By Holly Sweeney-Hillman,
Center Director,
Montclair, NJ

Looking through the *Lens of Science*:

The Nature of Balance and the Practice of Tai Chi Chuan

The ability to balance in an upright posture is most sought after in our earliest youth and again in our elder years. The young lady, Siera, is at the point in her life when she is investing great effort, concentration, and practice in learning uprightness. Soon, her mastery of upright balance will allow her to walk, run, and reach for things without toppling over. She will have many falls as she learns the art of balancing but she won't be discouraged by them. To move upright is a prize well worth the tumbles. The talent for sustaining balance in fully upright posture is unique to human beings and is our most treasured physical capability. We spend more time learning how to balance than any other creature. (Figure 2) As we get older, we sometimes feel less confident about our ability to balance. Losing our ability to balance makes us fearful about everyday activities, threatens our independence and damages our self-esteem. Falling and fear of falling are regarded as serious health threats for older people.

Siera Skye

In the United States, the National Centers for Disease Control and Prevention (NCDC) has invested millions of dollars over the past 20 years in fall-related research. Tai Chi leads the list of effective fall prevention programs that the NCDC advocates and the NCDC has approved additional funding for continued research into the benefits of Tai Chi for public health and safety.[1] Although the research examined by the NCDC focused on the incidence of falling in different populations, there is obviously a relationship between falling and the ability to balance. It is the premise of this article that the study and regular practice of Tai Chi helps people to find and maintain balance while standing or moving upright. To support this idea, we'll look at what science has to say about balance and then we'll look at how Tai Chi practice addresses the different components of balance.

In the world of science, a generally accepted definition of balance is being able to maintain a body's center of gravity over its base of support. This is precisely what the toddler, Siera, is learning how to do. Although many other creatures can balance upright, more or less perpendicular to the ground, for short periods of time, only humans take on this difficult balancing act as a full time job and without a tail to help. Why humans ever decided to do this is a matter of continuing scholarly debate. Science writer Jocelyn Rice has indentified a minimum of twelve competing hypotheses about where, why, when, and how humans got up off their knuckles. All the theories share one theme in common and that is motivation. Humans wanted to be upright for a reason; they wanted something that prolonged upright balance could provide. Here are a few of the motivational theories that have been put forth by various

figure 2

We spend more time learning to stand than any other creature.

scientists: early humans wanted to see above the grasses so they could spot potential predators (thus placing our origin on the savannah), early humans wanted to keep their heads above water (this places our origin in swamps), or, early humans wanted to be able to carry things over long distances and needed to have their hands free for this purpose (this theory hints that we are well evolved for the shopping mall).

In addition to motivation, some scientists have been interested in examining the biomechanical advantages to balancing upright, making the assumption that Nature chooses efficiency whenever possible. Biomechanically, the human gait of covering ground on two legs requires less energy than covering ground on four legs. The walking gait of humans is one of Nature's most efficient inventions, involving minimal muscular effort because the legs are swung like pendulums using rhythmic momentum instead of muscle energy. Most researchers have focused on walking as the gait that defines human evolution. That's why Harvard University anthropologist Daniel Lieberman has caused quite a stir in the scientific community with his hypothesis that the motivation that created our uprightness was running. Lieberman observes that humans can pretty much outrun any mammal in the world, particularly in hot dry conditions, because of the efficiency of our upright balance on two legs. Humans are not particularly fast runners but can run for much longer periods of time than other animals. Lieberman proposes that hunting and scavenging motivated our running behavior, stating that early humans could literally wear out their prey in prolonged chases. Lieberman makes some compelling observations about human structure to support his argument: compared to other primates, humans have huge extensor muscles, notably the gluteal muscles (i.e. butt muscles) and the hamstrings. These muscles become strongly developed by running because the body is leaning forward. Lieberman likes to say that when a person is running, they are always falling. These muscles contract strongly to help stabilize the torso, so we don't topple forward. Figure 3 shows drawings from Leonardo Da Vinci's notebook. Leonardo was also fascinated by the massive system of extensor muscles in our hips and legs. In addition to our well developed extensors, Professor Lieberman cites the tendon structure of the human leg as further support for his 'born to run' theory of human development. Humans have long tendons in the lower legs which act as energy storing springs. Lieberman says this kind of tendon structure only evolves in animals designed to run. Lastly, he talks about features of our head structure that sets us apart from apes and allows us to be good runners. He notes that humans have more sensitive semicircular canals than other apes. Semicircular canals are structures in the vestibular system of our inner ears that act as gyroscopes, meaning our heads can be bouncing all over the place and we can still figure out which way is up in order to maintain our balance. Also, humans have a special ligament which connects our head to our spine. This ligament, the nuchal ligament, stabilizes our head so it is held steady while we are running. Fast running and jumping animals like horses, dogs, rabbits, and humans all have well-developed nuchal ligaments. In humans, the strength and elasticity of this ligament also contributes greatly to our ability to hold our head upright as we stand or move around. Lieberman maintains that none of these structural features could have evolved from walking.[2]

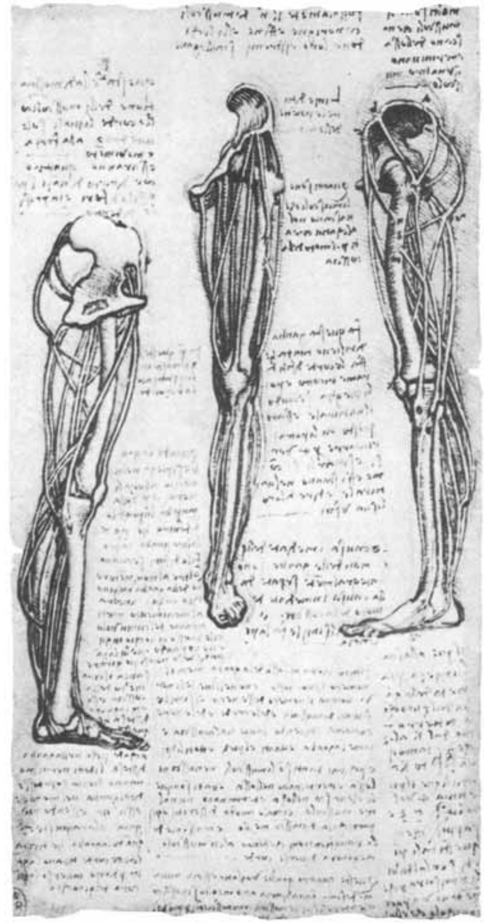
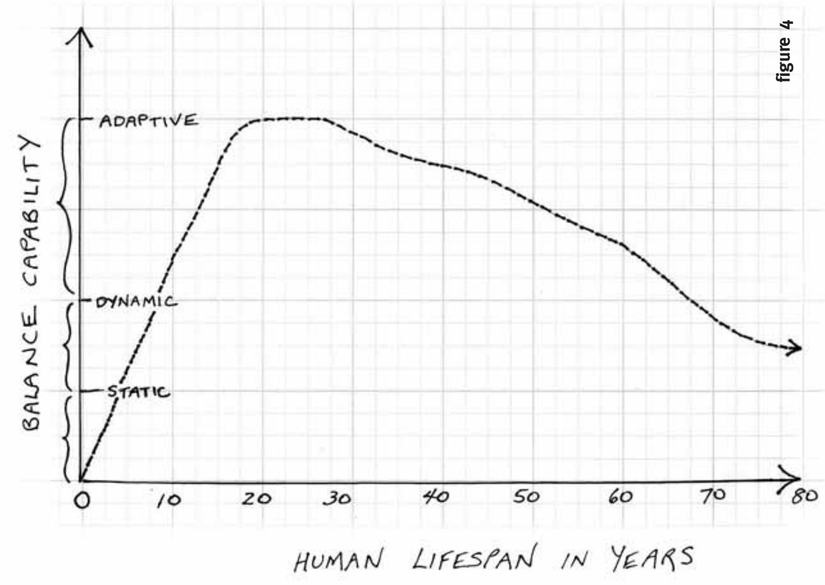


figure 3

If Lieberman's observations are correct, running may have helped early humans evolve some of the structural capacities that help us balance today: large extensor muscles that stabilize us from pitching forward, highly developed semicircular canals that keep us from being disoriented while we are moving, strong nuchal ligaments to hold our



heads upright. If running was the why that helped us develop some structural advantages to balance upright, the next problem is how, how do we accomplish our balancing act?

Although we frequently use the phrase "holding our balance," true balance is an equilibrium of the moment. To achieve equilibrium, a person must possess three distinct but interrelated types of balance: static, dynamic, and adaptive. Static balance is the ability to sustain a chosen posture*. Dynamic balance is the ability to maintain chosen postures while moving. Adaptive balance is the ability to move while maintaining chosen postures while negotiating changing environmental demands. Figure 4 diagrams the competence gained in these skills over the course of human life span. The highest peak in the graph occurs at young adult age, a gradual decline is seen in aging populations. To better understand how balance skills are lost, let's first take a look at how they are gained. *(*The term "chosen posture" recognizes that the human balance spectrum is broad, going from the average person's more or less uprightness to the acrobat's perfect upsidedowness to the figure skater's twirling miracle of unfolding configurations while revolving on the blade of one skate.)*

Scientists have spent decades trying to understand exactly what is going on as the young lady in Figure 1 goes from dependence to independence by mastering the art of balance. In the early 20th century, a researcher named Magnus created a theory of "reflex hierarchy" to explain how balance is achieved. His theory was based on countless gruesome experiments on animals. He interpreted his experiments with animals as indicating that the ability to balance was based on reflexes, in other words, balance was 'hardwired' into our physiology and would manifest in a predictable and orderly sequence of postural behaviors. However, the postures and movement responses of animals when examined outside the contrived and artificial parameters of his laboratory studies did not support his theories. Scientists began to realize that the variety and spontaneity of postures and movements that are witnessed in healthy animals interacting in a natural environment could not be explained by Magnus's theories which confined balance to the rigid limits of postural reflexes. Although his theories shaped an entire generation's thinking on child development, by the 1980's another group of scientists had replaced Magnus's reflex model with an entirely different model based on systems theory.[3]

Systems theory states that: "A system, by definition, consists of an organized set of parts (the subsystem level) that interact with each other in such a way as to generate unique properties (emergents) expressed at the level of the whole (the systems level). In other words, systems generate unique behaviors that emerge out of a complex set of subsystem/system/suprasystem interactions."[4]

The application of systems theory to the phenomenon of human movement created scientific research that was quite different from Magnus's laboratory studies. Interesting findings began to emerge from this new research and one of the most important discoveries was that flexibility of behavior is achieved through practice and repetition and that with repetition, movement patterns become more adaptable and less rigid or stereotypic. "Practice and experience allow the organization of action systems to accomplish a functional end... rather than acquiring a motor program, the individual develops a skill. That skill is the ability to use information to coordinate movements and postures flexibly in the context of a task." [5] In other words, we could define balance as a learned and practiced complex skill rather than a rote function of the nervous system.

Action systems researchers made another important observation about balance. They discovered that balance while performing an activity was dependent on anticipatory postural adjustments. They demonstrated that postural changes preceded the overt movements necessary to perform a task and these changes prepared the body to balance. This anticipatory postural activity prevented a person from losing their balance as they performed different activities. These findings indicated that cognition is an important component of the ability to balance.[6]

"Cognition" is defined as the process of knowing, perceiving, and remembering. Regarding human movement, cognition is knowing what you want to do (for instance, "Brush knee left, push right"), perceiving what you are doing as you move (how closely your "brush knee left, push right" conforms to the standard your teacher shows you), and remembering what you did so you can try it again. Master Yang Zhenduo's comments on the progression of Tai Chi study, moving from "approximate" to "detailed" to "refined" practice is a perfect description of how cognition affects practice and practice affects cognition.

Before any movement is performed, our nervous system needs to anticipate how to balance our body as it moves. This anticipatory activation of postural muscles is based on experience and the process of cognition. Studies have shown that lack of ability among older adults to anticipate and adequately prepare their postural control systems for movement was linked to losing balance during experiments. Studies also showed that older adults showed proportionally more improvement in balance tests than younger subjects if the balance tests were repeated several times. This suggests that older adults intuitively rely more on cognition than reaction time to control their balance.[7]

In addition to cognition, there are physiological factors that contribute to the ability to balance. The big three in this category are: the vestibular system, vision, and proprioception.

The vestibular system, located in our inner ears, resolves conflicts about balance through a complex structure of semicircular canals which can sense acceleration and turning. (These are the structures that Lieberman says evolved from running). Most of us have had experiences which give examples of our vestibular system in action. One is when we are in a stopped vehicle and the vehicle next to us starts moving. Our eyes can be tricked into perceiving that we are moving but in a moment or two our vestibular system sorts things out and lets us know that we are not moving but standing still. Another example is when we are in an elevator that zooms down fast. Even after the elevator has stopped moving, we have a dizzy feeling that we are moving but in a moment, the fluid within our semicircular canals stops swirling and we know we are no longer moving. These examples show that the vestibular system tends to exert a controlling influence over all other sensory systems of balance. Degeneration or disturbance within the vestibular system is not uncommon in people over 50 years of age. People with vestibular problems can be helped by doing exercises which help them rely more on vision and proprioception.[8] Tai Chi movements like 'Wave Hands Like Clouds', which combine turning head movements with a specific visual focus are similar to movements used in vestibular therapy. Also, Tai Chi's emphasis on developing a 'root' in the feet is an example of how we use proprioception to increase confidence in our sense of balance.

Research conducted on balance consistently finds that vision impairment due to low light conditions or poor eyesight negatively affects our ability to balance. Most of us know the relationship between sight and balance through direct experience. The aging process frequently reduces visual capabilities and this is an important consideration when looking at balance in older adults. Relying more on proprioception can help reduce the impact of poor vision on balance.

Proprioception is the foundation of all our movements and the ability to achieve equilibrium. It is the sense that allows us to know the positions of our limbs, the amount of tension in our muscles, and how much our joints are bent and the amount of pressure we can feel within our joints. Proprioception could be described as our internal GPS that maps our structure and body mechanics on a moment to moment basis. Disuse, more than aging, reduces our proprioceptive abilities. In the Big Three of Balance, (vestibular system, vision, and proprioception) proprioception seems to be the most robust, trainable, and durable sense throughout our lifespan.

However, it is important to keep in mind that it is the interaction between these three systems that enable us to balance. This interaction is a function of our nervous system and our nervous system demonstrates "plasticity" throughout our lifetime.

"Plasticity" describes the ability of our nervous system to make structural changes in response to internal and external demands. One of the structural changes the nervous system is capable of throughout our lifetime is to continue to grow dendrites. Dendrites are long tentacle shaped projections that receive incoming stimuli and pass the information to the cell body of a neuron. Neurons are the nerve cells that allow the nervous system to exchange information throughout the body and to direct movement activities. Every dendrite is branched to receive multiple inputs from other neurons. You could imagine a neuron like the trunk of a tree and the dendrites as the branches, the more branches on the tree, the wider the area of shade the tree would cast. In the nervous system, this area of shade would be termed a "receptor field". The bigger and denser the 'shade' cast by the forest of dendrites, the richer and more detailed is the information network shared by neurons. This information network allows us to put together many bits of sensory information in order to accomplish complex tasks like balancing.[9] In the

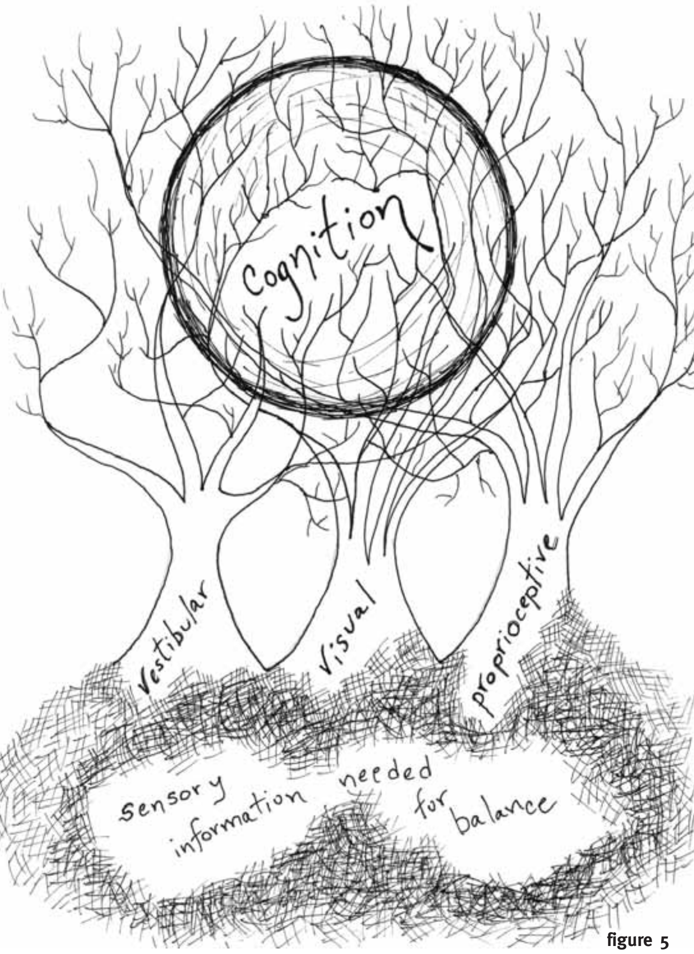


figure 5

language of Yang Chengfu's 10 Principles of Tai Chi Practice, the 'dendrite forest' helps the nervous system *unify internal and external*. The growth of dendrites is a perfect example of the concept of "use it or lose it'. The number of dendrites we have to use will be determined by how much we challenge our capabilities and by how much we practice to maintain our abilities.

Figure 5 is a fanciful illustration of the 'dendrite forest' of our nervous system. Cognition is shown as the sunlight that motivates the growth of the forest. Neurons of the vestibular, visual, and proprioceptive 'trees' grow countless dendrites to connect and integrate all the pieces of sensory information that we need to balance. The dense shade under the trees represents a rich field of sensory information that we can use to find our balance.

This article has investigated the components needed to produce balance; defining balance as being able to maintain center of gravity over base of support while standing still (static balance), while moving (dynamic balance), and while spontaneously coping with the environment (adaptive balance). The elements that appear to be essential in the development of balance are motivation, certain physical capabilities, cognition, and sensory integration.

Scientific thought on balance leans toward motivation as the reason we balance upright in the first place. We have evolved to want to balance upright which is different from saying we evolved knowing how to do it. We have to learn to balance, we are not born knowing how. In order to keep balancing throughout our lifetime, we have to keep wanting to learn how to do it. Just like the toddler Siera, we have to keep trying till we get it right. As our bodies change, we can keep our balance skills up to date with practice. The more we practice, the more we'll get it right.

The way Tai Chi is practiced addresses the different types of balance. The individual postures of Tai Chi give students the opportunity to practice static balances of varying degrees of difficulty. The Tai Chi forms, which are sequences of postures connected by transitional movements, challenge dynamic balance capabilities. Practicing Tai Chi in a group and in different environments provides adaptive balance practice. Tai Chi Tui Shou (push hands) provides the most rigorous

figure 6

practice requiring all three types of balance.

Figure 6 shows some students practicing Tai Chi sword form. We can see that the way they are balancing on one leg looks more like running than walking. Tai Chi develops physical capabilities that walking alone could not develop. The lowered, bent knee stances of Tai Chi develop strength in the extensor muscles of the hip and leg. Increased strength in these muscles help stabilize us when we move, keeping our torso from toppling forward. The way weight is transferred from one leg to another in Tai Chi is completely different from walking and requires much more muscle effort. The slow controlled transfer of weight maintains higher numbers of motor units and thereby contributes to increased strength overall. The mechanics of Tai Chi movement are closer to running that walking. Just like running, we move from a supporting bent leg toward an extended forward leg. Like running in slow motion, we gradually bend the forward leg while we straighten the back leg to transfer weight from one leg to another. In Tai Chi, we bend and straighten our legs like compressing and releasing springs. This pattern of compression and release conditions our tendons.[10]

The variety of Tai Chi movements and the precision of their performance gives cognitive abilities quite a work-out. An experienced Tai Chi player knows more than a hundred distinct postures and many more transition movements that connect one posture to the next in a continuous flow of movement that can go on for nearly an hour to complete just one Tai Chi form sequence. It takes a lot of cognitive skill to remember, anticipate, and track so many discrete movements. The cognitive aspects of Tai Chi practice give students a huge repertoire of anticipatory balance strategies.

Tai Chi practice includes persistent application of sensory integration. For example, the "prepare" (yu bei shi) posture at the opening of each form represents specific and intense sensory observation: Is my head upright? Is my back lifted up and my chest contained? Is my waist area loose? Are my shoulders relaxed down? Is my spirit lifted? Is my mind tranquil? As a student progresses through the study of Tai Chi, the challenge of integrating sensory information increases, leading to incredible sensory refinement – the ability to sense beyond structure to perceive energy and intention.

But, as any Tai Chi player knows, it all comes down to practice. And practice is a matter of motivation and motivation is a matter of spirit. If you can raise up your spirit and practice Tai Chi everyday, you will improve your balance. Science is on your side.

Sources for this article:

1 Sleet, David; Moffett, Daphne; Stevens, Judy; "CDC's research portfolio in older adult fall prevention: a review of progress, 1985-2005, and future research directions." J Safety Res., 39 (3) June 2008; pgs.259-67

2. Hadzipetros, Peter; "Born to Run, Harvard anthropologist Daniel Lieberman on why humans run", CBC News in OnLine, April 11, 2007

3. Cech, Donna; Martin, Suzanne, *Functional Movement Development Across the Life Span.* Philadelphia: W.B. Saunders Company, 1995, pgs. 275-281

4. Schwartz, G.: "From Behavior Therapy to Cognitive Behavior Therapy: Toward an Integrative Health Science". *Paradigms in Behavior Therapy*, ed. .Fishman, D.; Rotgers, F.; Franks, C.; 1988, pgs. 294-320.

5. Cech and Martin, op.cit., pg. 281

6. Ibid, pg. 280

7. Woollacott, Marjorie. "Gait and postural control in the aging adult"; *Disorders of Posture and Gait*, ed. Bles, W. and Brandt, T., Amsterdam, Elsevier Press, 1986, pgs.42-52.

8. Cech and Martin, op.cit., pgs. 223-243

9. Ibid., pgs. 190-233.

10. Sweeney, Holly. "Practice Continuously and without interruption." The International Yang Style Tai Chi Chuan Association Journal, Vol. 16, Spring 2005. 14 -16