>
<td>3.63 ± 0.41</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>45.52 ± 0.90</td>
</tr>
<tr>
<td></td>
<td>$R_T$ ($10^2 x / \text{segment length}$)</td>
<td>29.45 ± 0.27</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>10.57 ± 0.83</td>
</tr>
<tr>
<td>Trunk</td>
<td>Mass (% mass)</td>
<td>46.73 ± 2.38</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>51.77 ± 1.15</td>
</tr>
<tr>
<td></td>
<td>$R_{xx}$ ($10^2 x / \text{segment length}$)</td>
<td>32.49 ± 0.75</td>
</tr>
<tr>
<td></td>
<td>$R_{yy}$ ($10^2 x / \text{segment length}$)</td>
<td>33.84 ± 0.93</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>19.47 ± 1.69</td>
</tr>
<tr>
<td>Head</td>
<td>Mass (% mass)</td>
<td>7.20 ± 0.71</td>
</tr>
<tr>
<td></td>
<td>Center of Mass (% segment length)</td>
<td>51.87 ± 1.56</td>
</tr>
<tr>
<td></td>
<td>$R_{xx}$ ($10^2 x / \text{segment length}$)</td>
<td>29.52 ± 0.68</td>
</tr>
<tr>
<td></td>
<td>$R_{yy}$ ($10^2 x / \text{segment length}$)</td>
<td>29.52 ± 0.68</td>
</tr>
<tr>
<td></td>
<td>$R_{zz}$ ($10^2 x / \text{segment length}$)</td>
<td>20.09 ± 1.11</td>
</tr>
</tbody>
</table>
7.3 Quiet Standing, Two Feet, Eyes Open

The subjects were asked to stand still on a force plate for 30 seconds in a normal two-footed upright stance with their eyes open. During this time period, force plate data were collected which permitted determination of the motion of the center of pressure (COP). The COP motion was quantified using a number of metrics (Table 7.2). There was a statistically significant difference between the two groups, Karate and Strength Training, in the COP standard deviation in the medial-lateral direction, the COP length, and COP velocity before training. There were no statistically significant changes in the metrics of the COP motion for the Karate Training Group as a consequence of training. There was only a statistically significant change in three metrics as a consequence of strength training; these were the standard deviation of the COP, the range of motion of the COP, and the alpha value from the Detrended Fluctuation Analysis, all in the medial-lateral direction. These three metrics all increased in value; comparing values from before to after the training period.
Table 7.2: The means (± standard deviations) of metrics of the center of pressure motion during 30 seconds of quiet standing with eyes open for the two experimental groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karate Group</td>
<td>Strength Group</td>
</tr>
<tr>
<td>SD-ML (mm)</td>
<td>2.1 ± 1.1*</td>
<td>1.4 ± 0.6</td>
</tr>
<tr>
<td>SD-AP (mm)</td>
<td>4.3 ± 1.0</td>
<td>4.1 ± 2.6</td>
</tr>
<tr>
<td>Range-ML (mm)</td>
<td>11.7 ± 5.8</td>
<td>8.9 ± 3.0</td>
</tr>
<tr>
<td>Range-AP (mm)</td>
<td>20.5 ± 4.2</td>
<td>20.3 ± 8.7</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>298.6 ± 71.5*</td>
<td>244.5 ± 56.3</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>10.0 ± 2.4*</td>
<td>8.2 ± 1.9</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>101.4 ± 68.0</td>
<td>77.1 ± 110.2</td>
</tr>
<tr>
<td>Fractal Dimension (-)</td>
<td>2.06 ± 0.10</td>
<td>2.01 ± 0.10</td>
</tr>
<tr>
<td>Alpha – ML (-)</td>
<td>1.79 ± 0.47</td>
<td>1.37 ± 0.14</td>
</tr>
<tr>
<td>Alpha – AP (-)</td>
<td>1.57 ± 0.05</td>
<td>1.57 ± 0.07</td>
</tr>
</tbody>
</table>

**Note** – * indicates a statistically significant difference between the Karate and Strength Training groups pre-training. + indicates a statistically significant difference between the Strength Training group pre- and post-training.
7.4 Quiet Standing, Two Feet, Eyes Closed

The subjects were asked to stand still on a force plate in a normal upright stance on both feet for 30 seconds with their eyes closed. During this time period, force plate data were collected which permitted determination of the motion of the center of pressure (COP). The COP motion was quantified using a number of metrics (Table 7.3). There was a statistically significant difference between the two groups, Karate and Strength training group, in the COP path length and COP velocity before training. There were no statistically significant changes in the metrics of the COP motion for the Karate Training group as a consequence of training. There were no statistically significant changes in the metrics of the COP motion for the Strength Training group as a consequence of training.
Table 7.3: The means (± standard deviations) of metrics of the center of pressure motion during 30 seconds of quiet standing with eyes closed for the two experimental groups.

| Parameter  | Pre-Training |  | Post-Training |  |
|------------|--------------|-----------------|-----------------|
|            | Karate Group | Strength Group | Karate Group | Strength Group |
| SD-ML (mm) | 2.4 ± 1.0 | 1.7 ± 0.8 | 2.5 ± 0.8 | 2.2 ± 1.0 |
| SD-AP (mm) | 5.1 ± 0.9 | 4.8 ± 2.6 | 5.3 ± 1.1 | 5.2 ± 3.2 |
| Range-ML (mm) | 13.6 ± 4.5 | 10.7 ± 4.1 | 16.8 ± 6.5 | 15.3 ± 7.1 |
| Range-AP (mm) | 26.9 ± 4.5 | 24.9 ± 10.5 | 32.1 ± 7.7 | 28.5 ± 11.7 |
| Length (mm) | 389.6 ± 85.8* | 318.5 ± 95.7 | 450.6 ± 163.4 | 326.3 ± 118.6 |
| Velocity (mm/s) | 13.0 ± 2.9* | 10.6 ± 3.2 | 15.0 ± 5.4 | 10.9 ± 4.0 |
| Area (mm²) | 134.7 ± 69.7 | 101.1 ± 108.0 | 155.7 ± 77.8 | 139.1 ± 133.6 |
| Fractal Dimension (-) | 2.16 ± 0.11 | 2.09 ± 0.14 | 2.22 ± 0.10 | 2.07 ± 0.14 |
| Alpha – ML (-) | 1.45 ± 0.12 | 1.37 ± 0.12 | 1.43 ± 0.10 | 1.46 ± 0.11 |
| Alpha – AP (-) | 1.51 ± 0.06 | 1.55 ± 0.09 | 1.49 ± 0.09 | 1.55 ± 0.08 |

Note – * indicates a statistically significant difference between the Karate and Strength Training groups pre-training.
7.5 Quiet Standing, One Foot, Eyes Open

The subjects were asked to stand still on one foot, using their preferred leg, on a force plate for 30 seconds with their eyes open. During this time period, force plate data were collected which permitted determination of the motion of the center of pressure (COP). For the Karate Training group in the pre-training trials, three subjects could not maintain upright posture for the full 30 seconds for one of their trials, similarly three subjects could not maintain this posture for one trial during the post-training testing. For the Strength Training group in the pre-training trials, one subject could not maintain upright posture for the full 30 seconds for one of their trials, similarly two subjects could not maintain this posture for one trial during the post-training testing, and one subject could not maintain it for two of the three trials. The COP motion was quantified using a number of metrics (Table 7.4). There were no statistically significant differences between the two groups, Karate and Strength, in the COP metrics before training. There were no statistically significant changes in the metrics of the COP motion for the Karate Training group as a consequence of training. There were no statistically significant changes in the metrics of the COP motion for the Strength Training Group as a consequence of training.
Table 7.4: The means (± standard deviations) of metrics of the center of pressure motion during 30 seconds of quiet standing on one foot with eyes open for the two experimental groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karate Group</td>
<td>Strength Group</td>
</tr>
<tr>
<td>SD-ML (mm)</td>
<td>5.4 ± 1.4</td>
<td>5.0 ± 0.9</td>
</tr>
<tr>
<td>SD-AP (mm)</td>
<td>6.9 ± 1.2</td>
<td>6.9 ± 1.7</td>
</tr>
<tr>
<td>Range-ML (mm)</td>
<td>29.4 ± 6.7</td>
<td>26.7 ± 3.8</td>
</tr>
<tr>
<td>Range-AP (mm)</td>
<td>36.6 ± 7.0</td>
<td>36.8 ± 13.9</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>927.7 ± 333.5</td>
<td>858.0 ± 226.9</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>33.0 ± 11.4</td>
<td>28.9 ± 7.6</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>446.9 ± 179.7</td>
<td>416.4 ± 145.6</td>
</tr>
<tr>
<td>Fractal Dimension (-)</td>
<td>2.61 ± 0.24</td>
<td>2.52 ± 0.18</td>
</tr>
</tbody>
</table>
7.6 Quiet Standing, One Foot, Eyes Closed

The subjects were asked to stand still on one foot, using their preferred leg, on a force plate for 30 seconds with their eyes closed. During this time period, force plate data were collected which permitted determination of the motion of the center of pressure (COP). For the Karate Training group in the pre-training trials, only six subjects could maintain upright posture for the full 30 seconds for all of their trials, similarly four subjects could maintain this posture for all trials during the post-training testing. For the Strength Training group in the pre-training trials only six subjects could maintain upright posture for the full 30 seconds for all of their trials, similarly four subjects could maintain this posture for all trials during the post-training testing. The COP motion was quantified using a number of metrics (Table 7.5). There were no statistically significant differences between the two groups, Karate and Strength Training, in the COP metrics before training. There was a statistically significant change in the range of the medial-lateral motion of the COP for the Karate Training group as a consequence of training; there were no other statistically significant differences. There was a reduction in the range of motion of the COP in the medial-lateral direction; comparing values pre- and post-training. There were no statistically significant changes in the metrics of the COP motion for the Strength Training group as a consequence of training.
Table 7.5: The means (± standard deviations) of metrics of the center of pressure motion during 30 seconds of quiet standing on one foot with eyes closed for the two experimental groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karate Group</td>
<td>Strength Group</td>
</tr>
<tr>
<td>SD-ML (mm)</td>
<td>12.8 ± 8.1</td>
<td>16.1 ± 11.9</td>
</tr>
<tr>
<td>SD-AP (mm)</td>
<td>14.1 ± 7.0</td>
<td>14.9 ± 7.3</td>
</tr>
<tr>
<td>Range-ML (mm)</td>
<td>58.2 ± 34.1</td>
<td>81.5 ± 71.0</td>
</tr>
<tr>
<td>Range-AP (mm)</td>
<td>86.5 ± 41.8</td>
<td>89.6 ± 44.3</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>1797.9±1392.2</td>
<td>1620.3±1048.0</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>84.4 ± 45.9</td>
<td>79.9 ± 31.4</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>2672 ± 3902</td>
<td>3549 ± 4232</td>
</tr>
<tr>
<td>Fractal Dimension (-)</td>
<td>2.99 ± 0.32</td>
<td>2.86 ± 0.25</td>
</tr>
</tbody>
</table>

Note – # indicates a statistically significant difference for the Karate Training group pre- and post-training.
7.7 Perturbation Condition, Two Feet, Eyes Open

The subjects were asked to stand still on their two feet, in a normal upright posture, on a force plate for 30 seconds with their eyes open. At an undisclosed point during the stance, the subjects received a perturbation to their stance. During the time period following the perturbation, force plate data were collected which permitted determination of the motion of the center of pressure (COP). The COP motion was quantified using a number of metrics (Table 7.6). There were statistically significant differences between the two groups, Karate and Strength Training, in the COP metrics before training; specifically in the range of motion of the COP in the anterior-posterior direction, the COP path length, its velocity, and the fractal dimension. There was a statistically significant change in the standard deviation of the motion of the COP range in the medial-lateral direction for the Karate Training group as a consequence of training; there were no other statistically significant differences. The standard deviation of the COP in the medial-lateral direction increased; comparing values pre- and post-training. There were no statistically significant changes in the metrics of the COP motion for the Strength Training Group as a consequence of training.
Table 7.6: The means (± standard deviations) of metrics of the center of pressure motion after a perturbation while standing on two feet with eyes open for the two experimental groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karate Group</td>
<td>Strength Group</td>
</tr>
<tr>
<td>SD-ML (mm)</td>
<td>8.6 ± 9.9</td>
<td>3.9 ± 1.6</td>
</tr>
<tr>
<td>SD-AP (mm)</td>
<td>13.6 ± 6.2</td>
<td>16.6 ± 4.9</td>
</tr>
<tr>
<td>Range-ML (mm)</td>
<td>44.5 ± 48.3</td>
<td>29.2 ± 8.3</td>
</tr>
<tr>
<td>Range-AP (mm)</td>
<td>103.2 ± 28.6*</td>
<td>141.0 ± 33.3</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>1227.6 ± 544.4*</td>
<td>728.1 ± 211.9</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>41.1 ± 18.4*</td>
<td>24.6 ± 7.2</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>1753 ± 3085</td>
<td>748 ± 476</td>
</tr>
<tr>
<td>Fractal Dimension</td>
<td>2.59 ± 0.23*</td>
<td>2.23 ± 0.21</td>
</tr>
</tbody>
</table>

Note – * indicates a statistically significant difference between the Karate and Strength Training groups pre-training, \# indicates a statistically significant difference in the Karate Training group pre- and post-training.
7.8 Perturbation Condition, Two Feet, Eyes Closed

The subjects were asked to stand still on their two feet in a normal upright posture on a force plate for 30 seconds with their eyes closed. At an undisclosed point during the trial the subjects received a perturbation to their stance. During the time period following the perturbation, force plate data were collected which permitted determination of the motion of the center of pressure (COP). The center of pressure motion was quantified using a number of metrics (Table 7.7). There were statistically significant differences between the two groups, Karate and Strength Training, in the center of pressure metrics before training, specifically in the standard deviation in the medial-lateral direction, range of motion of the COP in medial-lateral direction, the COP path length, its velocity, area, and the fractal dimension. There were no statistically significant changes in the center of pressure motion for the Karate Training group as a consequence of training. There were no statistically significant changes in the metrics of the center of pressure motion for the Strength Training group as a consequence of training.
Table 7.7: The means (± standard deviations) of metrics of the center of pressure motion after a perturbation while standing on two feet with eyes closed for the two experimental groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre-Training</th>
<th>Post-Training</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karate Group</td>
<td>Strength Group</td>
</tr>
<tr>
<td>SD-ML (mm)</td>
<td>43.8 ± 52.2*</td>
<td>14.9 ± 21.4</td>
</tr>
<tr>
<td>SD-AP (mm)</td>
<td>32.2 ± 32.0</td>
<td>21.5 ± 10.2</td>
</tr>
<tr>
<td>Range-ML (mm)</td>
<td>166.1 ± 155.3*</td>
<td>73.3 ± 74.0</td>
</tr>
<tr>
<td>Range-AP (mm)</td>
<td>163.7 ± 88.0</td>
<td>160.6 ± 38.0</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>2982.4±1993.8*</td>
<td>1348.0±907.0</td>
</tr>
<tr>
<td>Velocity (mm/s)</td>
<td>99.4 ± 66.5*</td>
<td>44.9 ± 30.2</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>12409.7±16608 .3*</td>
<td>2564.1±3325. 8</td>
</tr>
<tr>
<td>Fractal Dimension (-)</td>
<td>2.97 ± 0.31*</td>
<td>2.45 ± 0.39</td>
</tr>
</tbody>
</table>

Note – * indicates a statistically significant difference between the Karate and Strength Training groups pre-training.
7.9 Summary

The two different groups, Karate and Strength Training, were assessed both before and after a 15-week period of training. Before training there were no statistically significant differences between the two groups in their body segment inertial parameters. The motion of their center of pressure was quantified for six different postural stability tasks for both groups and then the results from both groups were compared. There were only a limited number of statistically significant differences between the pre- and post-training center of pressure motion for the two groups. These differences did not show any trends in the metrics which were different from the pre- and post-training values nor did they indicate when the differences occurred for the two groups. In summary, there were no statistically significant changes in the center of pressure motion for either the Strength Training group or the Karate Training group as a consequence of training for a period of 15 weeks.
8.1 Introduction

Injuries incurred from falls are a major public health concern. Falls account for one out of every five injuries, one-third of hospitalizations, and one-fifth of all non-hospitalized injuries (CDC 2005). In the U.S., falls are the leading cause of injury across all ages. The overall rate of non-fatal falls for which medical attention is required is 43 per 1,000 population. These rates increase with age for adults beginning with age 18. The age group 18 to 44 years has the lowest rate of medically consulted falls at 26 per 1,000. Even though this age group has the lowest rate, falls are still of great concern as they affect quality of life, productivity, and they cause economic loss. The morbidity and mortality rates increase dramatically for the segment of the population over the age of 65, with persons aged 75 and above having the highest rate of medically consulted falls at 115 per 1,000 (CDC 2012b).

Researchers have thus investigated various forms of exercise for their potential to improve postural stability: aerobics, balance training, Yoga, and strength training, to name a few. Recently ancient martial art traditions such as T’ai Chi have received much attention. Research has demonstrated that T’ai Chi does improve static balance (Wolf, Barnhart et al. 1996). However, it may not be
effective in reducing the risk of falls in more dynamic tasks, such as recovering one’s balance from tripping while walking, slipping on ice or wet floors, or when one experiences sudden perturbations.

In contrast to T’ai Chi, other martial arts, such as Karate, incorporate training in both stationary and dynamic postures. Traditional Kata (standardized series of movements), require practice in moving through stances, and balancing on one leg. In addition, after the beginner phase of training is over, Karate emphasizes the maintenance of balance against perturbations through practice in Kumite (sparring). Thus at the beginning of this paper, it was hypothesized that improvements in balance can best be obtained through an exercise program, such as Karate, that incorporates both static and dynamic training, as well as practice in postural responses to perturbations.

The purpose of this study was to examine the difference in postural characteristics between Karate students and a control group after a relatively brief 15-week physical training session. It was hypothesized that the Karate students will show more improvement in balance as their training progresses compared to the control group. To test this hypothesis, both anthropometric measures, and COP metrics, were obtained from two groups of subjects: Karate students and a control group consisting of students engaged in Strength Training. This research project was initiated in order to explore two issues of importance for fall prevention programs. First, do relatively short 15-week
postural stability enhancement programs produce meaningful improvements as measured by center of pressure (COP) metrics? Secondly, does a 15-week training program in Karate produce better results than a Strength Training program?

To help answer these questions, we first looked to the past, to those who have come before. As the great Karate master Gichin Funakoshi stated:

To search for the old is to understand the new.
(Funakoshi 1973)

From the cave art of prehistory, to the ancient Martial Arts and Greek philosophers, through the history of the development of biomechanics, we have traced our search to understand stability, both philosophical and physical. Along with an examination of the ancient writings, we have looked at recent publications in order to determine the current knowledge base concerning posture and movement, and the direction that current postural stability research has taken. In this last chapter we will summarize our findings and then discuss our results. Based on what we have learned from this study, we will then discuss the implications these findings have for future research in postural stability, in fall prevention, and in rehabilitation.
8.2 Summary of Findings

During this study, two groups of subjects were evaluated: Strength Training and Karate. Postural stability is influenced by the inertias of the body's segments, thus, before this training began, the segmental inertial parameters were determined for all subjects. This was done by modeling the body segments as series of geometric solids. For this study it was found that there were no statistically significant differences between the two groups for any of the inertial parameters.

Before training began, each subject performed a series of postural stability tests while standing on a force plate, during which center of pressure metrics (COP) were obtained. During the postural stability trials, each subject performed six experimental tasks, both before and after a relatively brief 15-week period of training. These balancing tasks were performed both with and without perturbation. Subsequently, individual program evaluations, and between program comparisons, were based on pre- and post-training COP parameters. Following is a summary of the findings from the analysis of the COP metrics.

8.2.1 Quiet Standing Conditions

The postural stability tasks that the subjects performed were of two basic types: without perturbation and with perturbation. The first series of tasks involved quiet
standing without any physical perturbations to the subject’s stability. Analysis of the COP data for the task Quiet Standing, Two Feet, Eyes Open, indicated that as a result of training, the Strength Training Group did show a change, but this change was in only three COP metrics.

The above task was repeated but this time with eyes closed. Analysis of the task Quiet Standing, Two Feet, Eyes Closed demonstrated that there were no statistically significant changes in the metrics of the COP motion for either the Strength Training Group or the Karate Training Group as a consequence of training.

The eyes open task was then repeated but this time with the subjects standing on one leg. For the task Quiet Standing, One Foot, Eyes Open it was found that there were no statistically significant changes in the metrics of the COP motion for either the Strength Training Group or the Karate Training Group as a consequence of training.

For the next task the one-footed stance was repeated but with the eyes closed. The results of the trials for the Quiet Standing, One Foot, Eyes Closed indicated that for the Karate Group there was only one statistically significant change. There was a reduction in the range of the medial-lateral motion of the COP. There were no statistically significant changes for the Strength Training group.
8.2.2 Perturbation Conditions

For the next set of trials the two-footed quiet standing tasks were repeated but this time a perturbation was applied to test the subject’s ability to maintain postural stability. For the Perturbation Condition, Two Feet, Eyes Open: the only statistically significant change was that the standard deviation of the COP in the medial-lateral direction increased for the Karate Group. The Strength Training Group showed no statistically different changes. The above condition was then repeated but this time with the eyes closed. For the Perturbation Condition, Two Feet, Eyes Closed: there were no statistically significant changes for either group as a consequence of training.

8.3 Results Discussion

Since postural stability is influenced by the body’s segmental inertias, each subject underwent careful anthropometric measuring. A statistical comparison of the two groups indicated that there were no statistically significant differences between the two groups for any of the inertial parameters. Pre- and post-training COP parameters of both training groups were then compared.

This study created a complicated data and statistical analysis problem due to the comprehensive range of balance tasks. However, such a vigorous approach lends strength to the validity of the results. Analysis of the data obtained
indicates that there were only a limited number of statistically significant
differences between the pre- and post-training center of pressure motion for the
two groups. These differences did not show any trends in the metrics which
were different from the pre- and post-training values. In summary, there were no
statistically significant changes in the center of pressure motion for either the
Strength Training group or the Karate Training group as a consequence of
training for a period of 15 weeks.

The results of this study are not in agreement with other research focused on the
use of T’ai Chi in fall prevention programs. For example, a comprehensive
review of 47 selected studies on the effects of T’ai Chi training on health benefits
was conducted (Wang, Collet et al. 2004). Eleven of these studies specifically
looked at the effects of T’ai Chi on balance. While the researchers found that
short term studies did produce benefits, overall, long term programs produced
the best outcomes. The 11 balance related T’ai Chi studies indicate that training
programs lasting 8 to 16 weeks significantly reduce the risk of falls and improve
balance. This is contrary to the results of the study carried out for this paper.
Why is there a discrepancy?

The authors of the review study above note that there were many problems with
the 11 studies that they evaluated. Five of these were nonrandomized studies,
some had no comparison group, and others had very small sample sizes.
Furthermore, the three cross-sectional studies were too limited to explain the
cause-effect relationship. In addition, the subjects selected for the 11 balance studies exhibited a wide range of T'ai Chi exercise experience ranging from 8 weeks to 35 years. Further, some studies did not control for exercise time during the training sessions. Thus, it is difficult to compare the duration of exercise sessions or total training time to the resulting benefits.

In contrast, the study for this paper compared two separate groups who underwent two different types of training: Strength or Karate. Each group was composed of a large number of subjects (40) who had similar levels of experience in their chosen activity. In addition, each subject’s time in training was equal at three hours per week for 15 weeks. Furthermore, each subject’s activity level was similar and carefully monitored for the entire 15 weeks. Measurements were carefully obtained of each subject’s body segment inertial parameters. Each subject completed a battery of balance stability tests both before and after the training period. Thus, this author feels that the results are valid and robust. Fifteen week programs of either Strength Training or Karate Training produce no significant effects on postural stability.

### 8.4 Study Limitations

For this study, I was able to recruit a large group of physically fit subjects who did not have any balance impairments. Also being university students, they were motivated to attend their training classes for the entire 15-week period, as
attendance is required in order to earn credits toward their degrees. These students provided an excellent source from which to gain data. However, this presented a few limitations for this study. For instance, a total of 40 subjects began the study, but students can withdraw from a university course for a number of reasons. Subsequently, five subjects withdrew from the study and thus did not complete the second testing session.

There was also a discrepancy in the number of male versus female subjects. At the start of the study, there were 22 males and 18 females who were tested, but they were not equally distributed between the two training groups. The Karate group consisted of 14 males and 6 females, whereas, the Strength Group consisted of 8 males and 12 females. The distribution for the second test was similar; the Karate group consisted of 13 males and 5 females, and the Strength group consisted of 6 males and 11 females. This difference in gender distribution has implications when considering the influence of strength and the body segmental parameters.

In general, care should be exercised when examining studies of segmental inertial parameters. The inertial properties of each subject’s body were determined via modeling (Challis 2004). In determining each subject’s body segmental parameters the body segments were modeled as various geometrical solids. There are several assumptions made during this procedure. One of the principle assumptions is that each segment has uniform density. For this study,
the density values were assumed to be uniform throughout a given segment for both male and female. However, care should be taken when making this assumption. Research has shown that men have peak bone mineral density values that are 12-25% higher than women. For example, in the distal forearm from age 20 to 80 years women have a 50% greater bone loss in percentage terms than men (Warming, Hassager et al. 2002).

Another consideration is that the classic sources of segmental parameters have focused on male cadavers (Dempster 1955; Clauser, McConville et al. 1969). There have been few studies that have examined female inertial parameters. One such study has shown that female lower limb segmental inertial parameters, estimated by using a geometric model, were different than those of males producing different swing times in gait (Challis, Winter et al. 2012). This most likely was not a factor in this study as the subjects were tested only in stationary stances.

Another limitation of this study is that it focused on beginning students in both strength training and Karate. In Karate specifically, beginner training does not emphasize either one-legged stances or recovery from perturbations. The beginner does practice these skills, but the training is very generalized, and it does not focus on any one aspect of stance or movement. The beginner receives practice in controlled, relatively slow movements for both stances and techniques. It is only after the first six months of training that the Karate student
begins to emphasize more dynamic movements, such as during Kumite (sparring), and in practicing kicking drills.

In summary, the primary limitation of this study is that it only looked at subjects who completed a relatively short 15-week training period. It is reasonable to explore if benefits from Karate training would emerge with a longer training period. Unfortunately, the available subjects were enrolled in university courses which are only 15 weeks long.

### 8.5 Direction for Future Research

The results of this study apply to healthy individuals, with no known balance impairments, and who are in the age group 18-25. These people will receive no significant improvement in the control of postural stability through 15-week programs in either strength training or Karate. However, these results may not hold for individuals who must undergo rehabilitation, for those who have impairments to their balance, or for older adults. Future studies should look at these populations.

In addition, this study just looked at the effects of a 15-week training period. It is reasonable to expect that longer training periods would have a greater chance of showing significant positive changes in control of postural stability. Thus, future studies should first focus on the effects of longer training periods. Based on the
author’s extensive experience in teaching beginning Karate students, most students begin to show improved postural stability by the end of six months of training. At that point in their training they begin to practice multiple kicks while standing on one leg. They also demonstrate enough balance control that they can begin to rapidly change stances, and resist perturbations, when they spar. Secondly, a training program based on Karate, which focused on balancing in one-legged stances, has the potential to show more positive results. Such a program could focus on performing multiple kicks while in a one-legged stance, and rapidly moving from one stance to the other, as in Kumite (sparring).

8.6 Conclusions

The conclusion of this study is that brief training periods will have no appreciable effect on improving postural stability. The results of this study are not in agreement with other research focused on the use of martial arts training in fall prevention programs. Almost all research has been conducted on the effects of T’ai Chi on balance. Compared to T’ai Chi, Karate training is more aerobic, requires more flexibility, and requires more dynamic postural movements. It was expected that if any short-term program could have produced favorable results, it would have been Karate. The research for this paper demonstrated that relatively short 15-week programs of either Strength Training or Karate Training will not have any significant effect on balance in the age group 18-25. Thus, future research on fall prevention or rehabilitation programs for this age group
should focus on the development of programs lasting longer than 15 weeks. This may very well hold for other age groups as well. I believe that I stand in good company in this assertion as many before me have agreed; from the ancient Greek philosophers, to the authors of the T’ai Chi Classics, to the present Karate masters in Okinawa. Fitness and balance should be part of one’s lifestyle; it should also be a lifelong pursuit.
APPENDIX A

INFORMED CONSENT FORM
INFORMED CONSENT FORM
The Pennsylvania State University

Title of Project: The Influence of Karate Training on Postural Stability.

Principal Investigator
Dane Sutton
Biomechanics Laboratory,
Rm. 39 Recreation Building
The Pennsylvania State University,
U. P., PA 16802
Phone (814)-863-3445
FAX (814)-865-2440
Email dxs186@psu.edu

Advisor
John H. Challis
CELOS
Rm. 29 Recreation Building
The Pennsylvania State University
U. P., PA 16802
Phone (814)-863-3675
FAX (814)-865-2440
Email jhc10@psu.edu

This is to certify that I ____________________________ have been given the following information with respect to my participation as a volunteer in a program of investigation under the supervision of Dane Sutton and John H. Challis.

1. Purpose of Study
This study will examine the postural characteristics of a group of subjects in a variety of upright postures. The changes in the center of pressure (the point about which you are balancing) will be recorded. Variability between subjects of the patterns of movement will be determined, which will provide insight into postural control.

2. Procedures to be followed
• Questionnaire – this will access your activity levels and experience in sports.
• Measurements – your body dimensions will be recorded (height, weight, and circumferences of all body segments). The measurements are the same as those taken when you are being fitted for clothes.
• Tasks:
  • You will stand barefoot on a force plate in three positions for 30 seconds each: stand upright on both feet, on one foot, and on one foot with eyes closed. The tasks are to maintain these positions:
    ○ Without moving.
    ○ After releasing a weight.
    ○ After a destabilizing movement is applied to your hips.
    ○ After hopping onto the force plate.
  • Karate subjects will complete 15 weeks of Karate training with the PI. Strength Training subjects will continue with their strength training for 15 weeks. Subjects must be involved in Karate or Strength Training however the Karate and Strength Training classes are not part of the research study.
  • You will be tested three times: at the start of the semester, mid-semester, and at the end of the semester. You will be tested at a time when it is convenient for you.
3. Discomfort and risk
None of the protocols should cause you any physical discomfort. Subjects will be excluded from the study if they report a physical or medical problem which affects their balance. No medical information will be collected. During the one-legged tasks you will be free to put your raised foot down if you feel that you are losing your balance. Protective padding will be used on the equipment and the surrounding area. A spotter will be available to assist you during the one-legged and eyes closed tests.

4. Potential benefits: It is anticipated that this study will provide a better understanding of the influence of Karate training on postural stability.

5. Time duration of the procedures and study
- You will be shown the Biomechanics Laboratory and the data collection equipment.
- Any questions that you have will be answered.
- You will sign the Informed Consent form.
- Your body measurements will be recorded.
- You will stand barefoot on a force plate in three positions for 30 seconds each while performing the tasks.
- Your time commitment should be no more than one hour for each of the three sessions.
- You will be tested three times: at the start of the semester, mid-semester, and at the end of the semester. Class time will not be used for this study.

6. Statement of confidentiality
Your participation in this research is confidential. Only the principal investigator and his assistants will have access to your identity and to information that can be associated with your identity. The Office for Research Protections and the Biomedical Institutional Review Board (IRB) may review records related to this project. In the event of publication of this research, no personally identifiable information will be disclosed.

7. The right to ask questions
If at any stage of data collection you require clarification or explanation of the experimental procedures please ask. If you have questions at any other time, please contact the Principal Investigator. You may contact the Office for Research Protections (814-865-1775) if you have any questions about your rights as a research participant.

8. Injury Clause
I understand that medical care is available in the event of injury resulting from research, but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

9. Compensation
- If I am in an ESACT Karate or Strength Training class: For participation in this research study I will earn extra credit attendance/participation points to be applied to my base points for my final grade. If I complete all three research sessions I will earn extra credit that will cancel out three class absences. I understand that I must complete all three research sessions in order to earn this extra credit. If I choose to not be involved
in the study I can still earn the same extra credit by performing instructor approved out of
class activity sessions. I understand that these activity sessions must involve physical
activity at an intensity and duration that approximates a normal class session. I must
then submit a training log to document the time, place, and the activity. If I am not
enrolled in an ESACT Karate or Strength Training class I will not receive compensation.

• I may withdraw from the research study at any time without penalty and then complete
three supervised out of class activity sessions as an alternate way to make up three
class absences.

This is to certify that I consent to and give permission for my participation as a volunteer
in this program of investigation, and that I am over 18 years of age. I have been given
the opportunity to ask any question I may have, and all such questions or inquiries have
been answered to my satisfaction. I understand that my participation in this study is
voluntary, and that I may withdraw from this study at any time by notifying the
investigator. I understand that I may decline to answer specific questions. I understand
that I will receive a signed copy of this consent form. I have read this form, and
understand the content of this form.

Volunteer __________________________ Date ____________  Investigator __________________________ Date ____________
APPENDIX B

PHYSICAL ACTIVITY QUESTIONNAIRE
PHYSICAL ACTIVITY QUESTIONNAIRE

Title of Project: The Influence of Karate Training on Postural Stability.

Principal Investigator: Dane Sutton  
Biomechanics Laboratory, Rm. 39 Recreation Bldg.,  
The Pennsylvania State University, U. P., PA 16802  
Phone +(814)-865-3445  
FAX +(814)-865-2440

ALL INFORMATION WILL BE HELD IN STRICT CONFIDENTIALITY

PRINT YOUR NAME _____________________________
LOCAL PHONE __________________ E-MAIL ______________
GENDER: MALE ___________ FEMALE ________
AGE: ___________ HEIGHT ___________ WEIGHT ________

1) Can you complete both testing sessions? YES ______ NO ______
2) Do you have any physical or medical problem that affects your balance?  
   YES ______ NO ______
3) Are you currently physically active? YES ______ NO ______
4) List the sports and physical activities in which you currently participate:  
   ACTIVITY : HRS /WEEK NO. OF YRS ACTIVE
   ____________________ ___________ __________________
   ____________________ ___________ __________________
   ____________________ ___________ __________________

4) Have you ever had training in any of these activities?  
   Karate ________ Strength Training ________ Martial Arts ________
   Tai-Chi ________ Dance ________ Gymnastics ________
   Yoga ________ Fencing ________
APPENDIX C

INTRODUCTION TO KARATE (ESACT 183)
INSTRUCTOR: SENSEI DANE SUTTON

COURSE DESCRIPTION: This is a beginning course in Karate technique, Okinawan culture, history, and related physical conditioning. It is assumed that the student has limited experience in Karate or self-defense. This course is designed to promote a lifestyle of health and fitness through Karate.

WEEKS   TOPIC
3-4   Review; Basics 16-23; Kata 1-5; Self-defense; Sanban Kumite
5-6   Review Basics, First half of Seisan Kata; Jiyu Kumite.
       Fitness Test #1; Written Test #1
7-8   Review Basics, Finish Seisan Kata, Self-defense
       Kata and Basics Test #1
9-10  Review Basics, Seisan Kata, Self-defense
       Aerobic Test : VO2
11-12 Self-defense, First half of Seiuchin Kata.
       Fitness Test #2, Written Test #2
13-14 Finish Seiuchin Kata, Sanbon Kumite, Self-defense, Jiyu Kumite.
15   Kata and Basics Test #2; Research Paper due

Basic Techniques
1) Shomen Ni etc.   8) Yoko Kekomi   15) Yoko Keage   22) Tsuru Ashi
2) Seisan Dachi    9) Uraken Uchi   16) Age Uke    23) Kake Dachi
3) Seiken         10) Gedan Uke    17) Gedan Shuto  24) Self-defense
5) Tate Tsuki     12) Shuto Uchi   19) Kote Uke   26) Jiyu Kumite
6) Mae Geri Keage 13) Shuto Uke    20) Morote Age Uke
7) Mawashi Geri    14) Seiuchin Dachi 21) Mae Geri Kekomi

Kata Drills
1) Ude Uke; Tate Tsuki
2) Gedan Shuto Uke; Kote Uke
3) Ude Uke; Tate Tsuki Futatsu; Mae Geri Keage; Tate Tsuki
4) Uraken; Mae Geri Keage; Gedan Uke; Tate Tsuki
5) Shuto Uke; Mae Geri Keage; Tate Tsuki

Grading: 200 Skills Tests (2)
200  Written Tests (2)
300  Fitness Tests (2); Aerobic Test (1)
200  Tournament
100  Research: Two page paper on Karate History or Biomechanics of Karate.
     Attendance, Participation: -2.5% per absence or incomplete assignment.
KINES 068  STRENGTH TRAINING (1.5)  This beginner course in strength is designed to improve muscular strength and endurance, and teach students how to develop an effective personal strength and endurance training program for lifelong fitness.

INSTRUCTOR:  MICHAEL J. MORSE

COURSE DESCRIPTION:  The purpose of this class is to teach the basic principles of strength training, the role of weight lifting in an overall program of health and wellness, and to acquire the necessary skills and experience to develop an individualized program for developing muscular strength and endurance.

KINES 068 will require the student to understand the following specific objectives:
1) Become proficient in the use of various types of equipment used to improve strength and endurance.
2) Learn the essential components of a weight training program, and an overall fitness program.
3) Conduct specific tests to measure muscular strength and endurance.
4) Assess muscular fitness level by comparing strength testing results to national averages.
5) Improve muscular strength and endurance.

KINES 068:  This course is designed to introduce students to the acquisition of muscular strength through different methods.  All students are introduced to manual resistance training, nautilus machines, and free weights.  The course requires each student to develop personal goals and to implement those goals into a practical personal program.  It is intended that upon completing the course the student will understand key concepts such as:  muscular strength versus muscular endurance; proper technique; development of balance through proper training of antagonist muscles; effective breathing; concurrent development of flexibility; the recognition of overtraining and momentary muscle failure; basic nutrition and proper hydration as a tool to enhance the training program; and the use of the "buddy system" as a tool for proper spotting, as well as for motivation. Finally, it is hoped that students will develop an understanding of heredity and the biochemical factors which influence muscle growth, and as a result of that understanding, the students will develop a positive body image, self-esteem, and the benefits of a sound work ethic.
APPENDIX E

ANTHROPOMETRIC DATA SHEET
# Anthropometric Measurements

## For Segmental Inertia Parameters

Measurement Recorded by: ___________________________ ( / / )

Subject Name: __________ Age: _____ Mass: _____ kg Height: _____ m

### Upper Arm - Measurements

<table>
<thead>
<tr>
<th>Measure</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1. Circumference at Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2. Mid-Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U3. Elbow Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U4. Limb Length</td>
<td></td>
<td></td>
</tr>
</tbody>
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### Left Hand - Measurements

<table>
<thead>
<tr>
<th>Level</th>
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<th>Base of Thumb</th>
<th>Knuckle</th>
<th>Wedding Ring Nail</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Forearm - Measurements

<table>
<thead>
<tr>
<th>Measure</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1. Elbow Circumference (U3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2. Mid-Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F3. Wrist Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F4. Limb Length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Right Hand - Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Wrist</th>
<th>Base of Thumb</th>
<th>Knuckle</th>
<th>Wedding Ring Nail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Thigh - Measurements

<table>
<thead>
<tr>
<th>Measure</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1. Circumference at Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2. Mid-Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3. Knee Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4. Limb Length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Left Foot - Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Ankle</th>
<th>Mid-Arch of Foot</th>
<th>Mid-Ball of Foot</th>
<th>Big Toe Nail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Shank - Measurements

<table>
<thead>
<tr>
<th>Measure</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1. Knee Circumference (T3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2. Mid-Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3. Ankle Circumference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4. Limb Length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Right Foot - Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Ankle</th>
<th>Mid-Arch of Foot</th>
<th>Mid-Ball of Foot</th>
<th>Big Toe Nail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Head & Neck - Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Base of Neck</th>
<th>Bottom Ear Lobe</th>
<th>Eye Brow</th>
<th>Top of Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
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</tbody>
</table>

### Trunk - Measurements

<table>
<thead>
<tr>
<th>Level</th>
<th>Hip</th>
<th>Naval</th>
<th>Base Ribcage</th>
<th>Nipple</th>
<th>Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
NOTES ON ANTHROPOMORPHIC MEASUREMENTS

**Widths** - All widths are measured in the mediolateral direction.

**Lengths** - These are cumulative lengths: the distance from the start of the proximal geometric solid to the end of the geometric solid currently being measured.

**Precision** - All measurements should be made to a precision of 0.001 m (i.e. a millimeter), but recorded in meters.

**Symmetry** - The upper arm, forearm, thigh, shank, and head & neck segments are assumed to be symmetrical about their x and y-axes. These moments of inertia will be equal giving one moment of inertia about a "transverse axis".
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