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A SYSTEMS APPROACH TO THE PROBLEM OF FALLS IN OLD AGE

Patrick A. Dillon
University of Kentucky, pat.dillon@uky.edu
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Patrick A. Dillon, Student

Dr. Graham D. Rowles, Major Professor

Dr. John F. Watkins, Director of Graduate Studies

A SYSTEMS APPROACH TO THE PROBLEM OF FALLS IN OLD AGE

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Public Health at the University of Kentucky

By
Patrick A. Dillon

Lexington, Kentucky

Director: Dr. Graham D. Rowles, Professor of Gerontology

Lexington, Kentucky

2017

ABSTRACT OF DISSERTATION

A SYSTEMS APPROACH TO THE PROBLEM OF FALLS IN OLD AGE

The problem of falls in old age is enormously costly and disruptive for the older individual, others, and society, and its severity is likely to intensify as our population ages. This dissertation takes a systems-oriented approach toward the falls problem and is presented in two parts. The first part critically develops a new approach to the problem of falls. The second part describes an empirical study that applies this new approach in a pragmatic manner.

Conventional fall prevention strategies employ a reductionist approach to the problem of falls. This approach is questioned because it corresponds poorly to the holistic nature of postural control. A systems-oriented conceptual framework explains postural instability in old age as the gradual decline of a postural control system's ability to adapt.

Realizing that falls arise from a complex system of interacting components of various levels and domains makes it imperative to investigate interventions aimed toward systemically fostering robust postural control. A dynamic systems theoretical framework is outlined that views postural control to be the result of synergies which function to control myriad inherent degrees of freedom. Complexity-based measures of postural sway are suggested as indicators of postural control system robustness.

This new approach to the problem of falls is applied in an empirical study in which Tai Chi serves as a systems-oriented intervention. Using a dynamic systems perspective, motor imagery, along with other Tai Chi principles, are hypothesized to provide interacting physical and cognitive constraints on motor behavior that form synergies which enable robust postural stability into old age.

This hypothesis was tested in a quasi-experiment comparing effects of Tai Chi motor imagery in Tai Chi experts and non-experts. The expected significant effects on postural sway complexity were not found, but significant main effects and interactions on sway variability and ease of imagery were discovered with respect to expertise and imagery type. Findings, results, innovations, implications and future directions are

presented, and discussed as they pertain to four specific aims, and to ameliorating the problem of falls in old age.

KEYWORDS: Falls, Older Adults, Tai Chi, Dynamic Systems, Motor Imagery, Postural Control

Patrick A. Dillon

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Date

A SYSTEMS APPROACH TO THE PROBLEM OF FALLS IN OLD AGE

By
Patrick A. Dillon

Dr. Graham D. Rowles
Director of Dissertation

Dr. John F. Watkins
Director of Graduate Studies

January 23, 2017
(date)

To the one I fell for, and who keeps me stable

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Chapter 1: Confessions of a Recovering Reductionist

> We have looked at many aspects of low back pain and disability, and it is time to fit them all together. Let us step back and try to see the whole picture. It should be clear that the traditional disease model is inadequate to understand low back pain and disability. We need a new model… (Waddell, 2004, p. 265).

Orthopedic surgeon, Gordon Waddell, MD published these words in his book, *The Back Pain Revolution*, in response to a time of exponential increase in lower back pain-related disability and social security benefits in the United Kingdom that lasted into the mid-1990s.

Around the same time of which Waddell wrote, I was practicing physical therapy with my wife, Michelle, in our privately-owned clinic in Maysville, KY. My special interest had been spinal pain and dysfunction, and my particular training was in the *mechanical* assessment and treatment of spinal problems. My approach was often reductionist and reliant on a disease model, in which the culprit pathology responsible for a spinal problem was thought to involve one or just a few anatomical structures, not the least of which was the intervertebral disc. I was well aware of how back and neck pain involved the social and psychological domains of life, but I considered these domains as removed from practically all my training as a *physical* therapist and, quite honestly, I preferred not to deal with them unless absolutely necessary.

It was around the same time that (being the perpetual student that I am) I considered advancing my specialty training in spinal disorders, but did not. Looking back, I know now that ultimately my choice was to see things in terms of whole systems. My reductionist thinking probably started to crumble when I began to dabble in traditional Chinese martial arts as an interesting and motivating way to get physical exercise. I found it curious how Chinese kung fu training was as much mental as it was physical. Some of the mental training even struck me as perplexingly paradoxical and bizarre. For instance, one training method was to stand still and perform a variety of mental imagery tasks. It became clear to me that I assumed that the physical and mental domains were much more distinct and separate than the kung fu paradigm suggested. I wondered: how is it possible that mental imagery training could play a role in acquiring physical skill? If so, what is the nature of this mind-body relationship?

I also began to question how I should understand my patients and the conditions I was called upon to treat. Barring complete unconsciousness on the part of the patient, can I really separate effects of the physical treatment from all the non-specific effects related to a patient-provider encounter that experimental research endeavors so intensely to control (Benedetti, 2014; Harrington, 1997, 2008; Moerman, 2002)? Furthermore, would I want to if I could?

My reductionist ways of thinking were further contested during my graduate education. I came to understand that the sum of the parts often does not always fully explain the whole. Rather, new properties can arise out of the relationships among parts of a system that are not always reducible to the parts themselves. This process of something new arising at the level of a whole system from nothing but its component parts, is known as *emergence* (Goodenough & Deacon, 2008). Emergence has a long history in systems-oriented thinking (Clayton, 2004) and has broad applications. Not only has emergence been a paradigm to understand physical, mental and social phenomena (Clayton, 2004; Deacon, 1997, 2013), but it has also served as a theological paradigm to reconcile understandings of God in a culture that has increasingly valued scientific rationality (Kauffman, 2008; Kaufman, 2004; Rue, 2005, 2011).

Although systems-oriented thinking has been around for a long time with several applications, the development of a systems-oriented approach within research addressing the problem of falls is new.

This dissertation is presented in two parts. The first is an investigation of a new approach to the problem of falls and is presented in Chapters 2, 3 and 4. The second applies this new approach in an empirical study with four specific aims and is presented in Chapters 5 and 6. Chapter 7 unites these two parts in a discussion of the sample, study design, and findings from each of the specific aims of the empirical study. In this chapter I integrate the two overall themes in discussion of the innovations, implications and future directions provided by the entire dissertation project. Chapter 8 concludes the dissertation.

Chapter 2: Falls in Old Age

This chapter will elaborate on what a fall is, why humans are prone to falling, when and how falling is a problem, and why falling is pressing concern in old age. The many and varied identified factors that place older adults at risk will be discussed, and the enormous complexity of the problem will be demonstrated. After summarizing a systematic review of falls prevention programs for older persons, the conceptual approach of current research and practice is critically evaluated.

The Problem of Falls in Old Age

A "fall" is generally defined in the research literature as an event in which a person comes to rest unintentionally on the ground or other lower level (Masud & Morris, 2001). Definitions vary depending on the source. For instance, definitions may specify that a fall is not caused by a major intrinsic event (such as a heart attack) or overwhelming hazard (Tinetti, Speechley, & Ginter, 1988), or that a stumble qualifies as a fall (Ory et al., 1993), or that the height of the descent of a fall must be greater than one meter (Kannus et al., 1999). A fall may occur from any starting position, including sitting or even lying, but because of the relationship of the center of gravity to base of support, humans are more prone to fall from the standing position.

The Relation between Center of Gravity and Base of Support and Human Postural Control. For any stationary object to maintain stability requires that its center of gravity (the downward vertical projection of gravity on the center of mass) be kept over the support area (Latash, 2012). When the object's center of gravity is positioned beyond the area of its base of support, it falls. Figure 2.1 depicts a table in three different positions of tilt. The dot represents the center of gravity, where the center of mass is being acted upon by the downward vertical force of gravity. The tables to the left and in the center of the figure will not completely topple because the center of gravity is positioned over their support base. The table on the right is unstable and will fall on its side because the center of gravity is positioned beyond its base of support.

The higher the center of gravity relative to base width, the less inherently stable is an object. Figure 2.2 illustrates two wine glasses with the same actual base width that are resting on a slope at the same angle of tilt. The *effective* base width (as measured perpendicular to the vertical projection of gravity) of these glasses is smaller than their actual base width because they are on a slope. Even though their effective base widths are equal, because of the higher center of gravity belonging to the full glass, the vertical projection of its center of gravity is positioned much closer to the edge of its effective base and prone to tipping in that direction if disturbed. In this respect, we could say the full glass in less stable than the empty glass.

The integrity of the materials of an object could also be a factor in stability. A wine glass with a cracked base may be less stable because it is less likely to withstand a disruptive force without breaking and falling over.

The same principles making inert objects less stable apply to human bodies. One's stability is affected by the height of one's center of gravity relative to one's base width. Holding a heavy object overhead will effectively raise one's center of gravity and reduce stability. Widening one's stance to increase base width or crouching will lower the center of gravity and improve stability. Conversely, narrowing one's stance can reduce stability. Standing on a slope reduces stability by making the effective base smaller compared to standing on flat ground. One's musculoskeletal integrity can be a factor of stability. Like the wine glass with a cracked base, a person with a weak ankle is less able to withstand forces that challenge his or her upright position.

In all cases, when center of gravity is kept over base of support, as in the left hand and middle illustrations of Figure 2.3, stability is maintained. When the center of gravity becomes positioned beyond a person's base of support, as in the right hand illustration of Figure 2.3, the person will fall, *unless* the center of gravity is quickly repositioned over the base of support. In fact, humans must do this during walking, a situation in which a moving center of gravity is repeatedly positioned beyond the base of support and is recovered by placement of the swinging leg.

Compared to most quadruped animals, bipedal humans have a relatively high center of gravity and a small base of support. These characteristics make humans inherently unstable in standing (Latash, 2012). This is illustrated in Figure 2.4.

Unlike the inert objects discussed above, humans can act to get from one place to another and maintain their stability. This is accomplished by way of a class of motor behaviors known as *postural control*, the ability to purposefully move about, and respond to destabilizing forces. Postural control is concerned with controlling the body's position in space for stability, and also with orienting the relationships among body segments, and the relationship between the body and its environment. *Postural stability*, or *balance*, refers primarily to postural control, but specifically to the ability to control the center of gravity with respect to the support base (Shumway-Cook & Woollacott, 2012). In these terms, an unintentional fall is the result of a failure in postural stability. Since the orientation of inter-segment relationships in the body, and orientation of the body-environment relationship is integral to postural stability, an unintentional fall is also a failure in postural control.

When and How Falling Is a Problem. Falling is a fact of life for humans. As long as there is no injury, falling is considered normal in developing postural control as children learn to hold their head up, sit up, roll over, stand, walk, play and explore their environment (Peden, 2008). But not all falls are harmless or normal. Some cause injury, and these are a problem at any age.

It is mostly in old age that falling is a problem. This is easily illustrated by Figures 2.5 and 2.6 that show falls data collected in Ontario, Canada, during fiscal year 2005/06. Notice in figure 2.5 that falls requiring emergency department visits are well represented in every age group. But, as illustrated in the figure 2.6, more severe and costly falls requiring hospitalization occur at disproportionately higher rates among older adults (Falls Across the Lifespan: Evidence-Based Practice Synthesis Document, 2008).

Data collected by the Kentucky Injury Prevention and Research Center (KIPRIC) reveal the same pattern (Figures 2.7 and 2.8; Kentucky Injury Indicators 2013, 2016). Although emergency department visits in Kentucky for unintentional falls occurred in 2013 at substantial rates in all age groups, hospitalization from falling occurred at a much higher rate among older age groups. Figure 2.9 shows that deaths resulting from falls occurring in 2013 in Kentucky are also disproportionately more frequent among the elderly.

Incidence and Cost of Falling among the Old. Evidence that falling is primarily a problem in old age is not limited to data from Ontario and Kentucky. Older people fall frequently regardless of location. Thirty-five to 40 percent of all adults aged

65 years or older and living in the community fall every year, with a higher incidence in those 75 years or older (Kenny, Rubenstein, Martin, & Tinetti, 2001; Rubenstein, & Josephson, 2002). In older persons with dementia the proportion of falls per year is 60-80% (Bassiony et al., 2004; Shaw et al., 2003; Tinetti et al., 1988; van Dijk, Meulenberg, Van de Sande, & Habbema, 1993).

Falls among those 65 and older represent the leading cause of non-fatal injuries, accounting for 2,791,459 fall-related injuries in the US in 2014 (Centers for Disease Control and Prevention [CDC], 2016a). Studies have found that 23% of older adult fallers experience a serious injury, and that 12% of older fallers suffer serious injury as a result of their first fall (Tinetti, Doucette, Claus, & Marotolli, 1995; Tinetti, Doucette, & Claus, 1995).

When falls harm older people the injuries are disproportionately severe. One retrospective study found that falls were the mechanism of injury 48% of the time in those 65 years and older, and 32% of those falls were rated as severe. In contrast, falls were the mechanism of injury in only 7% of those under 65 years of age, and only 11% of these falls were severe (Sterling, O'Connor, & Bonadies, 2001).

Fatal falls are also more common in the old. Falling in the US ranked as the fourth leading cause of injury death in 55-64 year olds in 2014, but ranked first in those aged over 65 years with 27,044 deaths (CDC, 2016a). Older adults living longer with chronic disease are less likely to survive a fall, and the increasing proportion of these chronically ill older adults probably explains a 55.3% increase in rates of fatal falls from 1993 to 2003 in persons aged 65 years or older in the US (Stevens, Ryan, & Kresnow, 2006). Rates of fatal falls in older adults have continued to rise and are likely to remain high given that, in 2014, 61.6% of adults 65 years and older in the US had multiple chronic conditions (CDC, 2016a, 2016b; Ward, 2016).

The direct economic impact of falls in older persons is enormous. When adjusted for inflation, direct medical costs in the US attributable to falls in older adults total $34 billion annually, with hospitalization accounting for two-thirds of the total cost (Centers for Disease Control and Prevention, 2014c; Stevens, Corso, Finkelstein, & Miller, 2006). Medicare costs in 2015 for non-fatal falls in older persons exceeded $31 billion, nearly as much as the $36 billion spent by Medicare on cancer in the same year (Burns, Stevens & Lee, 2016). Mean cost for those 65 years and older for a hospitalization due to non-fatal fall in 2010 was estimated at $38,412 (CDC, 2016a).

The economics of falls in older adults are compounded by indirect costs affecting broader societal productivity. It is estimated that in 2020 the direct and indirect falls-related cost (in 2012 dollars) will be $67.7 billion (CDC, 2014b; Fred Englander, Hodson, & Terregrossa, 1996).

There are non-economic costs related to falls in older adults. One direct non-economic cost is fear. In a 1997 study of older adults, the 219 who fell were asked, “Are you worried about falling again?” Thirty-two percent reported they were (Vellas, Wayne, Romero, Baumgartner, & Garry, 1997). In a cross-sectional study of 4,031 Dutch older adults, 54.3% reported being afraid of falling. Among those afraid, 37.9% reported avoiding certain activities because of their fear (Zijlstra et al., 2007). Falls not only create fear among the old, but also a contraction of freedom and reluctance to venture away from familiar environments. Other direct non-economic costs affecting the older faller may be frustration, loss of physiological confidence, or anger, all of which influence life quality on an emotional level. Non-economic costs that indirectly affect the older faller may include the loss of opportunity to engage in normal activities or social interaction.

In summary, being a bipedal human means having to move and control bodies that are inherently unstable. Not surprisingly, falls occur in all age groups. Harm occurs in every age group too, but the problem of falls is particularly severe in old age. Older adults are falling at a rate of 35-40% and suffer the highest rates of injury, highest rates of hospitalization, and the highest rates of death due to falls. The economic and non-economic costs to the faller and to society are huge. The facts speak for themselves: falling in old age is an enormous problem in terms of human suffering and economics. This dissertation focuses on exploring strategies to best ameliorate the problem of falls in old age. It begins by examining the very nature of the problem, starting by evaluating the factors that place older adults at risk for falling.

Risk Factors for Falling.

A fall risk factor is a situation or circumstance that increases the likelihood of a person falling. Fall risk factors have been classified as either intrinsic or extrinsic. Intrinsic fall risk factors are considered those in which a condition or characteristic of the individual increases the risk of falling. Extrinsic factors are those in which some environmental factor increases risk of a fall. Some risk factors are modifiable while others are generally not (Masud & Morris, 2001). Table 2.1 stratifies intrinsic and extrinsic risk factors based on modifiability resulting in four distinct groups. Examples are given for each group.

Tables 2.2 and 2.3 provide a more comprehensive summary of intrinsic and extrinsic factors that put community-dwelling older adults at risk for falling (Deandrea et al., 2010; Fried, et al., 2001; Hanlon, Landerman, Fillenbaum, & Studenski, 2002; Koepsell et al., 2004; Nicklett, & Taylor, 2014; Menz, Morris, & Lord, 2006; Tencer et al., 2004; Tinetti & Kumar, 2010).

A striking feature of Tables 2.2 and 2.3 is the large number of individual fall risk factors identified in older persons. Table 2.2 lists 21 intrinsic factors. Table 2.3 lists 39 extrinsic risk factors relating to an older adult's environment, and the hazards listed are only those most commonly encountered. Unlisted are countless other possible hazardous environmental conditions.

Another salient feature of the lists in Tables 2.2 and 2.3 is wide variation and complexity among fall risk factors. Among the long list of intrinsic fall risk factors, are a vast array of bodily systems, including the musculoskeletal, neurological, endocrine, and cardiovascular. Emotional and cognitive domains are also included in the mix. Some individual risk factors reflect discreet underlying impairments such as Parkinson 's disease or visual impairment. Most are not so discreet. "Gait Impairment/Difficulty Walking" may involve abnormalities in multiple bodily systems including the musculoskeletal, peripheral nervous, central nervous, or vestibular systems. Fall risk associated with medication use could involve drug-induced impairment of just about any of the intrinsic bodily systems, depending on the specific medications and their side-effects. The fall risk factor of frailty, by definition, also suggests multiple possible underlying causes that may include abnormalities involving musculoskeletal, metabolic, digestive, or emotional domains (Fried et al., 2001).

Understanding fall risk becomes more complicated when considering how two or more concurrent risk factors may be interacting with each other to produce greater risk overall. Tinetti, Speechley, & Ginter, (1988) conducted a one-year prospective study of 336 adults of at least 75 years of age who were living in the community and found a dramatic rise in fall risk as the number of risk factors increased from one to four or more (Tinetti, Speechley, & Ginter, 1988). Fall risk factors considered were sedative use, cognitive impairment, lower extremity disability, palmomental reflex, foot problems and gait/balance abnormalities. Figure 2.9 illustrates the relationship between the number of fall risk factors and overall risk of falling (Tinetti, Speechley, & Ginter, 1988).

In this case, there appears to be no clear linear or non-linear trend in which fall risk rises incrementally as the number of risk factors increases, but it appears that the largest jump in fall risk in an older person occurs during the transition between the presence of two and three risk factors. There are at least three of the individual fall risk factors considered that are not discreet and that could involve multiple body systems. This design precludes a clear understanding of their relationship when more than one are present. For example, lower extremity disability, foot problems, and gait/balance abnormalities could all share the same underlying cause, such as a sprained foot or foot weakness secondary to a peripheral nerve pathology. It is also possible that they could have entirely distinct underlying causes, such as knee arthritis causing a lower extremity disability, toe arthritis causing a foot problem, and Parkinson's disease causing a gait/balance abnormality. The data presented in Figure 2.9 do not permit an adequate interpretation of how the mechanisms underlying these risk factors may, or may not, be interacting with each other to produce the result of greater risk.

Another layer of complexity is revealed when critically evaluating attempts to categorize fall risk factors (Fabre, Ellis, Kosma, & Wood, 2010). Categorization for some fall risk factors is ambiguous. Medication use has been listed as a fall risk factor that is extrinsic. This extrinsic categorization seems perfectly reasonable when medications are outside of the body. But an extrinsic categorization is hard to reconcile at the point where medications actually become incorporated intrinsically with the bodily systems of older adults, and where the interactions occur that actually produce increased risk. Categorizing the use of a walking aid or footwear as intrinsic or extrinsic risk factors may be ambiguous. The decision of one over the other may be arbitrary since both are at the very interface of individual and environmental interaction.

Absolute categorization of fall risk factors into intrinsic and extrinsic is false at a more fundamental level. If postural stability is the motor behavior that enables the older person to avoid a fall, then individual and environment are inseparably intertwined. Recall that postural stability is the ability to control one's center of gravity with respect one's base of support. Accordingly, the older individual who intends to maintain balance is constantly and inextricably interacting with the external force of gravity and other possibly destabilizing environmental forces. Any fall risk factor intrinsic to the individual older person is by default a fall risk factor to an individual-environmental relationship. With respect to postural stability or instability, the absolute division of fall risk factors into categories of intrinsic and extrinsic, or individual and environmental, does not align with the very nature of how older people balance.

Taken together, the underlying mechanisms contributing to falls are complicated, dynamic and still rather unpredictable in their effects; they are associated with a wide-range of multiple bodily systems and innumerable environmental factors that defy placement into absolute intrinsic or extrinsic categories.

Falls Prevention.

For the purpose of describing conventional strategies for preventing falls in older adults, and the conceptual framework upon which these strategies rely, an often cited systematic review by the Cochrane Collaboration authored by Gillespie, et al. (2013), is summarized here (Gillespie et al., 2013). A total of 159 randomized trials of interventions for preventing falls in community-dwelling older adults aged 60 years or older were included in this systematic review. The review analyzed falls prevention interventions using two functional measures. The first was a rate ratio (RaR) comparing the rate of falls per person per year between intervention and control groups. The second functional measure was a risk ratio (RR) based on the total number of fallers in each group. Only trials that reported data relating to these two functional measures of fall rate and fall risk were included in the review. Sample sizes of the trials ranged from 10 to 9,940 with 230 as the median sample size.

Interventions in the Cochrane review were divided into three categories: single, multiple and multi-factorial. Single interventions involved only one major category of intervention (e.g., exercise, medication modification, or vision treatment). Multiple interventions included two or more major categories of intervention that were given to all participants in the study. Multi-factorial interventions consisted of two or more major categories of interventions but individual participants received different interventions depending on their identified risk factors. Some of the Cochrane review's main findings are presented below.

Exercise was categorized as a single intervention but sub-divided into either multi-category or single category exercise programs. Single category exercise interventions included:

- Programs intended to train only gait, balance or function;
- Resistive exercise programs intended to improve muscle strength;
- Three-dimensional programs, defined as "constant repetitive movement in all three spatial planes (Gillespie et al., 2013, p. 8)" including Tai Chi and square stepping; and
- General physical activity, such as walking groups.

Multi-category exercise interventions included two or more single exercise interventions (e.g. balance *and* strength training) and were found to reduce both rate and risk of falls compared to controls. Tai Chi reduced risk of falls and bordered on significantly reducing the rate of falls. In sub-groups of participants that were not at high risk of falling, Tai Chi did reduce the rate of falls significantly. Single exercise interventions of only balance, gait or functional training reduced the rate but not the risk of participant falls versus controls. Strength training alone failed to reduce rate or risk of fall significantly. Walking programs as a single exercise category also did not conclusively reduce risk or rates of falls at a level of acceptable significance. Overall, exercise significantly reduced risk of fracture. In sum, exercise as a single category intervention has been demonstrated to effectively prevent falls in older adults who live in the community.

Other single category interventions analyzed by the Cochrane review were also effective in reducing the risk and/or rate of falls. Home safety modification, for example, reduced the rate and risk of falls especially in those individuals with high fall risk who were treated by an occupational therapist. Gradual withdrawal of psychotropic medication reduced rate but not risk of falls. However, a program for primary physicians focusing on modifying patient medications reduced fall risk. Certain shoe modification and podiatry programs were found to reduce fall rate. An intervention that replaced multifocal lenses with single lenses reduced the number of falls in the subgroup who were regularly active outdoors.

Some single interventions had no significant effect of fall risk or rate, including Vitamin D, cognitive behavioral therapy, and falls education. One intervention in which 616 participants' vision problems were treated paradoxically *increased* fall risk and fall rate in the group. One possible explanation given by the authors was that many participants had major changes in prescriptions and were more vulnerable to falling while adjusting to the changes (Cumming et al., 2007). Multi-factorial interventions, in which treatment is based on the individual's identified risk factors, reduced rate of falls.

The Cochrane review contributed much toward understanding the effectiveness of falls prevention programs in older community-dwelling adults. It has potential to greatly influence what kind of programs healthcare providers prescribe, in what programs individuals themselves decide to participate, and the direction and funding of falls prevention research in the future. For these reasons it is essential to evaluate the conceptual framework by which a review of such a large and influential body of falls research is understood. Examining the implicit assumptions of the Cochrane review gives clues about the conceptual lens that shapes it.

An implicit assumption guiding the interventional strategies systematically reviewed by the Cochrane Collaboration is that falling is the result of abnormality in one or more underlying components as identified by individual fall risk factors. This is evident in the classification of falls prevention programs into discreet categories of single, multiple, and multi-component interventions. This assumption suggests that to effectively prevent falls requires implementing one or more discrete and targeted interventions to reduce underlying fall risk components. This is plainly illustrated by the Cochrane Collaboration's determination that Tai Chi is a single category exercise intervention properly classified as three-dimensional movement training. This categorization reduces Tai Chi's potential contribution to fall prevention to a focus on narrow movement characteristics that address mobility-related falls risk factors. It is true that Tai Chi movement is three-dimensional, but this is a gross simplification compared to how Tai Chi communities themselves describe the integrative complexity of the characteristics of movement, and the goals of their art (Wayne & Fuerst, 2013; Yang et al., 2011; Yang, Grubisich & Feng, 2005).

The point here is that the Cochrane review seems to approach the problem of falls in old age by addressing components of the problem rather than the full gestalt of an older person falling. Its approach identifies and addresses the presence of component risk factors associated with falling but does not look at the problem at the level of a whole system as it behaves across time and space. It seems to assume that a fall results from the sum of one or more component risk factors and that falls prevention is a matter of normalizing the values of these component risk factors (e.g., measures of muscle strength, range of motion, visual acuity, single leg stance time, blood pressure). This reductionist model is linear in its thinking. It assumes that falling is explained and resolvable by correcting its component parts.

A reductionist approach contrasts with a systems-oriented approach, which acknowledges that properties arise from the system as a whole in a manner that cannot be explained solely by its component parts. Whereas a reductionist interventional approach focuses on normalizing static values of one or more single factors based on the assumption that outcomes are additive, a systems-oriented approach takes into account the dynamic and non-additive behaviors of a whole system in which components are interacting with each other (Ahn, Tewari, Poon, & Phillips, 2006). Table 2.4 summarizes differences between key characteristics of a reductionist versus a systems-oriented approach (Ahn et al., 2006).

The linkages between interacting factors affecting fall risk are changing, not only by effects of age-related processes occurring in the individual, but also by socially determined influences related to cohort, and by historical influences related to the period during which the individual is living. A reductionist approach to fall risk and the problem of falls does not take into account these dynamics.

As an alternative to a reductionist approach toward understanding the problem of falls in older adults, Chapter 3 presents a systems-oriented conceptual framework that is consonant with the holistic nature of postural instability in old age.

Table 2.1. Categorization of Fall Risk Factors.

	Intrinsic Risk Factors	Extrinsic Risk Factors
Non-Modifiable Factors	Age Sex Race Chronic Disease	Gravity
Modifiable Factors	Acute Illness Gait/Mobility Impairment Strength Impairment Visual/Sensory Deficits	Medications/Side Effects Footwear Home Hazards Community Hazards

Source: Expanded from Fabre, Ellis, Kosma, & Wood (2010).

Table 2.2. Intrinsic Risk Factors for Falling among Community-Living Older Adults.

Intrinsic Fall Risk Factors
Previous Falls
Balance Impairment
Decreased Muscle Strength, upper or lower extremity
Visual Impairment
Gait Impairment, Walking Difficulty
Depression
Dizziness or Hypotension
Functional Impairment in Activities of Daily Living or Instrumental Activities of Daily Living
Age >80 years
Female
Low Body Mass Index
Frailty, defined as three or more of the following: unintentional weight loss (10 lbs. in past year), self-reported exhaustion, weakness (grip strength), slow walking speed, and low physical activity
Urinary Incontinence
Cognitive Impairment
Diabetes
Pain
Fear of Falling
Parkinson's Disease
History of stroke
Use of Walking Aids
Palmomental Reflex

Sources: Compiled from: Deandrea et al. (2010); Fried, et al. (2001); Hanlon, Landerman, Fillenbaum, & Studenski (2002); Koepsell et al. (2004); Menz, Morris, & Lord (2006); Nicklett, & Taylor (2014); Tencer et al., 2004; and Tinetti & Kumar (2010).

Table 2.3. Extrinsic Risk Factors for Falling among Community-Living Older Adults.

Extrinsic Fall Risk Factors	
Medications:	>4 Medications
	Psychoactive Medication Use
Footwear:	No Shoes
	High Heels (>2.5 cm.)
	Lack of Slip-Resistant Soles
	Inadequate sole-to-surface contact area
Indoor Lighting Hazards:	Inadequate Lighting
	Glare
	Shadows
	Poor Access to Switches
Indoor Flooring Hazards:	Throw Rugs
	Slippery/High Gloss Flooring
	Potentially Confusing Flooring Patterns
	Raised Transition Strips at Thresholds
	Poor Contrast at High Thresholds
	Loose Carpet
Indoor Furnishing Hazards:	Unstable Furniture
	Furniture Obstructing Pathways (e.g. coffee tables)
	Low-level Furniture
	Soft Chairs without Arms or High Back
	Poorly Fitting Chairs
	Poor Contrast Between Furnishing, Walls and Floors
	Inadequate Cabinet Heights
Stair Hazards:	Lack of Handrails
	Poor Contrast between Stair Tread and Riser
	High/Steep Steps
	Worn Treads
	Lack of Intermediate Landings
Bathroom Hazards:	Lack of Grab Bars
	Lack of Non-Skid Mats
	Inadequate Toilet Seat Height
Other Indoor Hazards:	Clutter
	Pets
Outdoor Sidewalk/Street/Pavement Hazards:	Cracks
	Tree Roots
	Poorly Marked Curbs/Steps
	Lack of Snow/Ice Removal
	Ostacles (e.g., flower boxes, trash cans)

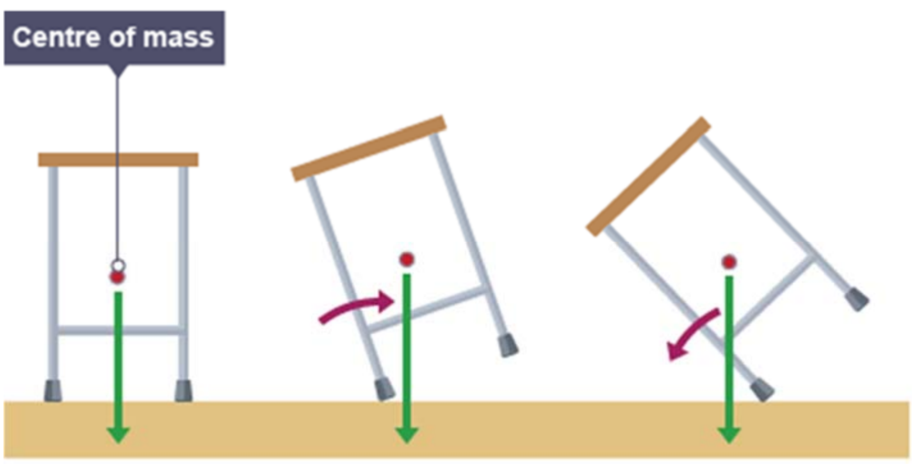
Source: Compiled from: Dickinson, Shroyer, Elias, Curry, & Cook, (2004); Fabre, Ellis, Kosma, & Wood, (2010); Koepsell et al., (2004); Menant, Steele, Menz, Munro, & Lord, (2008); Menz, Morris, & Lord, (2006); and Tencer et al., (2004).

Table 2.4. Reductionism versus a Systems-Oriented Approach.

Characteristic	Reductionism	Systems-Oriented Approach
Principle	Behavior of a biological system can be explained by the properties of its component parts	Biological systems possess emergent properties that are only possessed by the system as a whole and not by any isolated part of the system
Metaphor	Machine, magic bullet	Network
Approach	One factor is singled out for attention and given explanatory weight of its own	Many factors are simultaneously evaluated to assess the dynamics of the system
Critical Factors	Predictors/associated factors	Time, space, context
Model Characteristics	Linear, predictable, frequently deterministic	Non-linear, sensitive to initial conditions, stochastic (probabilistic), chaotic
Medical Concepts	Health is normalcy	Health is robustness
	Health is risk reduction	Health is adaptation and plasticity
	Health is homeostasis	Health is homeodynamics

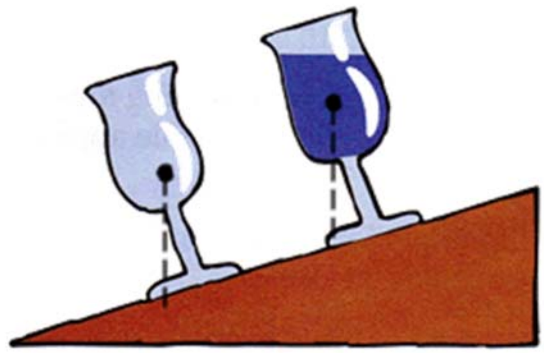
Source: Adapted from Ahn et al. (2006), Table 1 (p. 0710).

Figure 2.1. Center of Gravity of Table in Three Different Positions of Tilt.



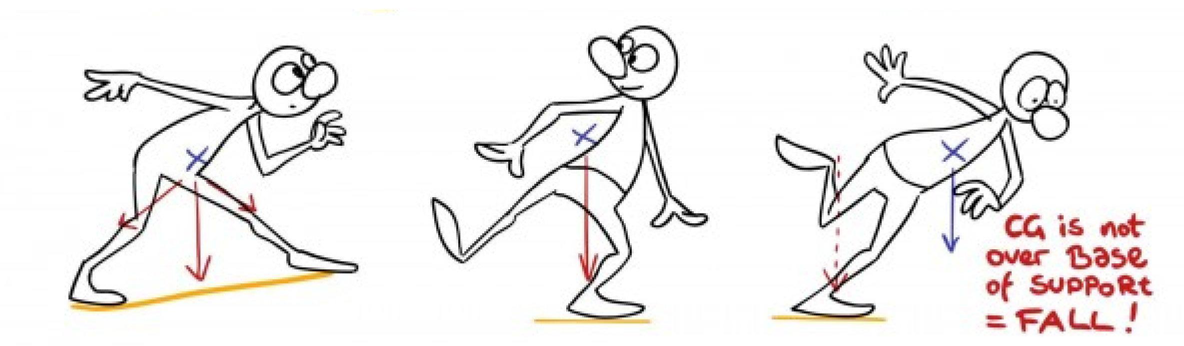
Source: Taken from BBC GCSE Bitesize, (2016).

Figure 2.2. The Wine Glass with the Higher Center of Gravity is Less Stable.



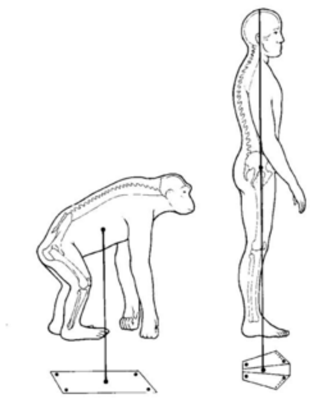
Source: Taken from: Chapter 10-Center of Gravity (Stanbrough, 2016)

Figure 2.3. Human Stability and Instability in Standing.



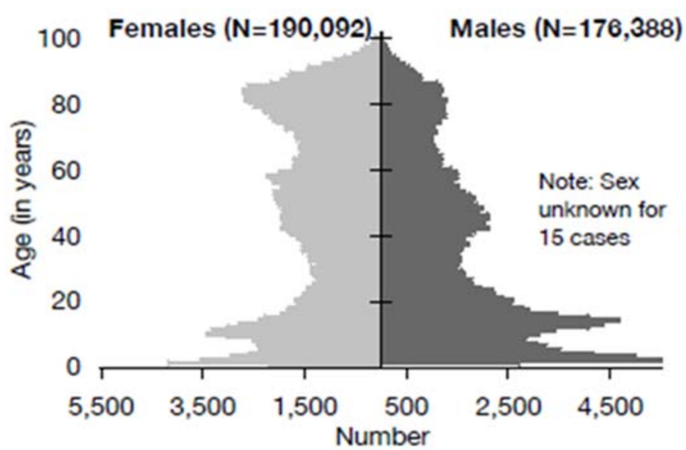
Source: Taken from Englander (2013).

Figure 2.4. Inherent Instability of Bipedal Humans versus Quadruped Animals.



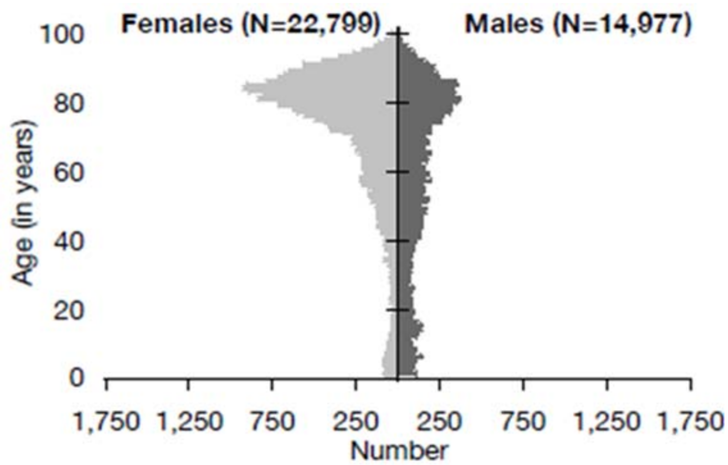
Source: Taken from Lumbard (2014).

Figure 2.5. Emergency Department Visits in Ontario, Canada for Unintentional Falls in FY 2005/06.



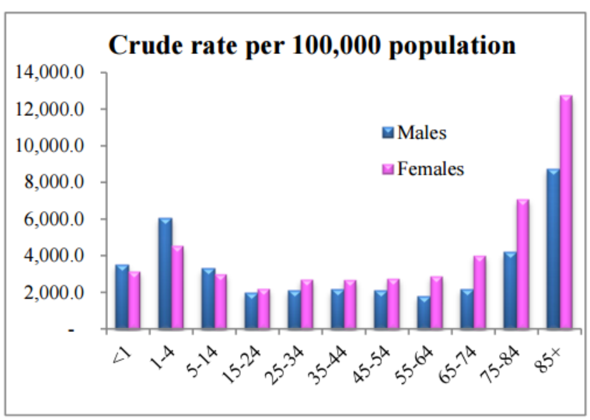
Source: Taken from Falls Across the Lifespan: Evidence-Based Practice Synthesis Document (2008).

Figure 2.6. Hospitalizations for Unintentional Falls in Ontario, Canada in FY 2005/06.



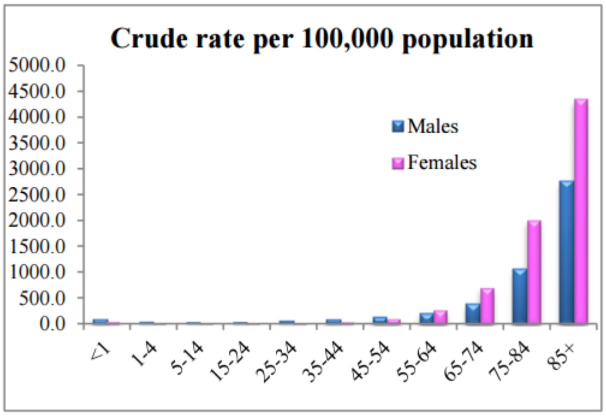
Source: Taken from Falls Across the Lifespan: Evidence-Based Practice Synthesis Document (2008).

Figure 2.7. Emergency Department Visits in Kentucky for Unintentional Falls in 2013.



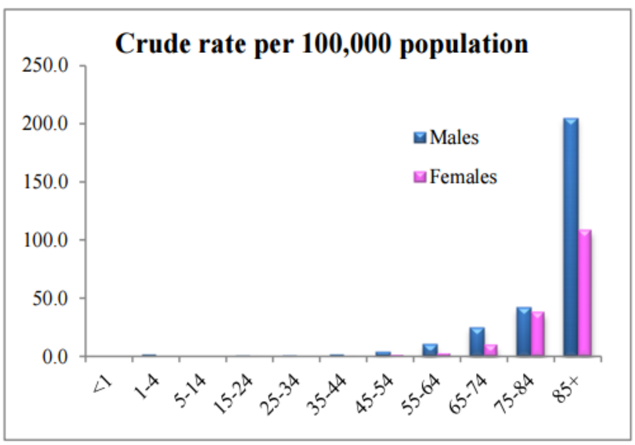
Source: Taken from "Kentucky Injury Indicators 2013" (2016).

Figure 2.8. Hospitalizations in Kentucky for Unintentional Falls in 2013.



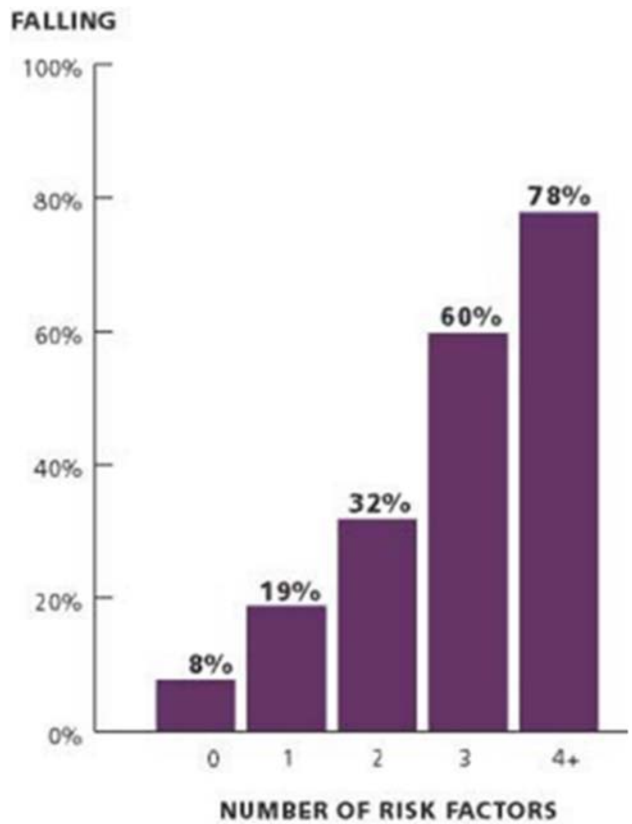
Source: Taken from "Kentucky Injury Indicators 2013" (2016).

Figure 2.9. Fatalities in Kentucky Caused by Unintentional Falls in 2013.



Source: Taken from "Kentucky Injury Indicators 2013" (2016)

Figure 2.10. Occurrence of Falls According to the Number of Risk Factors.



Source: Taken from Tinetti, Speechley, & Ginter (1988), Figure 1. (p. 1705)

Chapter 3: A Systems Approach

An implied assumption of conventional fall prevention strategies is that the problem of falls is reducible to one or more component fall risk factors. This chapter calls into question this linear reductionist approach because it corresponds poorly to the holistic nature of human postural control. In the course of arguing for a systems-oriented approach to the problem of falls, it will be necessary to confront a current controversy among theorists about the essential character of human postural control, and motor behavior in general. The problem of falls will be re-framed as that which arises from a complex dynamic system. Tai Chi will serve as an example of a systems-oriented approach for optimal postural stability into old age.

The Nature of Human Motor Behavior

There is a fundamental disagreement among contemporary motor control theorists about the essence of human action. Current theories driving motor behavior research have been described as belonging to one of two opposing camps: *representational* or *anti-representational* (Kelso, 1982).

Representational Theories. Representational conceptual models have dominated motor behavior research (Kelso, 1982). They came about in cognitive science to interpret the inner operations of the mind occurring between stimulus and response that had largely been ignored by behaviorist psychologists. Representational theories assume mental operations between stimulus and response are computational, typically occur in the brain, and "involve operations over symbols, where these symbols are entities with a representational content and an arbitrary connection to that which they represent"

(Shapiro, 2011, p.14). In other words, the human brain is like a general purpose computer or a symbol-manipulating device, and human thinking is thought processes like the processes which occur in a computer. From a representational research perspective, the goal is to understand the programs that run the computational mechanisms of the mind (Shapiro, 2011)

A core representational concept in motor control is the motor program, defined as an abstract representation of a movement sequence stored in memory (Schmidt, 1982a; Schmidt, 1982b). The concept was developed from the *engram* proposed by Nikolai Bernstein (Latash, 2012).

Bernstein thought engrams were stored memories that were recalled when coordinated movement was required. He proposed that engrams encoded salient features of movement which could be scaled in magnitude and time. He demonstrated their existence by noting the remarkable similarity in writing the same word written with dominant and non-dominant hands and other body parts, despite the use of entirely different joints, muscles and areas of the body (Latash, 2008b, 2012). Figure 3.1 depicts the word "Coordination" (in Russian) written by Nikolai Bernstein with the pencil grasped by the dominant hand, non-dominant hand, attached to dominant and non-dominant elbows, to the right and left feet, and gripped with the teeth. The similarity of the of writing samples at different scales suggest that learning a skill, such as writing, is not a matter of learning a program of specific commands to particular muscles, but rather a more abstract pattern (in this case a topological pattern) that is transferrable to coordinated movement in disparate areas of the body (Latash, 2012). [Bernstein used the term "topology" to denote "the whole of the *qualitative* characteristics of space configurations and of the form of movements in contrast to the quantitative, metric ones (Whiting, 1984, p. 102).”]

In the 1970’s Bernstein’s idea of engram became the basis for the concept known as the Generalized Motor Program (GMP). Like the engram, the GMP was associated with learning abstract patterns of the spatial and timing relationships of a movement pattern, and was stored as memory in the central nervous system. Later theorists took a major break from previous conceptions and assumed that the GMP encoded not only abstract features of movement, but also specific peripheral mechanical variables, such as motor unit firing, muscle forces and joint torques. This notion of the GMP served as a conceptual precursor of contemporary Internal Models, a theoretical construct heavily influenced by control theory and engineering (Latash, 2008a). Internal Models are essentially neural representations in the central nervous system that function to model the outside world and the body so that movement can be computed or predicted. Internal Models assume that the peripheral variables of movement (muscle contractile forces, joint torques, motor unit activation patterns) are all pre-computed, and the perceptual consequences are predicted, by neural structures in the brain before a movement starts (Latash, 2012).

The Implausibility of Representational Theories of Motor Behavior. Contemporary representational models of human motor behavior are disputed on both pragmatic and philosophical grounds. Turvey, Fitch & Fuller (1982) do this by way of a “straw man” argument and clever use of a theory of motor control once popular in the 19th century (Turvey, Fitch, & Tuller, 1982). In Figure 3.2 there is a “little man” or homunculus who has access to motor plans stored in memory. When coordinated movement is required, the homunculus executes a selected motor plan as though it were a musical score played on the brain's cortical keyboard. The specifics of the executed motor plan are likened to musical notes being played on various instruments of the movement system, depicted in Figure 3.2 as motor units, alpha-gamma links, muscles or joints (Turvey et al., 1982). Like contemporary representational theories of motor behavior, the homunculus in the brain must have motor plans in memory for all possible movements, and all the peripheral details of movement must be pre-computed by a motor plan before the selected movement is executed.

This scenario is extremely unlikely because of the motor system's inherently large number of *degrees of freedom*, independently variable factors that affect the range of possible states of a system. The greater number of degrees of freedom, the greater the number of possible states in which a system may exist. Estimating the number of degrees of freedom in a simple coordinated movement of the human arm demonstrates the enormous amount of computation necessary. Coordinated movement in a single arm requires an executive controller in the brain to determine values for seven degrees of freedom of involved joints (two in the wrist, one in the forearm, one in the elbow, three in the shoulder), twenty-six degrees of freedom of involved muscles (one degree of freedom per muscle), and 2600 degrees of freedom of involved motor units (conservatively estimating 100 motor units per muscle) (Turvey et al.,1982). The neural controller would also need to compute for variability related to the context of movement, such as anatomical sources of variability (variability of an individual muscle's function on a joint movement), mechanical sources of variability (non-muscular forces, such as gravity, momentum), and physiological sources of variability (peripheral neural influences on muscle activity).

Finally, there remains a storage problem for the brain. Does the brain have the capacity to store pre-computed motor plans for every possible movement? This is improbable, in light of the motor system's more than 2600 degrees of freedom in the human arm alone, not including the hand. Imagine a steering control system of a car that has these four degrees of freedom: one steering wheel for each its four wheels. Controlling all four steering wheels would make steering that car very difficult. Controlling over 2600 independent degrees of freedom is monumental in comparison (Turvey *et al*., 1982).

The representational idea of a motor program has been rejected on philosophical grounds because it necessarily implicates an intelligent controller. Any representation is something that represents for or to someone, and this requires a user or interpreter that is external to it (Dennett, 1981). A motor program implies a user with intelligent attributes (goals and interests) of the human whose behavior it attempts to explain, and has been likened to a homunculus inside the brain. The problem with a homunculus strategy to explain goal-directed human behavior is that it does not really explain it. It only deflects it, leading to an infinite chain of regression wherein a proposition's truth relies on the truth of another, which in turn relies on the truth of still another, and so on (Dennett, 1981; Kelso,1982).

Representational theories are extremely implausible explanations for how human motor behavior arises. A systems-oriented conceptual model is anti-representational because it avoids the intractable pragmatic and philosophical problems of representational theories by explaining the order and properties observed in human motor behavior without invoking a homunculus-like central authoritarian controller (Shapiro, 2011; Kelso, 1982). Rather than referring to representations in the brain to explain human actions, a systems approach looks to the way a system is designed, and the *constraints* on the system that make the emergence of movement possible (Kelso, 1982).

A Systems-Oriented Approach to Motor Behavior.

A *system* is "a collection of components that interact or that have some functional relationship to each other, so that the collection possesses a wholeness of unity" (Riley, et al., 2011, p. 6). A *dynamic system* is "any system which is comprised of a number of elements that cooperate to cause change in the system over time (Perry, 1998, p. 4)." Dynamic systems theory (DST) is the name systems-oriented researchers in the field of motor control have given to this approach, a designation taken from the larger area of study of how complex dynamic systems change over time (Kamm, Thelen & Jenson, 1990; Kelso & Tuller, 1984; Perry, 1998; Shumway-Cook & Woollacott, 2012). Although dynamics as a field of study deals with any system that changes over time, dynamic systems theorists are particularly concerned with the behavior of systems that are *non-linear* at a level of complexity that makes the system behavior unpredictable (Latash, 2012; Strogatz, 2015).

A linear dynamic system is one in which the component parts of the system interact additively, such that the behavior of the whole system at some future time can be fully described by the sum of the parts. That is, if we know the initial conditions of the parts of a linear dynamic system, then each part can be solved separately and combined to solve what the state of the system will be at some time in the future (Strogatz, 2015).

A *non-linear* system has parts that interact with each other multiplicatively, although it may also include linear interactions as well. In non-linear dynamic systems of a certain complexity, a small change in the initial conditions can produce disproportionate changes in the future behavior of the whole system (Kuznetsov, Bonnette, & Riley, 2013). This high-sensitivity to the initial conditions of its components, can make solving the future behavior of a non-linear system impossible. This feature of unpredictability in non-linear systems is also referred to as *chaos* (Strogatz, 2015). Non-linear systems also enter in and out of stable behaviors referred to as *attractor states* (Shumway-Cook & Woollacott, 2012; Strogatz, 2015).

The principle of *self-organization* is foundational to DST. Self-organization occurs spontaneously in dynamic systems when individual components of a system are coupled and interact with each other to behave collectively and in an orderly manner (Shumway-Cook & Woolacut, 2012). Self-organization is found throughout nature in systems that are dissipative and far from equilibrium. In the inanimate world, self-organizing systems form weather patterns, planetary systems, and snowflakes. In the animate world they result in growth of tree branches and leaves, kidney function, and the swarming behavior of birds and fish. Self-organization is also found in economic and political behaviors (Haken, 2008).

A self-organized system functions with no outside controller. This feature is a key difference in how the nature of human motor behavior is conceptualized by DST compared to a representational perspective. Figure 3.3 illustrates the conceptual differences between self-organized and externally-organized systems in postural control that distinguish dynamic systems from representational theoretical approaches. The hand-controlled marionette is an example of the perspective of an externally-controlled system. For the marionette to assume its posture, the hand must control its many degrees of freedom.

Figure 3.4 illustrates the perspective of a self-organized system. The many degrees of freedom are reduced by the coupled relationship of its component parts. There are less strings for the same number of parts as the externally-controlled marionette. No external controller is needed for the marionette to assume its posture (Turvey, 1990).

A systems-oriented approach views postural control as emergent behavior of a self-organized, dynamic system. It seeks to understand how the vast number of possible states of the postural control system are constrained so that a posturally stable behavior can emerge. Important to this approach is the concept of *synergies*, also known as *coordinative structures* (Bernstein, 1967; Kelso, 2009; Latash, 2008; Turvey, 1990)

"Synergy" has been defined as "groups of motor system degrees of freedom (e.g., joints, muscles, or motor units) that are coupled to act as a single, functional unit to achieve and maintain a behavioral goal" (Riley, Kuznetsov & Bonnette, 2011, p.7). Synergies do two things that make control of a high-dimensional motor system simpler. First, synergies provide *Dimensional Compression* by coupling the many available degrees of freedom at the component level of organization (such as joints, muscles or motor units) in order to *constrain* or reduce degrees of freedom at the system level. This remedies the computational difficulties associated with having to control every variable separately (Turvey et al., 1982). Second, synergies result in *Reciprocal Compensation*, which refers to how degrees of freedom within a synergy compensate for one another to stabilize the performance of the motor task, even when variations are occurring in degrees of freedom at the component scale. Reciprocal compensation allows greater variability in how a task is successfully performed, by stabilizing the performance without need of authoritarian centralized control (Riley et al., 2011).

Synergistic control of a motor control system with more available degrees of freedom is a more adaptable system because there are more possible configurations available to achieve a motor task. Suppose that when playing basketball, we only had only one degree of freedom in the joint movements of the arm, elbow flexion/extension, and that this was sufficient to make a goal playing basketball. Even though one degree of kinematic freedom is enough to get the basketball in the hoop, this severely restricts the possible joint configurations by which to successfully make the shot. Instead, there are at least seven degrees of joint freedom in the human arm, many more than needed and with many more possible joint configurations that could be used to score. The benefit of having so many more joint degrees of freedom in the arm is that when they are linked together for the purpose of making a shot, there is greater adaptability in changing the joint configurations as needed depending on the external circumstances. When a defender bumps the forearm and disrupts the elbow joint angle during a shot, the synergistic relationship of the entire arm allows the angles of the other joints to compensate to make the shot.

This benefit of high dimensionality in the motor control system is known as the "principle of abundance," a positive response to negative connotations associated with the so-called "problem of motor redundancy," also known as the "Bernstein problem" (Gelfand & Latash, 1998, 2002; Latash, 2010, 2012; Latash et al., 2007).

Systems-oriented approaches also view the postural control system as extending beyond the individual, an idea influenced by a perspective inspired by, and developed from, the work of James Gibson in the 1960's called The Ecological Approach. The Ecological Approach is marked by an appreciation of how an organism's action is fundamentally oriented to, and constrained by, the environment (Gibson, 1966; Lee & Young, 1986). According to an Ecological Approach, purposeful action relies on, and is tightly coupling with, goal-specific perceptual information within a specific environment (Reed, 1982). Important to the individual organism is the perception and use of what Gibson referred to as "affordances," or any possible behaviors for an organism in a given environment (Gibson, 2014; Riccio & Stoffregen, 1988). In many environments, stance is an affordance for humans. Human stance may afford other behaviors, such as locomotion by walking or running, or manipulation of objects at greater height. Affordances themselves offer opportunities for the individual. Affordances also constrain behavior because there are a limited number of affordances for an individual in any given environment (Riccio & Stoffregen, 1988).

Consonant with The Ecological Approach is Newell's (1986) classification of three general kinds of interacting constraints from which coordinated movement arises: the *environment*, the *individual*, and the *task* (Newell, 1986). In the context of environmental gerontology, Iwarsson (2004) proposed a similar classification of interacting components to explain functional performance of the older adult (Iwarsson, 2004). In Newell's model, *environmental* constraints on motor behavior are those existing outside of the individual, such as gravity, support surface, ambient temperature, or light (the relationship of environmental constraints and fall risk is reflected in Table

2.3). *Individual* constraints are those intrinsic to the individual (such as neurons, motor units, muscles, or joints) happening at every level of analysis. *Task* constraints relate to the goal of the activity being performed, but may include any imposed rules of movement or specific tools or machines being used (Newell, 1986). According to DST, motor tasks are goals to meet, or problems to be solved, and the movement strategies produced by the system are the solutions (Perry, 1998).

Newell's (1986) classification of constraints on motor coordination apply to postural control. Individual attributes shape the strategy that a postural control system generates. For example, brain aging associated with reduced automaticity of walking may produce a postural stability response of slower gait velocity (Liu, Chan, & Yan, 2014). Fear of falling may promote a postural control strategy of avoiding that which may be more stability-challenging for the older person, such as walking outside of one's home on variable terrain.

Task demands and environmental conditions shape the requirements of postural stability, and therefore shape the strategy of the postural control system (Horak, 2006). The task of sitting, for instance, has less stability demands than standing, which has less and different stability requirements than walking while reading a book. The requirements of postural stability also change according to the environment. The stability requirements in standing vary depending on whether one is standing on a moving bus, against strong winds, or on an icy incline.

Systems Approach to Postural Control.

Woollacott & Shumway-Cook (2012) incorporated concepts from both dynamic systems and ecological theories of motor control, and call their theory of motor control simply, Systems Approach (Shumway-Cook & Woollacott, 2012). They adopted Newell's idea that movement emerges from interacting constraints of individual, task and environment, and Gibson's idea of tight perception-action coupling (Gibson, 1966; Newell, 1986).

Figure 3.5 is a schematic conceptualization of a Systems Approach. Movement and postural control emerge from a complex dynamic system of interacting constraints of individual, task and environment. Attributable to the individual are interacting constraints of perception, action and cognition. Perception is the conscious and unconscious processing that integrates raw sensory input into information that is interpreted and given meaning, as it relates to movement afforded by a given environment. Action refers to the particular activity associated with any movement, such as reaching, standing, sitting, walking, running, or jumping. Cognition refers to the cognitive processes that underlie the intent of purposeful movement, such as attention, motivation, emotion, planning, and problem solving (Shumway-Cook & Woollacott, 2012). Constraints of the individual are perceptual and involve action systems that continually interact and influence each other at multiple levels of a cognitive processing hierarchy. Perception-action-cognition refers to constraints attributable to the individual yet still strongly coupled with the environment and the goal of the motor task.

Systems Approach provides an explanatory framework for changes in postural stability observed during various sensory conditions. Computerized dynamic posturography (CDP) is used by researchers to determine the contributions of the visual, vestibular and musculoskeletal sensory systems on postural stability. As will be explained in the next paragraph, by testing six different sensory conditions, the Sensory

Organization Test (SOT) is performed using CDP to measure an individual's ability to use or suppress each of three sensory systems in order to maintain standing postural stability. Among the six conditions, the task is to maintain balance in standing, the environment is altered in order to manipulate how visual or somatosensory input and the individual's perceptual and action systems interact through cognitive processes to generate a postural response.

In condition 1 the individual stands on a stable surface with eyes open so neither visual nor somatosensory input is manipulated. In conditions 2 and 3 visual information is either removed completely, or manipulated by having the visual screen sway with the individual producing an illusion that the person is not swaying. Conditions 4 through 6 are the same as 1 through 3 except the supporting surface moves with the individual's sway, thus providing unreliable somatosensory information. The six conditions are illustrated in Figure 3.6.

Evidence from CDP research on normal healthy adults suggests that cognitive processes in the central nervous system adjust the importance, or weight, of a sensory input (visual, somatosensory, or vestibular) being manipulated by environmental changes, depending on its relative accuracy in orienting the body in space. In other words, through perceptual and cognitive processing of sensory information, more weight is given by the central nervous system to more reliable sources of sensory input. This perception-action-cognition interaction enables a successful postural response to emerge given the constraints of environmental conditions and the demands of the task (Nashner, 1982; Peterka, & Black, 1989; Woollacott, Shumway-Cook & Nashner, 1986).

Postural control in dual-tasking research reveals that postural stability is cognitively constrained by limited attentional resources. Although maintaining balance while standing and walking is typically an automatic process, the attentional demands required may be affected by the demands of a secondary cognitive task. This secondary task is known as a dual task, in a so-called dual task paradigm. When motor or cognitive performance levels decline because both a motor task (such as walking) and a cognitive dual task (such as counting backward from 100 by 7's) are performed simultaneously, the effects are referred to as dual-tasking interference or dual-task costs. Dual-tasking costs of performing a secondary attentional task that manifests as decreased gait speed or reaction time occur in both young and old healthy adults, but generally increase with age (Yogev-Seligmann, Hausdorff, & Giladi, 2008).

Not all dual tasks cause interference. When participants stood while performing a dual cognitive task of fixing their gaze on a target while counting letters in a block of text (versus looking at a blank target), standing postural stability was enhanced. This supports the idea that visual information is used by the central nervous system as part of an integrated perception-action system in which postural control is modulated (disrupted or enhanced) according to the goal of the task being performed (Stoffregen, Pagulayan, Bardy, & Hettinger, 2000).

One study suggests a link between executive cognitive function and postural stability in older adults (Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010). The study evaluated and tracked 201 participants without a history of falls for two years for changes in executive function (specifically including tests of response inhibition) and an array of gait, mobility and other cognitive functions. Lowered indices of executive function and greater gait variability (gait speed, swing time variability) during dual task conditions were found to be predictive of future falls, while other measures of gait, mobility and cognitive function were not. Multivariate analyses suggested that gait ability under dual task conditions was a functional measure of, and interchangeable with, executive function as a predictor of future falls. Taken together, the results imply that falls in older adults that have been interpreted as having no specific cause ("I just fell down") may have been attributable to declines in executive function and attentional resources. A further implication is that cognitive training which targets executive functions, such as divided attention, may potentially reduce falls in older adults.

It has been proposed that normal aging-related structural and functional brain changes are linked to cognitive changes, which in turn can adversely affect motor control and learning in older adults (Fasano, Plotnik, Bove, & Berardelli, 2012; Liu, et al., 2014). Cognitive function and gait performance decline concurrently in old age as the brain ages. Aging of the brain cortex disrupts its neural integrity and function. The consequence is a reduction in the automaticity of movements, such as walking, and the older person must use more conscious control and attentional resources in order to walk without sacrificing postural control.

The link between gait performance and attentional resources is hypothesized to be the result of evolution of human bipedal locomotion, which placed spatial and other cognitive processing needed for vertical balance in the higher-functioning levels of the central nervous system, including the cerebral cortex. This conjecture is supported by a disequilibrium syndrome associated with a rare autosomal recessive disorder characterized by severe spatial deficits and an inability to walk bipedally, despite intact sensory, vestibular and motor coordination function (Skoyles, 2006).

Cognitive training in older adults may be a promising strategy for falls prevention. Although it has been unclear whether falls prevention programs shown effective for normal older adults are truly effective in those with dementia or cognitive impairment (Oliver et al., 2007), there is evidence that cognitive interventions improve gait velocities with and without a dual cognitive task. Computerized cognitive training (while seated) significantly improves gait velocities in sedentary older adults (Verghese, Mahoney, Ambrose, Wang, & Holtzer, 2010). Dual-task training produces these same positive effects in older persons with balance impairment (Silsupadol et al., 2009). Preliminary evidence suggests that the failure of otherwise effective falls prevention programs to prevent falls in those with dementia and cognitive impairment may be because the programs do not address relevant cognitive constraints (Montero-Odasso, Verghese, Beauchet, & Hausdorf, 2012).

In summary, the Systems Approach is a reasonable conceptual model in which postural control is distributed, and emerges from, an individual-environment-task system. This conceptual framework avoids the practical and philosophical pitfalls associated with representational theories, and is consonant with the non-linear systems behavior that characterizes human action. Recent research supports the importance of cognition as a constraint shaping postural control, and may be under-appreciated among falls prevention strategies for older adults.

A Systems-Oriented Approach to Aging and Postural Instability in Old Age.

The concept of *homeostasis* dates back to Claude Bernard in 1865 and was later developed by Walter B. Cannon. It continues to be an essential principle in medicine by providing a model to explain how organisms successfully respond and adapt to stress by returning to equilibrium (Buchman, 2002). Influenced by modern dynamic systems thinking, Yates (2008) offers the term *homeodynamics* to describe the properties of biological systems characterized by a flexible *dynamic* stability necessary for adaptation to internal and external disturbances (Yates, 2008). Since the 1990s, the term homeodynamics has increasingly replaced homeostasis by virtue of the fact that internal physiology of complex biological systems is not static, is not in equilibrium, and interacts across various levels of organization (Rattan, 2012). Rejecting a reductionist disease-oriented approach in favor of a health-oriented systems approach to physiological aging, Rattan (2012, 2013) defines aging as an emergent expression of a failing homeodynamic system, rather than as the result of one or more age-related diseases. Aging, as described by Rattan (2012, 2013), is a shrinkage of *homeodynamic space*, using "space" as a metaphor that refers to the diminishing buffering capacity of an organism to adapt and maintain a healthy state in the midst of internal and external threats (Holliday, 2007; Rattan, 2012, 2013).

This homeodynamic buffering capacity is the organism's ability to counteract stress, repair and clean up any damage, and to constantly remodel and adapt to changes in its internal and external circumstances. Aging into old age is a process of gradual reduction in an organism's homeodynamic buffering capacity, and increasing probability of the emergence of age-related diseases and death (Rattan, 2012). Important here is that

Rattan's (2012) concept of aging is descriptive of properties at the systems-level, as opposed to reductionist descriptors of aging as one or more diseases, or deviations in static values of one or more bodily system components. Likewise, in systems-oriented thinking, "health" denotes "complete physical, mental and social well-being, as opposed to merely absence of disease or infirmity" (Rattan, 2013; World Health Organization [WHO], 2003).

A central goal of contemporary aging research has been to increase *health span*, defined as "…the period of maintained function and stress resistance that precedes debilitating decline" (Iwasa, Yu, Xue, & Driscoll, 2010, p. 490). An implication of Rattan's systems perspective with regard to this goal is that a robust homeodynamic adaptive capacity is that which leads to increased health span. Wellness promotion and disease prevention are more likely to accomplish this, rather than only treating disease and chronic health conditions associated with old age. Furthermore, increased health span is more likely when health-enhancing behavior is started early in life, or better yet, practiced lifelong. Another implication of Rattan's systems-oriented view of aging is that health is not reducible to a static state of disease absence (Rattan, 2012). Health is instead a systems-level *robustness* characterized by a large, resilient adaptive capacity against external and internal stressors (Ahn, Tewari, Poon, & Phillips, 2006; Rattan, 2012).

There are socio-economic implications of approaching health in old age from a systems-oriented perspective that deserve taking into account generational and historical life course influences. Given increasing life expectancies and an expanding proportion of older adults in the population, a disease-oriented approach is economically, socially and politically unsustainable when compared to social policies geared toward promoting long-term behaviors that reduce chronic health problems and compress the duration of end-of-life disability (Carnes, Olshansky, & Hayflick, 2013; Olshansky et al., 2011). This, of course, does *not* mean we should stop diagnosing and treating acute or chronic disease. Rather, a system-oriented approach suggests that the implications of a broader systems-oriented view be taken into account, and that we act accordingly.

The concept of aging as a gradual loss of systems robustness may be applied to the phenomenon of loss of postural stability in old age. Just as an individual's response to stress is more accurately described as a homeodynamic process rather than a homeostatic one, postural stability is also better understood as marked by change. Humans are never really still in standing: they constantly sway despite attempts to remain motionless (Loram, Gawthrop, & Lakie, 2006). Like the phenomenon of aging of the individual, the process of decreasing postural stability during old age may also be understood as an emergent property of a dynamic system. Seen from this perspective, postural instability in old age is the gradual reduction of a postural system's robustness that results in an increasing vulnerability and probability of the occurrence of a fall.

Thinking about the problem of falls as the result of a decline in robustness of a system (as opposed to abnormalities in one or more of its components) has implications similar to those of Rattan's conceptions of health in old age. If the goals are to increase the postural control system's health span and compress end-of-life disability, then they are more likely to be met by including and emphasizing long-term postural stability-enhancing behaviors. Recall that the bodily systems influencing postural control are reflected in the vast number and variety of intrinsic fall risk factors associated with those bodily systems (Table 2.2). It is not surprising then that long-term behaviors suggested for falls prevention in older persons, such as adequate physical activity, are similar to those for increasing health span of the individual in general (WHO, 2011, 2014). Given that fall risk may be susceptible to socially-determined cohort effects, and by influence of historical events, the suggestion that these long-term behaviors are best promoted throughout the life course is also unsurprising (Peel, Bartlett, & McClure, 2007).

If similar long-term health-enhancing behaviors improve the health span of both the postural control system, and the individual in general, then including and emphasizing social policies geared toward promoting prevention of chronic health problems in order to shorten end-of-life disability are favored when compared to an unsustainable illness-based strategy of solely prescribing falls interventions only after falls occur or when specific risk factors are recognized. This, of course, does *not* mean that we should stop identifying risk factors in older individuals and treating them. Instead, the implications of a broader, systems-oriented perspective are that falls prevention behaviors occur throughout the life course, and address many domains that promote a robust system of postural control.

In summary, the phenomenon of aging in old age involves the gradual loss of robustness in an individual's ability *as a whole system* to adapt to threats from within and from the environment in which the individual is embedded. Similarly, the phenomenon of postural instability in old age is explained by the gradual decline of the homeodynamic buffering capacity, or the robustness, of a postural control system's ability to adapt to intrinsic and environmental threats. The problem of falls, from a systems-oriented conceptual framework, emerges as the result of this decline in robustness at a level of description appropriate to a postural control system, rather than to the sum of its components. A systems-oriented perspective is a fitting lens for conceptualizing the problem of falls in old age. A systems-oriented strategy toward the problem is a holistic, long-term, and sustainable enterprise that takes into account life course influences, and which is aimed at promoting robustness in a postural control system so that the span of postural stability is increased, and the duration of postural instability is minimized at the end of life.

Postural Sway Variability, Robustness and Loss of Complexity.

Center of gravity (COG) is the downward vertical projection of gravity on the center of mass. The horizontal movement of one's center of gravity (COG) while standing is known as *postural sway*. Horizontal movement of the *center of pressure* (COP) on a supporting surface occurs during postural sway, but COG is not the same. COP is the point of application of the *total* force distribution that a standing person applies to a supporting surface (Shumway-Cook & Woollacott, 2012). It is believed that COG is a key variable by which the central nervous system controls posture (Scholz, et al., 2007). Shifting of the COP created by the activity of postural muscles produces change in the moment of force acting on the standing body, and is seen as the mechanism by which COG is controlled with respect a supporting surface (Latash, 2012). Even in quiet standing, the COP moves continually about a shifting COG producing unintentional sway (Latash, 2012; Shumway-Cook & Woollacott, 2012).

As one sways, the COP location moves on a two-dimensional support surface in accordance with that sway. Data on COP position is collected through a force platform upon which one stands. The COP position at any particular time on the two-dimensional horizontal platform surface is described by its values on anterior-posterior (forward-backward) and medial-lateral (side-to-side) coordinates. Data collected through a force platform during postural sway can be used to graph COP displacement across time. Figures 3.9 and 3.10 are graphs depicting COP displacement occurring during 30 seconds of postural sway while standing quietly that was decomposed into the anterior-posterior and medial-lateral directions of sway, respectively. Time-series data of COP displacement such as these are used to arrive at measures of *postural sway variability* that describe the patterns of change occurring in COP displacement across time.

The apparent irregularity in the pattern of peaks and valleys is typical of COP time series graphs and indicates a certain degree of variability that occurs during postural sway. The patterns of variability are clearly not a regular and predictable pattern of peaks and valleys as seen in sine waves. Neither are the patterns random, despite their apparent irregularity. Rather, the patterns of irregularity seen in Figures 3.7 and 3.8 lie on a continuum of complexity between the extremes of sine waves and random noise, and which is characteristic of non-linear dynamic systems (Goldberger, 1996).

The observable and measurable variability in COP displacement occurring with postural sway is an output known, in mathematical terms of dynamic systems, as *state dynamics*, one of three nested levels of dynamics by which all dynamic systems are described (Saltzman, Nam, Goldstein, & Byrd, 2006). Other physiological systems have observable and measurable state dynamics. Heart rate variability, respiration rate variability, and stride length variability are examples of physiological behaviors that are state dynamics of the cardiovascular, respiratory and gait systems, respectively. All exhibit non-linear behaviors in their state dynamics (Goldberger, 1996; Kuznetsov, Bonnette & Riley, 2013). A theoretical framework proposed by Riley et al. (2011) and outlined below, demonstrates how postural sway variability, as an observable output of a postural control system, may be analyzed to arrive at quantitative indicators of the robustness of an entire postural control system (Riley et al., 2011).

Three Levels of Dynamics. A key aspect to conceptualizing how postural sway variability leads to an understanding of the deeper structure of a postural control system comes from mathematical modelling of non-linear dynamic systems.

The indirect strategy employed here of investigating the whole postural control system by looking at the state dynamics of postural sway reflects the current limits in motor control science in mathematically modelling what happens at deeper levels of a postural control system (Riley, et al., 2011). These limits are understandable given the enormous complexity of a postural control system. However, the laws and rules of motion of simpler, and well-articulated models of non-linear systems (such as 2^{nd}-order systems of a damped mass-spring, a limit cycle pendulum clock, or n^{th}–order connectionist network systems) describe how all non-linear systems inform a theoretical framework of postural control, and how the state dynamics of COP displacement can explain the deeper structure of the whole system (Mitra, Amazeen & Turvey, 1998; Saltzman et al., 2006).

State, *parameter* and *graph* dynamics are the three types of variables by which all dynamic systems are completely described. A basic way in which these three levels of dynamics are related is that the graph and parameter dynamics determine the state dynamics of the system (Riley et al., 2011; Saltzman et al., 2006). For example, the anterior-posterior (A-P) and medial-lateral (M-L) positions of COP during standing are considered state variables for the postural control system. The dynamics of these state variables change quickly over time (Figures 3.9 and 3.10), and they do so according to parameter and graph dynamics.

In mathematical terms, parameter dynamics are the constants or coefficients in the dynamic system's equation and typically change at a slower rate than the state dynamics. Change in the muscle stiffness, or co-contraction, of muscles crossing a joint is an example of parameter dynamics in a postural control system that affects the behavior of postural sway state dynamics.

Graph dynamics are the "architecture" of the system and the slowest to change. In mathematical equations, the graph dynamics are altered if the coupling of state variables changes or if the parameter types change. Changes in the graph dynamics qualitatively alter the behavior of the system. A child learning to throw a ball who begins to employ other body segments beside the arm (such as the trunk and legs) is an instance of graph dynamics in a motor control system (Riley et al., 2011). Keeping both feet on the ground and moving at the hips or ankles as a response to a mild balance challenge, versus taking a step to maintain balance during a more forceful perturbation, is an example of graph dynamics in a postural control system.

Synergies. Typically, the underlying equations describing the deeper structure of postural sway dynamics are unknown, but the relatively easily observed and measured behavior of COP dynamics can be used to make inferences about the system's deeper aspects (Kuznetsov et al., 2013). According to the Embedding Theorem, a measure of a single-state variable is enough to understand the underlying dynamics of the whole system (Kuznetsov et al., 2013, Takens, 1981; Webber Jr & Zbilut, 2005). In other words, properties of a highly dimensional dynamic system can be reconstructed from a single dimensional time series. On the basis of the Embedding Theorem, non-linear methods are used to analyze the state dynamics of physiological systems in order to more fully understand the system as a whole. In the case of a postural control system, non-linear analysis of postural sway variability is used to investigate the postural control system's underlying structure (Riley et al., 2011).

Synergies are key in conceptualizing how this is accomplished. Recall that the motor system's way of controlling movement occurs by coupling and reducing the system's available degrees of freedom (DOFs) to form synergies so that motor system components work together as a functional unit, and stabilize the performance of a task. Figure 3.9 schematically depicts how a *postural synergy* is formed and produces non-linear behavior in the system's state dynamics system. The top of the figure depicts the high-dimensionality of a postural control system with many available DOFs (such as muscles, joints, or motor units) that must be controlled in order to coordinate a postural response. A postural synergy is generated from this high-dimensional substrate of available DOFs when interacting constraints related to the individual, the task and the environment bind the available DOFs together (top). This coupling reduces the number of available DOFs to a controllable number by forming a low-dimensional structure, or a postural synergy (middle). State dynamics (bottom) are the expressed behavior of a postural control system resulting from further constraint, and may have a lower dimensionality than the synergy from which it was distilled (Riley et al., 2011).

The constraints attributable to the individual, task and environment that form postural control synergies change from moment to moment. For this reason, it is postulated that postural control synergies are not general purpose devices that are applied to solve multiple tasks, but rather are contextually, quickly, and temporarily assembled to solve the specific demands of the task as afforded by a given environment (Riley, et al., 2011; Riley, Shockley & Van Orden, 2012).

Dynamic Levels and Synergies. Synergies in motor control may be understood as a graph-dynamic process (Riley, et al., 2011). A study of intermediate learning of a bimanual coordination task supports this relationship between synergy and graph dynamics by demonstrating that motor learning is a process by which a progressive reduction of DOFs of graph dynamics parallels improvements in performance of the learned task (Mitra, Amazeen & Turvey, 1998). As motor performance of the bimanual coordination task improved, there was a corresponding reduction in the number of active DOFs, as indicated by the minimum number of autonomous, differential equations needed to fully describe the system's behavior.

The same conceptual framework may be applied to postural control. In order to stand and maintain standing, the postural control system's available DOFs are synergistically coupled at the graph level of dynamics. Different combinations of muscle activation or joint configurations (for example, at the ankles or hips) can produce functionally equivalent postural sway adjustments (Edelman & Galley, 2001; Mayer-Kress, Liu, & Newell, 2006). It is the level of graph dynamics that determines what the specific architecture of the postural response will be---an architecture that is shaped by the values of the parameter dynamics (such as apparent muscle stiffness/co-contraction). The end result is a postural control system that is responsible for the evolution of the system's state variables, and expressed in COP displacement across time.

In sum, because non-linear measures of postural sway state dynamics are an output of the underlying architecture (parameter and graph dynamics), the behavior of these changes detected in the state dynamics of postural sway give indications of the underlying architecture of a postural control system. Based upon this conceptual framework, non-linear analyses of time-series COP data offer a way to understand the synergies undergirding the state dynamics behavior of a postural control system.

Loss of Complexity Hypothesis and Robustness. The *loss of complexity hypothesis* of aging and disease proposes that complexity in physiological control systems enables an organism to respond and adapt across a range of time scales in order to return to a more stable state in response to stress. Conversely, a *loss* of complexity is associated with a loss in the range of adaptive responses to physiological stress (Goldberger et al., 2002; Lipsitz, 2002). According to the hypothesis, the dynamics of a robust physiologic control system are characterized by a high degree of complexity. Aging and disease is associated with a loss of complexity (Goldberger et al., 2002; Lipsitz, 2002; Vaillancourt & Newell, 2002). Components of the body system decouple with age or disease, and when this happens, options for an adaptive response are reduced.

Figure 3.10 illustrates the physiological basis of frailty as a function of complexity loss with age (Lipsitz, 2002; Sleimen-Malkoun, Jean-Jacques, & Hong, 2014). Multiple interacting components of a physiological system (top) produce highly complex and irregular behavior in the systems output signal (middle), with greater function and adaptability in young adults (bottom). The decoupling of the components associated with old age produces less complex and more regular behavior of the output signal, and a loss of function that eventually reaches a threshold of frailty and poor adaptability.

Applied to postural control, the loss of complexity hypothesis predicts that aging produces decoupling in the component DOFs, resulting in more regular, and less complex, dynamics of COP time series behavior which accounts for postural instability seen in old age. Studies using non-linear analysis COP dynamics support this hypothesis and indicate that complexity in postural control systems declines from young adulthood through old age (Duarte and Sternad, 2008; Thurner, Mittermaier & Ehrenberger; Vaillancourt, 1998; Vaillancourt & Newell, 2002).

According to the loss of complexity hypothesis, the robustness of a postural control system is a function of systems complexity and indicated by the degree of complexity and irregularity in the system's state dynamics. Based on this hypothesis, complexity-based, non-linear analysis of COP time-series data is a way to measure the robustness of a postural control system.

Tai Chi as a Systems Strategy for Robust Postural Control into Old Age.

For several reasons, the martial art of Tai Chi is thought to provide training that results in high levels of postural stability which may be maintained or improved into old age. Tai Chi training practices evolved over hundreds of years to optimize postural stability as a necessary feature of skilled fighting. Postural stability training is an especially important element of Tai Chi. This is most clearly exemplified in an essential Tai Chi training component known as "push hands," a friendly competition between two players, wherein each tries to disrupt the balance of the other while preserving their own balance. Not only does this train reactive balance mechanisms to withstand unpredictable perturbations by an opposing player, but also it trains proactive balance mechanisms to maintain stability when applying forces intended to upset an opponent's balance.

In addition to training for postural stability, anecdotal evidence suggests that old age is not necessarily a barrier to high-levels of Tai Chi skill development. On average, physical work capacity (VO_2max) declines at a rate of 1.00-2.5% per year after age 25, strength decreases 1% per year beginning in mid-40s and accelerates after age 70, power declines with age at greater rates than strength, and motor coordination and skill deteriorates with age, especially with more complex movement (Spirduso, Francis & MacRae, 2005). Yet, Tai Chi masters are known in Tai Chi communities to reach peak push hands skill at ages around 50 to 60, and observed to maintain their physical vigor into old age. These observations contributed to Tai Chi's popularity in China (Grubusich, 2016).

Because a postural control system engages such a vast array of disparate bodily systems, good general health is likely to be associated with a robust postural control system. Although its design does not allow conclusions about causation, a positive correlation between general health and Tai Chi practice was found by a cross-sectional study of long-term practitioners. Analysis of an online survey suggests that in middle and late adulthood (but not young adulthood), Tai Chi practitioners enjoy better general health than Americans who perform some or no exercise, even when controlling for factors such as income and education (Kamelski, Miyazaki & Blieszner, 2012).

Another reason why Tai Chi skill development is not necessarily limited by old age is that movement speed, muscular strength and flexibility associated with youth are not requirements for Tai Chi skill development. In most instances, movement training in

Tai Chi is gentle, and slow or nearly static. Tai Chi skill relies on relaxation and efficiency of movement as opposed to brute muscular force, and is practiced effectively in natural and low-intensity postures at moderate levels of aerobic intensity (Li, Hong & Chan, 2001; Yang, Grubisich & Feng, 2005). The moderate intensity of muscular force, joint postures and speed characterizing Tai Chi training makes it suitable for older persons undergoing normal aging changes and age-associated limitations of joints, muscles and cardiovascular systems.

Not only is Tai Chi training suitable for several age-associated conditions, there is evidence that it may improve them. Systematic reviews conclude that Tai Chi may: reduce pain and disability associated with arthritis; reduce blood pressure; be a beneficial adjunctive therapy for some patients with cardiovascular disease or risk factors; improve psychological well-being by reducing stress, anxiety, depression and mood disturbance; improve functional capacity and quality of life in patients with chronic heart failure; and improve cognitive function, particularly executive function in older adults without significant cognitive impairment (Hall, Maher, Latimer, & Ferreira, 2009; Wang et al., 2010; Wayne et al., 2007; Wayne et al., 2014; Yeh, Wang, Wayne, & Phillips, 2009; Yeh et al., 2004).

In summary, Tai Chi training practices evolved to develop high-levels of postural stability and lead to skill-building that is not necessarily precluded by the limitations of old age.

The art of Tai Chi is holistic. It is a systems-oriented activity, geared toward long-term behavioral change and skill development in which mental, physical, and spiritual components are intended to interact and unify. This is shown below in two ways. The first is through the manner in which therapeutic components are coupled and interact as a system. The second is through the way in which Tai Chi movement characteristics and skill are described and understood in systems-level terms.

The Eight Active Therapeutic Ingredients of Tai Chi. Although there are likely health benefits associated with training in a single component of Tai Chi, such as those associated with the physical exercise component as a moderately intense aerobic activity, this singular training component fails to encompass the richness and complexity of Tai Chi practice and its therapeutic benefits (Wayne & Kaptchuk, 2008; WHO, 2011; Yang et al., 2011). Tai Chi is an integrated activity with many components, and this holism is what is thought to make it such a powerful and uniquely therapeutic and health-promoting activity.

Wayne & Fuerst (2013) describe the holistic nature of Tai Chi practice using an ecological model of Tai Chi's therapeutic components involving *The Eight Active Ingredients of Tai Chi* depicted in Figure 3.11 (Wayne & Fuerst, 2013; Wayne & Kaptchuk, 2008). The model illustrates how each of eight different components of Tai Chi practice can interact with each other, and that every component can have some therapeutic effect. Although these eight ingredients are not necessarily exhaustive of the components of Tai Chi, the authors consider them essential (Wayne & Fuerst, 2013).

The manner in which each component is integral to the others is illustrated in the single element of Tai Chi breathing practice. For example, to learn to move effectively and efficiently, Tai Chi movement training is often performed slowly, while intentionally relaxing the muscular system, and without deviating from correct body alignment. Integrating deep and slow breathing into these movements is essential Tai Chi practice.

Deep breathing is known to reduce elevated sympathetic activity in persons with chronic obstructive pulmonary disease, and reduce blood pressure in persons with hypertension (Joseph et al., 2005; Raupach et al., 2008). It is thought that deep breathing balances the autonomic nervous system by quelling an overactive sympathetic nervous system and stimulating the parasympathetic nervous system responsible. It is plausible that the calming effects of deep Tai Chi breathing interact with and enhance the slow and relaxed aspects of Tai Chi movement training to facilitate the coordination of movement and body alignment necessary for optimal postural stability.

Another example of how Tai Chi components are interrelated is illustrated by another essential ingredient to Tai Chi practice, mindfulness (Wayne & Fuerst, 2013). Jon Kabat-Zinn, developer of the Mindfulness Based Stress Reduction (MBSR) program, describes mindfulness as intentionally paying moment-by-moment attention, often to bodily sensations, remaining, as much as possible, emotionally non-reactive and non-judgmental toward distractions (Kabat-Zinn, 2005). A substantial body of research finds that mindfulness-based meditation programs improve mood, reduce perceived stress, and improve cognitive functions including sustaining attention and perceptual sensitivity (Baer, 2003; Davidson et al., 2003; Hofmann, Sawyer, Witt, & Oh, 2010; MacLean et al., 2010; Moore, Gruber, Derose, & Malinowski, 2012). The effects of mindfulness training are not limited to cognitive and psychological well-being. Mindfulness meditation has been found to enhance immune antibody response, lower levels of proteins associated with inflammation, and produce neuroplastic changes in brain function and structure---many of which are associated with learning, memory, positive mood, and reduced stress response (Davidson et al., 2003; Davidson & Lutz, 2008; Holzel et al., 2010; Holzel et al., 2011; Xiong & Doraiswamy, 2009). It seems that mindfulness can enhance well-being.

Assuming, as the research suggests, that Tai Chi mindfulness training improves mood and attention and reduces stress, it is reasonable to suggest that these effects enhance Tai Chi motor training by promoting body awareness, relaxation and enjoyment. In addition, the practitioner may be more motivated to persist and continue learning Tai Chi through regular participation in Tai Chi group classes, thus fostering therapeutic social aspects of practice. These patterns of coupling and interaction are argued to occur among all eight active Tai Chi elements (Wayne & Fuerst, 2013; Wayne & Kaptchuk, 2008).

Systems-Level Descriptors of Tai Chi Skill and Movement. Several traditional descriptors of Tai Chi skill reflect goals of Tai Chi training that are holistic and systems-oriented. Some traditional descriptors seem particularly translatable into terms consonant with modern systems theory of motor control.

One traditional descriptor of Tai Chi that is a particularly holistic term is *gong*, the purported foundation of Tai Chi. Traditionally, *gong* is thought to accumulate through the cultivation of *qi*, which has been defined as "life force" or "vital energy." This accumulation of *gong* denotes improvement in physical skills of power, balance, agility and coordination. Mentally and spiritually, *gong* pertains to a deepening experience of peace and tranquility. In the context of Tai Chi skill development, *gong* has the root meaning of "essential foundation," as essential as flour is to noodles, and is accumulated through the practice of *qigong*, described as certain exercises that nurture, circulate, and gather *qi*. *Gong* is said to be the basis from which Tai Chi martial techniques and high-levels of postural stability arise (Yang et al., 2005).

The purpose here is not to support or question the physical existence of *qi* or *gong*. Instead, the main point is to demonstrate that the traditionally-understood foundation of Tai Chi skill, *gong*, is conceptually a systems descriptor, in the same way that previously mentioned terms such as health, postural control robustness, homeodynamic buffering capacity, and aging are consonant with a systems-oriented thinking.

Traditional descriptors of Tai Chi movement characteristics are systems-level terms as well. One of these characteristic of Tai Chi movement is *yin/yang* balance. Over the hundreds of years of the art's existence, Tai Chi became a blend of traditional Chinese martial and healing arts, and Chinese philosophy, particularly Daoism. One characteristic of Tai Chi movement comes from the Daoist concept *yin* and *yang*, or the interplay of opposites, in which the extreme of one opposite gives rise to the other. According to tradition, Tai Chi practice seeks balance between *yin* and *yang* (Yang et al., 2005). In the following passage, Yang et al. (2005) offer several examples of how the balance of *yin* and *yang* are embodied in Tai Chi movement:

> If you want to go right, first you have to move left. If you want to release, first you have to store. If you want extreme quickness, first you have to practice slowly. If the left is attacked, you yield on the left and counterattack on the right. If the opponent attacks with the upper body, his or her lower body is undefended. If you want extreme hardness, you start with extreme softness (Yang, et al., 2005, p. 98).

The aim here is not to argue for or against a Daoist philosophical position, but simply to point out that the balance of *yin* and *yang* is a systems-level descriptor of Tai Chi movement.

A second characteristic of Tai Chi movement given in systems terms is *xin yi*, translated as mind/intention (Yang et al., 2005). *Xin yi*/mind-intention is a cognitive task that involves maintaining one's attention on the intention of the movement while remaining as relaxed as possible, and avoiding unnecessary muscular contraction. *Xin yi*/mind-intention contrasts sharply with the use of and dependence on, overt muscular force to accomplish a desired movement task.

One example of *xin yi*/mind-intention in Tai Chi training is found in movements that call for upward intention. The *xin yi*/mind-intention of upward intention may be accomplished by imagining that every cell of one's body is rising, *en bloc*, in an upward direction. Another example *xin yi*/mind-intention is used in Tai Chi movements requiring a downward intention, accomplished by imagining that every cell of one's body is dropping downward, as if sinking into the ground. Another example is the intention to move as if one is in water and must exert gentle force with one's entire body against the resistance of the water. Again, Tai Chi movement training and the cognitive task mind-intention do not depend on inherent athleticism to acquire an advanced level of Tai Chi motor skill. Both are learned and likely unfamiliar to the untrained (Yang et al., 2005). Because *xin yi*/mind-intention is a necessary feature of all Tai Chi movement and characteristic of Tai Chi movement as a whole, this traditional term is another systems-level descriptor.

The last systems-level descriptor of Tai Chi movement characteristics is *chan si*, or silk-reeling energy. Silk-reeling energy refers to the spiraling force that connects the body's joint movements and muscle forces in such a way that the entire body moves as a single coordinated functional unit. Silk-reeling is a characteristic of the whole movement system that enables a high degree of motor control and postural stability. Because the entire body moves and functions as a single holistic structure, when a balance-challenging force is applied to one part of the body, the other parts of the body compensate to maintain the structure's stability. Similarly, any part of the body may serve as the locus of force produced by the entire ensemble of body parts, while preserving postural stability (Yang et al., 2005). Silk-reeling force is another holistic term that is descriptive of a movement system.

Gong, *qigong*, *yin/yang*, *xin yi*/mind-intention, and silk-reeling force are all traditional descriptors of Tai Chi skill. All are descriptors that refer to skill, movement and postural stability at the systems-level. As with the eight ingredients of Tai Chi, the characteristics of Tai Chi movement are interrelated such that training of one can foster development of the others (Yang et al., 2005). Taken together, Tai Chi training is a systems-oriented strategy supportive of robust postural control.

Systems-level Tai Chi Skill Descriptors and a Systems-Oriented Approach to Postural Stability. There is an uncanny consonance between the traditional idea of silk-reeling and the more contemporary concept of synergy in a dynamic systems model of motor behavior. Recall that synergy is "groups of motor system degrees of freedom (e.g., joints, muscles, or motor units) that are coupled to act as a single, functional unit to achieve and maintain a behavioral goal:" this serves the two functions of dimensional compression and reciprocal compensation in the emergence of postural control (Riley, et al., 2011, p. 7). Also recall that silk-reeling energy refers to the spiraling force that connects the body's joint movements and muscle forces in such a way that the entire body moves as a single, coordinated functional unit. Given the discussion up to this point, it is evident that silk-reeling fits within the definition of synergy. Accordingly, silk-reeling is a coupling of a vast number of available DOFs involving joint and muscle forces. This coupling forms synergies in which the entire body acts as an integrated unit. The sharing task among the components of this whole-body structure fosters postural stability no matter where on the body a balance-challenging force is directed. In summary, it has been suggested that Tai Chi training is a holistic strategy toward developing and maintaining robust postural control that continues into old age, and enables this control through a learned class of motor synergies, known traditionally as silk-reeling.

Training principles essential to developing silk-reeling skill correspond remarkably well to constraints in dynamic systems theory. Silk-reeling is not an act of conscious will, but rather emerges through the correct performance of Tai Chi principles (Yang et al., 2005). The essential Tai Chi principles necessary for the emergence of silk-reeling, function as both physical and cognitive constraints on movement and posture.

The manner in which Tai Chi principles constrain motor and postural behavior is summarized in the Table 3.1. Examples of some (not all) Tai Chi principles are listed in the left column. The right column explains constraints provided by each principle. Excluding movement/activation other than that allowed by the constraints determines the remaining postural and movement possibilities within a highly dimensional motor system. Chest opening/closing, for example, requires that the scapula remain depressed, thus excluding any scapular elevation movement. Similarly, waist rotation requires that the pelvis and shoulder girdles remain horizontally level, and central equilibrium requires maintaining vertical alignment of the entire spine, both of which exclude side, forward or backward bending of the trunk. Whole limb movement/activation is spiraling in either a *shun* or a *ni*, and constrains against any other movement possibilities that deviate from this pattern.

Principles and constraints listed in Table 3.1 are understood to interact with one another. For example, mental tasks of relaxation, central equilibrium and mind-intention are constantly maintained during the physical movements of reverse breathing, limb spiraling, chest/abdomen opening and closing, waist turning and weight shifting. This cognitive mode by which all physical movement is performed is thought to have mechanical effects on the movement expressed that are deemed necessary to the emergence of the Tai Chi silk-reeling force (Yang et al., 2005). In turn, physically relaxed and slow movement, and deep reverse breathing have calming effects on emotional and mental states necessary for emergence of Tai Chi skill. Proper execution of essential Tai Chi principles is understood using a dynamic systems theoretical framework as constraints necessary for the emergence of silk-reeling synergies.

In conclusion, Tai Chi practice trains its practitioners to develop robust postural control that may continue into old age, and can be viewed as a systems-oriented approach to postural stability. The Tai Chi movement characteristic traditionally known as silk-reeling is particularly translatable into a dynamic systems theoretical framework of motor behavior. Within this theoretical framework, silk-reeling is a learned and special class of motor and postural control synergies that emerge from the mechanical and cognitive constraints provided by correct execution of Tai Chi principles. It is hypothesized that development of these learned synergies through Tai Chi training facilitates robust postural stability that can extend into old age.

Table 3.1. Examples of Tai Chi Motor Principles and Their Constraints on Motor Behavior.

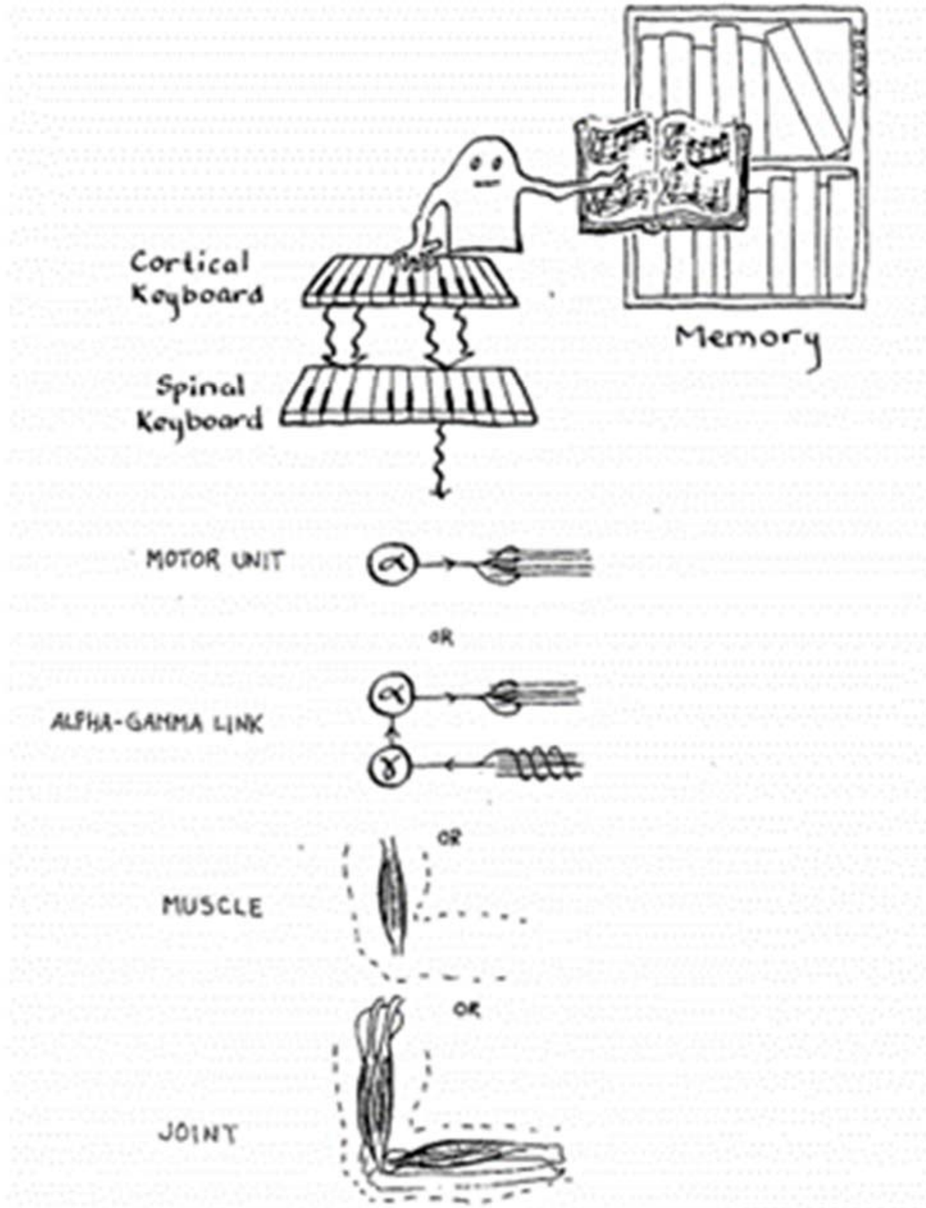
Tai Chi Principle	Constraints
Shun or *Ni* of Arms, Legs, Chest/Abdomen	*Shun* is spiraling movement/force of an entire limb inward. In the upper extremity, for example, *shun* constrains movement/activation to simultaneous shoulder internal rotation, forearm supination, and wrist internal rotation. *Ni* constrains movement activation to simultaneous shoulder external rotation, forearm pronation, and wrist external rotation. The chest/abdomen close during *shun* movement and open during *ni* movement. Movement/activation in any of these areas is either *shun* or *ni*, depending on the particular Tai Chi movement.
Waist Turning	Waist turning refers rotation of the thorax with respect to the pelvis in a horizontal plane. Waist turning, when required by a Tai Chi movement, is either constrained to either right of left rotation movement/activation.
Weight Shifting	Weight shifting refers to shifting of body's center of gravity toward a particular direction on a horizontal plane.
Deep Reverse Breathing	During the in-breath the diaphragm drops, the abdomen is drawn toward the spine and the pelvic floor lifts. During the outbreath the abdomen drops naturally.
Relaxation	Physically, relaxation constrains movement/activation to that of minimal muscular exertion except what is required to maintain other physical principles. Mentally, relaxation constrains to minimal emotional and psychological distress. Spiritually, relaxation has connotations relating to peace and tranquility as spiritual qualities.
Central Equilibrium	Physically, central equilibrium constrains movement/activation to maintaining vertical head/neck/trunk/pelvic alignment in which the point on the very top of the head is aligned vertically with the point on the pelvic floor between the genitals and anus. Mentally, central equilibrium refers to emotional and psychological balance. Maintaining central equilibrium in response to disturbances is fundamental to Tai Chi postural stability
Xin Yi/Mind-Intention	*Xin Yi*, or Mind-Intention, is a cognitive task that constrains attention to the intention of a movement with minimal overt muscular activation.

Source: Adapted from Yang et al., 2005.

Figure 3.1. Examples of the word "Coordination" (in Russian) written by Nikolai Bernstein with various parts of his body.

Source: Taken from Latash, 2012, as reproduced from Bernstein (1935).

Figure 3.2. A 19th Century View of Motor Control Similar to Contemporary Representational Theories of Motor Control.



Source: Taken from Turvey et al., 1982, Figure 10.1 (p. 240).

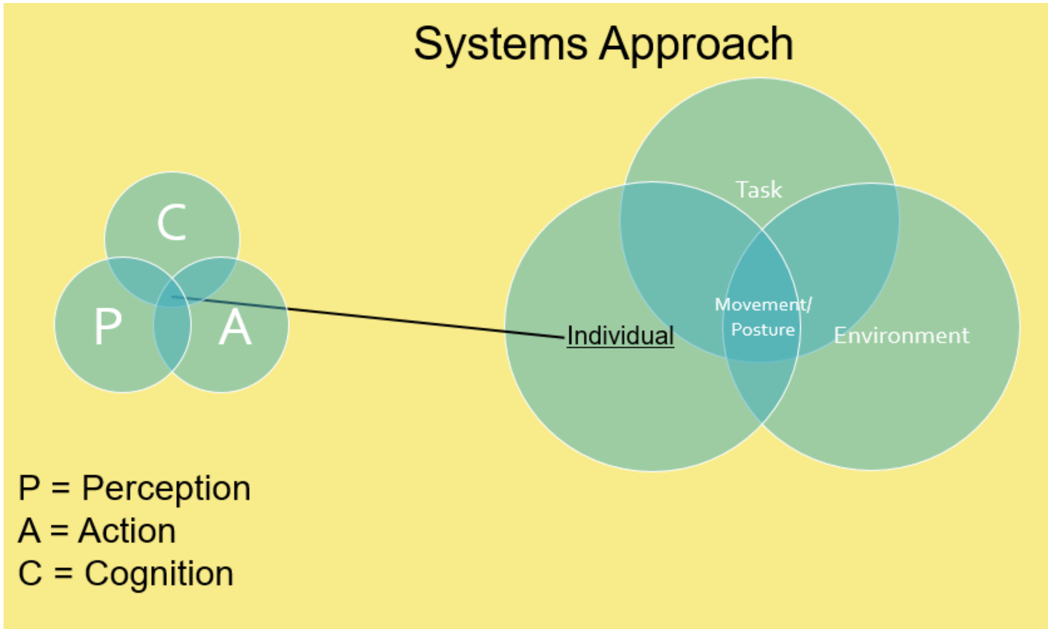
Figure 3.3. The Perspective of an Externally-Controlled System.

Source: Taken from Turvey, 1990, Figure 1 (p. 939).

Figure 3.4. The Perspective of a Self-Organized System.

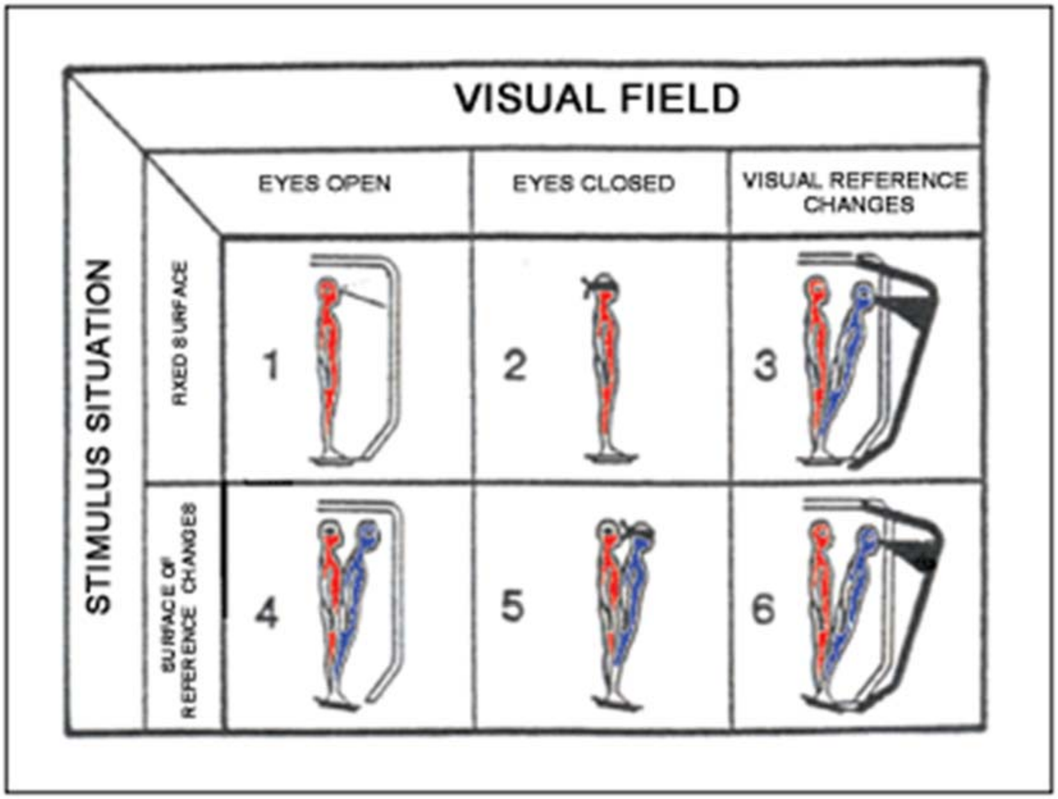
Source: Taken from Turvey, 1990, Figure 1 (p. 939).

Figure 3.5. The Systems Approach.



Source: Adapted from Shumway-Cook & Woollacutt, 2012, Figure 1.2 (p. 5).

Figure 3.6. Six testing conditions of the Sensory Organization Test.



Source: Taken from Bittar, 2007, Picture 2, (p.332).

Figure 3.7. Anterior-Posterior Center of Pressure Displacement during 30 Seconds of Quiet Standing.

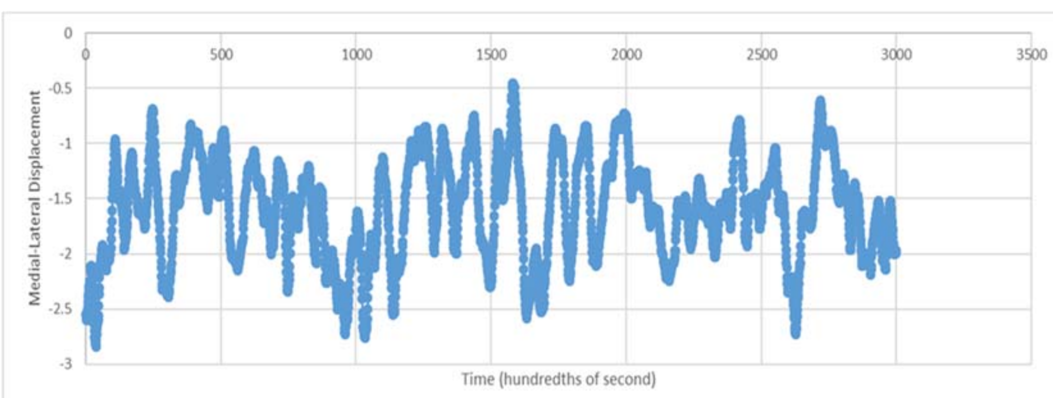


Figure 3.8. Medial-Lateral Center of Pressure Displacement during 30 Seconds of Quiet Standing.

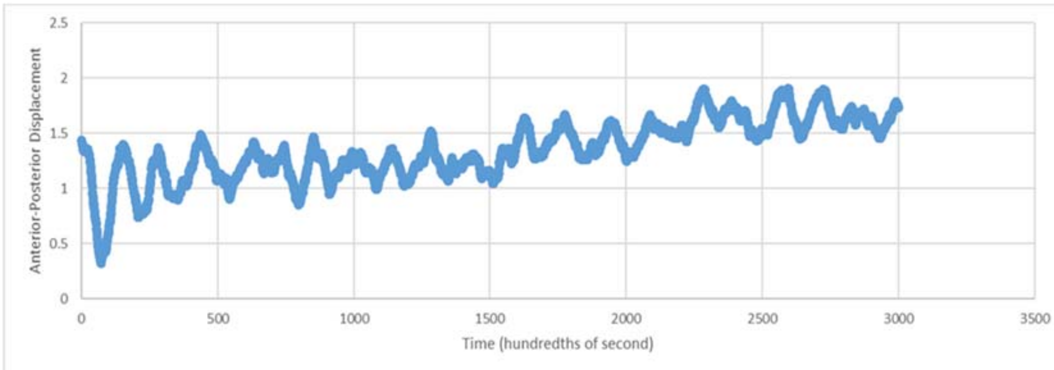
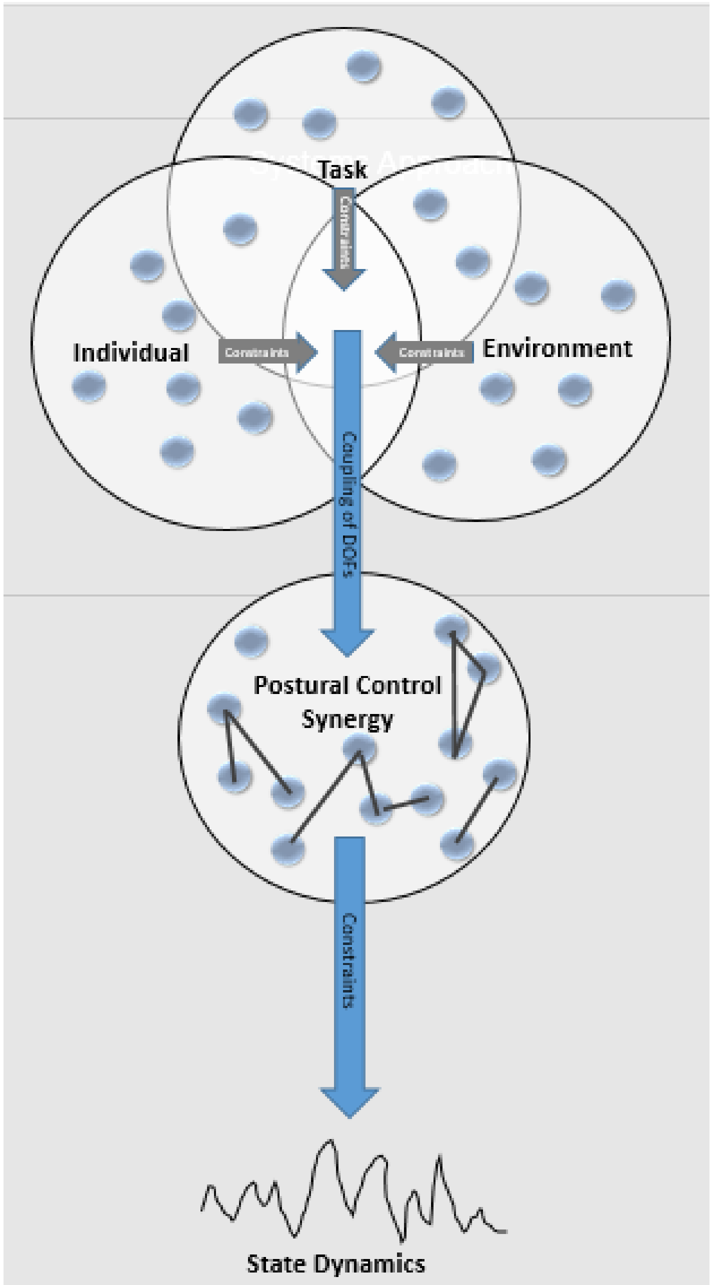


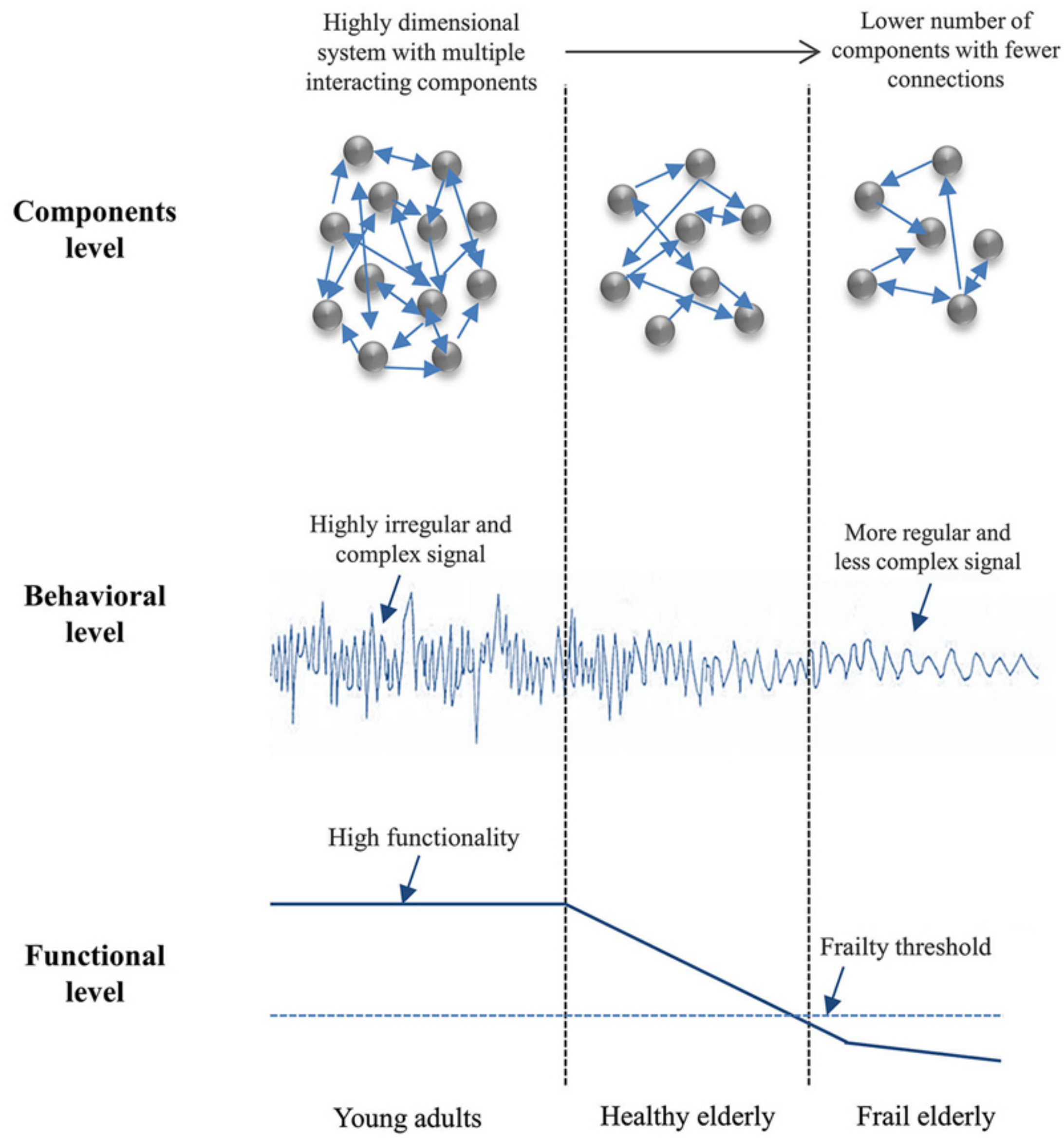
Figure 3.9. A Schematic Depiction of a Postural Control Synergy.



Legend: = each represents one of a diverse set of DOFs.

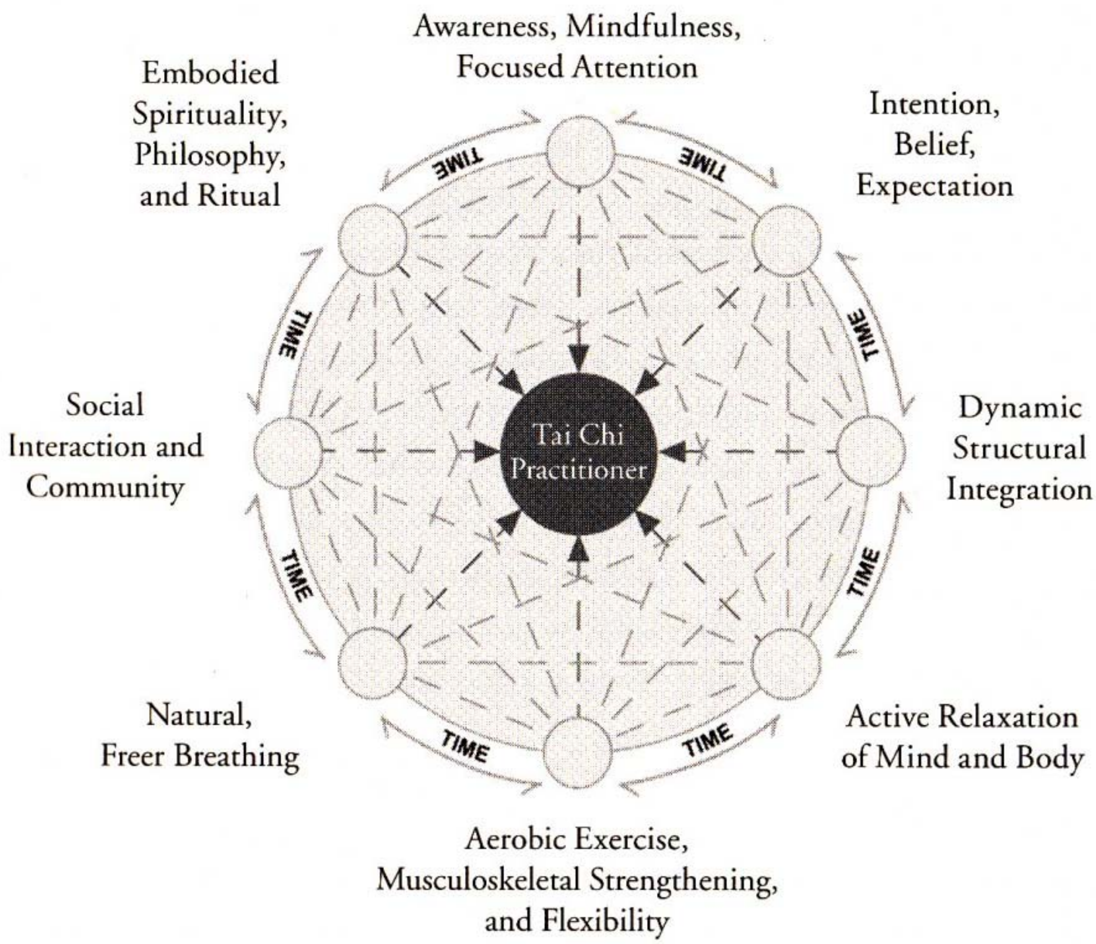
Source: Adapted from Riley, Kuznetsov, et al., 2011, Figure 2 (p. 7) as adapted from Riley & Turvey, 2002, and Kay, 1988.

Figure 3.10. Loss of Complexity with Age and Frailty.



Source: Taken from Sleimen-Malkoun et al., 2014 (p. 7) as inspired by Lipsitz, 2002.

Figure 3.11. The Eight Active Therapeutic Ingredients of Tai Chi.



Source: Reproduced from Wayne & Fuerst, 2013 (p. 35).

Chapter 4: *Xin Yi*/Mind-Intention and Motor Imagery Research

Xin yi, or mind-intention, is considered an essential principle of Tai Chi practice. It is traditionally known to be characteristic of all Tai Chi movement and integral to the generation of silk-reeling force (Yang et al., 2005). Chapter 3 demonstrated that, from a dynamic systems theoretical perspective, Tai Chi *xin yi*/mind-intention is one of a family of constraints necessary for the emergence of a class of synergies hypothesized to undergird silk-reeling movement and an associated robust postural control that seems to extend into old age. This chapter seeks to provide deeper understanding of *Xin yi*/mind-intention as a constraint on motor behavior by identifying it as a practical form of motor imagery, and interpreting relevant motor imagery research. In order to do this, it is necessary to clearly define and describe motor imagery.

Motor imagery involves kinesthetically imagining a motor task experience from a first person perspective, without executing the task. The focus of attention with motor imagery, as opposed to visual imagery, is on the somatosensory feelings experienced as if actually performing the motor task (Jeannerod, 1995; Munzert, Lorey, & Zentgraf, 2009; Stinear, Byblow, Steyvers, Levin, & Swinnen, 2006). Motor imagery has been of interest to researchers because it activates the nervous system, and produces training effects on motor performance, that are similar to overt execution of movement.

Motor imagery training has been practiced to improve motor performance in diverse areas including sports, the performing arts, martial arts, and physical rehabilitation (Cumming & Williams, 2012; Dickstein & Deutsch, 2007; MacIntyre & Moran, 2010; Wayne & Fuerst, 2013). In sports and the performing arts, motor imagery has long been incorporated with physical training, mixed with other types of imagery (visual, auditory, gustatory), and used through employing one or more perspectives (first person, third person) or agencies (self, other). The practice may include a wide range of metaphor images including color, objects not present, and actions that are impossible to perform (Holmes & Collins, 2001; Nordin & Cumming, 2005). There is now a substantial body of experimental research confirming that motor imagery training, either by itself or mixed with other modalities, improves motor performance across a number of tasks.

Yue and Cole (1992) trained subjects for five sessions per week for four weeks with one group producing maximal voluntary isometric contractions of the little finger abductors and a second group imagining the same effortful contractions. Average force production of the trained muscle group improved 22% in the motor imagery group and 30% in the isometric contraction group (Yue & Cole, 1992).

Another study investigated motor imagery training on speed and accuracy of a finger tapping sequence involving three groups: a motor training group who physically practiced, a mental training group who only performed motor imagery, and a third group who trained both physically and mentally (Nyberg, Eriksson, Larsson, & Marklund, 2006). Improvement in performance occurred in all three groups. The mental training group had the least improvement, the physical training group improved more than the mental training group, and the mental-plus-physical training group improved the most, with significant differences among the groups. An additional finding was that the mental-plus-physical training group was the only group to improve significantly on an untrained sequence, demonstrating that this group's improvement in motor performance generalized and transferred into an untrained task (Nyberg et al., 2006).

Four cycle-ergometer training groups were measured after six weeks for power on a cycle-ergometer: a motor imagery, a power training, a motor imagery-plus-power training, and a control group were employed. The power training, and the motor imagery-plus-power training groups each significantly improved in measures of power on the ergometer. However, only the motor imagery plus power training group significantly improved their 40-meter sprint time, representing another example in which motor imagery training combined with physical training produced motor skill learning that generalized to an untrained motor skill (Vangyn, Wenger, & Gaul, 1990).

Motor imagery has been investigated as one of a mix of imagery types in meta-analyses and single studies investigating effects of *mental* imagery (Braun et al., 2006; Driskell, Copper, & Moran, 1994; Holmes & Collins, 2001; Landers, 1983; Smith, Wright, & Cantwell, 2008). In these studies, mental imagery included motor imagery or visual imagery, or a combination of both, and the visual imagery was from either a first or third person perspective. Mixing types of imageries creates problems in discerning training effects specific to motor imagery, especially given that neural pathways for visual and kinaesthetic imageries are distinctive in both neural underpinnings and effects (Stinear et. al, 2006). Nevertheless, imagery experiments that mix motor imagery with other types of imagery provide evidence that motor imagery is a component that may improve motor skill.

One imagery technique from sports psychology takes into account several characteristics of imagery. PETTLEP combines seven elements represented by the acronym (Physical, Environment, Task, Timing, Learning, Emotion, and Perspective) (Holmes & Collins, 2001). The PETTLEP model is based on a hypothesis proposed by Jeannerod (1995) that physical and mental practice are cognitively represented in the motor system in functionally equivalent ways. Hence, the most effective imagery technique is one that matches as much as possible the conditions of effective physical practice (Holmes & Collins, 2001; Jeannerod, 1995).

In a study of a golf bunker shot performance after six weeks training, four training groups were compared: PETTLEP imagery, physical practice, PETTLEP-plus-physical practice, and a control. The PETTLEP group and the physical training group each significantly improved their bunker shot. The PETTLEP-plus-physical training group significantly improved more than any of the other groups (Smith, Wright, & Cantwell, 2008). The results provide additional evidence of the superiority of combining mental and physical training for improving motor skill.

Another study involved 20 active athletes with grade II ankle sprains. One group received 12 sessions of imagery rehearsal of physical therapy-plus-physical therapy, while the other group received physical therapy only (Christakou, Zervas, & Lavallee, 2007). The group that underwent imagery rehearsal-plus-physical therapy improved significantly in muscular endurance compared to the group that received physical therapy alone.

In a four week of study of 24 people with chronic hemiparetic stroke, one group performed locomotor imagery training-plus-physical therapy, and a second group watched television documentaries-plus-physical therapy (Hwang et al., 2010). The locomotive imagery training included first person perspective imagery and observed video (third person perspective) of each participant's own abnormal gait and the gait of a normal adult male. The locomotive imagery training group made significant improvement in measures of gait parameters, balance confidence, postural control and dynamic balance.

Thirty-two chronic stroke patients with moderate motor deficits were divided into two groups: one received relaxation exercises plus physical training of arm motor movements, and a second received first person perspective visual and motor imagery mental practice plus physical training of arm movements. After six weeks of training, involving 30 minute sessions twice per week, the motor imagery-plus-physical training group significantly out-performed the relaxation-plus-physical training group in measures of arm movement and daily functional skills (Goginsky & Collins, 1996).

Measures of combined gait and balance skill, improved in persons with chronic stroke after six weeks of gait training-plus-mental imagery when compared to gait training alone (Cho, Kim, & Lee, 2013). The mental imagery intervention consisted of both first person kinesthetic imagery and third person visual imagery of normal walking mechanics.

Experimental designs specific to effects of motor imagery on postural control provide some evidence that motor imagery training modulates postural stability (Choi et al., 2010). Performance of a dynamic balance task in healthy young adults improved both in the physical trained group and the motor imagery group after three weeks of training when compared to a no-training control. Typical of other controlled studies of motor imagery, effects were greater in the physical training group than in the motor imagery group (Nyberg et al., 2006; Vangyn, Wenger, & Gaul, 1990; Yue & Cole, 1992)

Hamel and Lajoie (2004) studied 20 healthy individuals ranging in age from 65 to 90 years (Hamel & Lajoie, 2005). The twelve participants in the intervention group performed a kinesthetic motor imagery task in the lying position in which each imagined standing perfectly still on a force platform daily for six weeks. The eight participants in the control group had no intervention. Pre-tests and post-tests of dual tasking revealed that the motor imagery group performed significantly better on a dual task of verbal response time to a visual cue than did the control group while performing a primary task of standing perfectly still on the force platform. The motor imagery group also demonstrated significantly less postural sway amplitude in the anterior-posterior direction versus the control group. The authors hypothesized that the motor imagery task had the training effect of reducing attentional demands during the performance of a dual task by making the standing-still task more automatic.

Despite the inability of these studies to determine effects attributable to motor imagery alone, the totality of the evidence suggests that such training improves motor performance. Although motor imagery training has a generally weaker effect than overt physical training on motor performance, there is evidence that combining motor imagery with physical training is superior to either one alone. In some instances, combining motor imagery training with physical training demonstrated effects that transfer to motor skills beyond those being trained. One study suggests that motor imagery improves attentional demands of a standing-still task during a dual cognitive task in older adults (Hamel & Lajoie, 2005).

***Xin Yi*/Mind-Intention as Motor Imagery.**

Tai Chi mind-intention practice meets two defining features of motor imagery; it is first person and kinesthetic. Take, for instance, performing a Tai Chi movement during the mind-intention task of imagining moving in water as if exerting a gentle force with one's entire body against the resistance of the water. The imagery task is first person because it requires attentional focus on imagining one's own bodily sensations, and is kinesthetic because it requires focus on the sensations of bodily movement, momentum, force and posture during the imagined motor task. Key here is that this task allows execution of movement (albeit with only enough muscular contraction to complete the movement slowly and still maintain other Tai Chi movement principles). Because movement is being executed, it is uncertain whether this task is really motor imagery according to some descriptions (Jeannerod, 1995; Munzert et al., 2009; Stinear et al., 2006). There are reasons, however, to suggest that it is.

One reason is that evidence of muscle activity detected during a motor imagery task suggests that some execution of the task occurs *unintentionally* during motor imagery (Bonnet et al., 1997; Gandevia et al, 1997; Guillot, Lebon, Rouffet, Champely, Doyon, & Collet, 2007). Electromyography (EMG) studies that record and evaluate electrical activity produced in muscles by motor neuron firing, find that effects of motor imagery on muscle activation and related physiological processes indicate motor imagery is more nuanced than many definitions of motor imagery allow.

Skeletal muscles have contractile properties that function to produce joint torques in order to move and control body movement and posture. Each skeletal muscle contains arrangements of many muscle cells, or *muscle fibers*. The muscle fibers are innervated by two types of effector neurons that originate in the spinal cord: alpha motor neurons (AMNs) and gamma efferent neurons (GMNs). When an AMN is activated and reaches its threshold, the action potential generated is sent peripherally along the neuron that ultimately causes a group of muscle fibers, known as a motor unit, to contract simultaneously. The force of this contraction depends, among other things, on the size of the motor unit and the frequency of the action potentials. AMNs innervate force-generating muscle fibers called *extrafusal* fibers, which are one of two types of muscle fibers. The other type, *intrafusal* muscle fibers, function primarily in detecting changes in muscle length for the purpose of motor control, rather than in generating contractile force.

Intrafusal fibers are innervated by GMNs, and are located in muscle spindles arranged parallel to the force-generating extrafusal fibers. Muscle spindles have the important function of providing sensory information that detects changes in muscle length and joint position. This proprioceptive information is sent back to the spinal cord by way of sensory fibers called Ia afferent neurons. Ia afferent neurons are some of the fastest sensory nerves with a transmission speed of up to 120 meters per second, suggesting that receiving timely information sent by these fibers is extremely important for motor control. In the case of some pathologies in which this afferent information is absent, motor control is still possible but severely impaired, especially when visual feedback is absent as when the eyes are closed (Cole, 1995; Latash, 2012).

The Ia afferents from the muscle spindles in a muscle send their proprioceptive information rapidly via a single synapse to the alpha motor neuron that innervates the same muscle. As this is a single synaptic pathway to the AMN, reflexes that use this pathway to cause a muscle contraction are called monosynaptic reflexes. Quick lengthening of intrafusal fibers stimulates muscle spindle organs that produce signals that synapse with, and activate, the AMN in the spinal cord, which in turn sends signals activating and contracting extrafusal muscle fibers.

Two different reflexes cause a muscle contraction by stimulating the Ia afferents, which in turn connect and cause firing of the AMNs: the tendon reflex (T-reflex) and the Hoffman's reflex (H-reflex). The T-reflex stimulates the Ia afferents through a quick stretch to the muscle fibers by tapping the tendon, whereas the H-reflex does this by electrical stimulation directly to the Ia afferents (Latash, 2012). AMNs are not only affected by the proprioceptive information coming from Ia afferents, but also by central motor commands sent from the brain and down the spinal cord by way of corticospinal pathways.

EMG studies indicate that motor imagery produces weak activations in the specific muscles relevant to the motor task being imagined (Bonnet et al.,1997; Gandevia et al., 1997; Guillot, Lebon, Rouffet, Champely, Doyon, & Collet, 2007). For example, in a study investigating actual and imagined movements involving the hand or foot, five of the seven participants background levels of EMG activity significantly increased in the relevant muscles compared to EMG activity at rest. These cases of unintended muscle contraction were due to activation of AMNs, and if strong enough, also produced muscle spindle afferent activity. It was concluded that muscle spindle afferent activity only occurred when there was AMN activation, and never independent of it (Gandevia et al., 1997).

Bonnet *et al.* (1997) investigated H-reflex and T-reflex activity in subjects performing actual and imagined motor tasks involving the gastroc-soleus muscle. Surface EMG activity during a mental simulation of the task increased to twice the resting levels, although twenty times less than when actually executing the task. Spinal reflex pathway excitability (in T-reflex, but not H-reflex excitability), was revealed to be "only slightly weaker" than during actual performance of the tasks. Correlation coefficients among H- or T-reflex amplitude and background EMG amplitude during the mental simulation strongly suggest that the increased background EMG activity during motor imagery was not strong enough to explain the large changes in monosynaptic reflex amplitudes. The finding that motor imagery produces high levels of increased excitability in the T-reflex but not the H-reflex, indicates that imagined movement selectively increases the activation of GMNs, since the H-reflex bypasses the neuromuscular spindles (Bonnet, Decety, Jeannerod, & Requin, 1997).

The implication of such a high level of gamma bias during motor imagery is that muscle spindles have similar sensitivity in detecting important proprioceptive information as when movement is fully executed, despite the lack of alpha motor activation. Studies of both animals and humans find this same type of gamma bias in muscle spindle activity during states of arousal and expectancy. The findings are purported to support a view that the gamma motor system behaves as a neural network independent of the AMN system. Through this network the increase in muscle spindle sensitivity is associated with gamma bias, and enables richer and more accurate feedback information about movement to be gathered and processed, even though the alpha motor system is quiescent (Bergenheim, Johansson, & Pedersen, 1995; Cordo, Inglis, Verschueren, Collins, Merfeld, Rosenblum,…Moss, 1996; Prochazka, 1989; Ribot-Ciscar, Rossi-Durand, & Roll, 2000)). Taken together, EMG studies of motor imagery make clear the presence of weak muscle activation in muscles related to the imagined motor task during motor imagery.

This is further supported by the presence of task-specific postural sway during motor imagery (Boulton & Mitra, 2013; Grangeon, Guillot & Collet, 2011; Lemos, Rodrigues & Vargas, 2014; Lemos, Souza, et al., 2014; Rodrigues *et al*., 2010). Using force platform data, Rodrigues *et al.* (2010) found that only kinaesthetic imaging performing calf raises resulted in increased postural sway in the directions specific to the task (anterior-posterior), but visual imagery of performing calf raises or control imagery of singing "Happy Birthday" did not. Surface EMG of posterior calf muscles showed no change in amplitude during motor imagery (Rodrigues et al., 2010). EMG data from the same study were later analyzed to find that, although the mean amplitude of EMG did not change while imaging performing calf raises, center of pressure changes and EMG fluctuations of the posterior calf muscle were correlated and synchronized (Lemos, Rodrigues, & Vargas, 2014).

Task-specific postural sway changes have also been detected during several other motor imagery tasks. These include calf raising, whole-body forward reaching, and whole-body lateral reaching (Lemos, Souza, et al., 2014), imagined arm movements (Boulton & Mitra, 2013), and jumping (Grangeon, Guillot, & Collet, 2011). Taken together, motor imagery in the standing position produces some motor execution in the form of modulating postural sway in directions specific to the task being imagined.

Outside of controlled conditions in the laboratory, it is likely that at least some executed movement is occurring in many practical applications of motor imagery. In some cases, this overt movement may be inadvertent, and below the imager's level of awareness. In other applications of motor imagery, the executed movement is an intended and conscious aspect of the motor imagery technique (Guillot, Di Rienzo, MacIntyre, Moran, & Collet, 2012). Tai Chi xin yi/mind-intention is a practical application of motor imagery accomplished by intentionally allowing conscious movement execution, but it is not the only one. Take the example of the Olympian who is mentally imagining her ski jump before its execution. Her motor imagery is typically accompanied by movements relevant to the key features of the jump, perhaps for the purpose of enhancing the vividness of her imagery task (Lorey, Bischoff, Pilgramm, Stark, Munzert & Zentgraf, K., 2009). Whatever the reason, it seems that the practical application of imagined movement includes some degree of execution (Gandevia, Wilson, Inglis, & Burke, 1997; Guillot et al., 2012).

It has been suggested that relaxation, imagination and action are a continuum (Gandevia, *et al*.,1997), a suggestion validated by increases detected in resting muscle activity and reflex excitability during motor imagery (Bonnet et al., 1997; Guillot, *et al*., 2007), and by changes in task-specific postural sway during motor imagery in standing (Boulton & Mitra, 2013; Grangeon, Guillot & Collet, 2011; Lemos, Rodrigues & Vargas, 2014; Lemos et al., 2014; Rodrigues et al., 2010). This continuum is further supported by studies of corticospinal excitability detected by changes in motor evoked potentials (MEP) thresholds during motor imagery. Motor imagery facilitates corticospinal excitability that is both temporally-specific, and muscularly-specific, to the imagined task, but at lower levels of excitability compared to when the same movement is executed (Clark, Tremblay, & Ste-Marie,2004; Guillot et al., 2012; Kumru, Soto, Casanova, & Valls-Sole, 2008; Léonard, & Tremblay, 2007; Rossini et al., 1999; Stinear, & Byblow, 2003; Stinear & Byblow, 2004).

Figure 4.1 depicts a proposed model of the action continuum that consists of rest, imagined movement, and executed movement, and lists evidence-based characteristics of each. This model refutes the notion that motor imagery is necessarily void of any form of execution. Instead, motor imagery may reasonable be understood to include a variable degree of motor activation and executed movement, produced either intentionally or unintentionally.

According to the model, Tai Chi *xin yi*/mind-intention training is a form of motor behavior that lies on the imagined movement segment of the continuum. Specifically, it is a practical application of motor imagery that may allow movement to occur consciously in its full range in accordance with other Tai Chi principles, but otherwise with a level of muscle activation as close to relaxation as possible. Reasonably placing *xin yi*/mind-intention in a category of motor imagery, as proposed here, substantiates the plausibility that this mode of Tai Chi movement facilitates proportionately high-levels of important proprioceptive input associated with more overtly executed movement, as observed in studies of reflex excitability during motor imagery (Bonnet, Decety, Jeannerod & Requin, 1997). It is also makes it plausible that Tai Chi motor imagery practice may improve motor performance as have other motor imagery training interventions.

Determining a conceptual framework that best explains effects of motor imagery is the focus of the next section.

Interpreting Relevant Motor Imagery Research.

Simulation Theory (Jeannerod, 2001) is the prevailing conceptual framework used to explain motor imagery training effects on motor performance. It is at its core representational (Jeannerod 2001, 2010). Simulation Theory posits that action is a continuum of two stages: covert (or unexecuted) action, and overt (or executed action). Covert action precedes overt action, but covert action does not necessarily result in overt action. Covert actions are thought to be mental states in which actions are *represented* in the central nervous system, and are similar to overt actions in terms of content and neural implementation. It is argued that this similarity is so close in neural representation that covert actions are postulated to equal overt actions, minus their execution. According to the theory, unexecuted representations of action occur, and are similar in content, to their corresponding executed actions in a number of mental states, called "S-states." Table 4.1 presents a taxonomy of behaviorally defined S-states (Jeannerod, 2001).

Several studies have been cited to support the assertion that covert action is functionally equivalent to overt action. These studies demonstrate similarity across a wide-range of indicators (Jeannerod, 2010). Chronometric durations of imagined action and executed action have been found similar (Decety, Jeannerod, & Prablanc, 1989; Landauer, 1962; Saimpont, Malouin, Tousignant, & Jackson, 2012, 2013). Spatiotemporal characteristics of overt and covert action are similar with each seemingly following Fitts' Law, an equation that describes the speed-difficulty trade-off that occurs regarding reaching a target (Decety & Jeannerod, 1995; Fitts & Peterson, 1964;

Georgopoulos & Massey). Imagined actions produce similar physiological responses as executed action with regard to heartrates and respiratory rates (Decety, Jeannerod, Durozard, & Baverel, 1993; Decety, Jeannerod, Germain, & Pastene, 1991). Imagined movement produces corticospinal excitability that is temporally-specific and muscle-specific to the same executed movement (Clark et al.; Guillot, et al., 2012; Kumru et al., 2008; Léonard & Tremblay, 2007; Rossini et al., 1999; Stinear & Byblow, 2003, 2004). There is also a high-degree of overlap between imagined movement and execution of the same movement with respect to brain activations (Lotze & Halsband, 2006; Munzert et al., 2009).

Jeannerod (2001) explains, from the representational perspective of Simulation Theory, how the training effect of motor imagery on motor performance is due to the functional equivalence of overt and covert action, and the similarities of their representation in the nervous system:

> …because all aspects of action appear to be involved in S-states, it seems a logical consequence of this rehearsal of the corresponding brain structures, and specifically the motor structures, that the subsequent execution will be facilitated. The presence of activity in the motor system during S-states would put the action representation in a true motor format, so that it would be regarded by the motor system as a real action. This facilitation would explain various forms of training (e.g., mental training) and learning (e.g., observational learning) which occur during S-states (Jeannerod, 2001, p. S108).

It is also assumed that there are ongoing inhibitory mechanisms during motor imagery so that the represented action, in the form of an elaborated central motor command, is not executed (Guillot et al., 2012; Jeannerod, 2010). The main point here is that motor imagery and its training effects, are explained by Simulation Theory as functionally equivalent to executed action in terms of *representation* of action. This explanation of motor imagery effects may be disputed on two fronts. The first disputes their equivalency. The second disputes the conceptual framework from which functional equivalency is argued.

Despite the large body of evidence demonstrating similarities between imagined and executed movement, there is also a long list of departures in similarity, many of which have already been demonstrated. Motor imagery training effects on motor performance are consistently lower than those of executed movement training. There are areas of non-overlapping areas of activation, and differences in degrees of activation, when comparing brain activation patterns occurring during imagined movement and during the execution of the same movement (Lotze & Halsband, 2006; Munzert et al., 2009). Corticospinal excitability is significantly less during movement imagery than during its execution. Similarity in ventilation between imagined and executed treadmill walking has been shown to depend on whether or not participants were competitive athletes (Wuyam et al., 1995). Similarity in chronometric characteristics has been shown to break-down depending on the task-demands (whether or not carrying weight, or in congruent body position during motor imagery, or familiar with the task), and depending on the age of the participants (Decety, Jeannerod, & Prablanc, 1989; Saimpont, Malouin, Tousignant, & Jackson, 2012; Nadja Schott & Munzert, 2007). In sum, the effects of actual movement and imagined movement are non-equivalent in many respects.

On another front, the idea of representational motor program is at the very heart of the conceptual framework of Simulation Theory (Jeannerod, 2006). To assert that *representations* in the central nervous system are the same in both imagined and executed movement assumes that, 1) representations are a necessary component of human motor behavior, despite their lack of explanatory value, and 2) the central nervous system has enough storage space to include instructions for all the content of those representations, including the motor system's enormous number of available degrees of freedom. The implausibility of these assumptions has already been demonstrated in Chapter 3.

Tai Chi *Xin Yi*/Mind-Intention as a Constraint on Postural Control Synergies.

An alternative and non-representational theoretical framework for understanding effects of motor imagery training is through the dynamic systems approach explained in Chapter 3. This conceptual framework posits that motor imagery is a cognitive constraint that is attributable to the individual, and along with constraints attributable to the task and the environment, shapes the formation of postural synergies in a self-organized postural control system (Figure 3.11). Within this framework, Tai Chi *xin yi*/mind-intention training is understood as a (cognitive) task constraint that may be categorized as motor imagery. As motor imagery it constrains motor behavior to produce real motor effects that are distinguishable from both complete relaxation and fully executed movement (Figure 4.2).

Summary of Conceptual Review (Chapters 2, 3 and 4).

Chapter 2 demonstrated that the problem of falls is primarily one of old age, and that its underlying mechanisms are complicated, non-additive in their effects, and associated with a wide-range of multiple bodily systems and innumerable environmental factors that defy placement into absolute intrinsic or extrinsic categories. It was argued that reductionist approaches to fall risk and falls prevention are inappropriate given the complex and interactive nature of component fall risk factors.

Building on this base, Chapter 3 presented a systems-oriented conceptual framework consonant with the holistic nature of postural instability in old age. The phenomenon of postural instability in old age was explained as the gradual decline of *robustness* in a postural control system's ability to adapt to intrinsic and environmental threats. Falls in old age emerge as the result of this decline in system robustness. A dynamic systems theoretical framework was outlined that views postural control as the result of synergies wherein individual, task and environmental constraints combine and reduce available degrees of freedom. On the basis of the loss of complexity hypothesis, complexity-based measures of postural sway data are suggested to be indicators of a postural control system's robustness.

Chapter 3 ended with an explanation of Tai Chi as a systems strategy for robust postural control into old age. It was hypothesized that Tai Chi principles are a family of interacting physical and cognitive constraints on motor behavior, and that the Tai Chi characteristic known as silk-reeling is a class of synergies that emerge as a result, and enable a high degree of postural stability.

If this hypothesis is correct, then when Tai Chi motor imagery (*xin yi*/mind-intention) is performed in quiet standing by experts who have had extensive training in Tai Chi principles, silk-reeling postural control synergies may emerge, and their level of robustness may be captured with complexity-based, non-linear analysis of postural sway center of pressure data. Findings from this kind of research may have important implications toward optimizing strategies to prevent falls in older persons.

The research presented in the next chapter is a quasi-experimental design, the purpose of which is to explore effects of Tai Chi motor imagery during quiet standing, in both Tai Chi experts and those naïve to Tai Chi practice, on measures of postural sway. These measures include traditional measures of path length and standard deviations of sway amplitude, and one complexity-based measure, Sample Entropy (SampEn).

Specific aims of this research are:

Specific Aim #1: To develop a methodology to investigate Tai Chi motor imagery

Specific Aim #2: To investigate people's self-rated ability to perform motor imagery.

Specific Aim #3: To explore the effects of Tai Chi motor imagery on postural control.

Specific Aim #4: To compare traditional measures with a complexity-based measure of motor imagery effects on postural control.

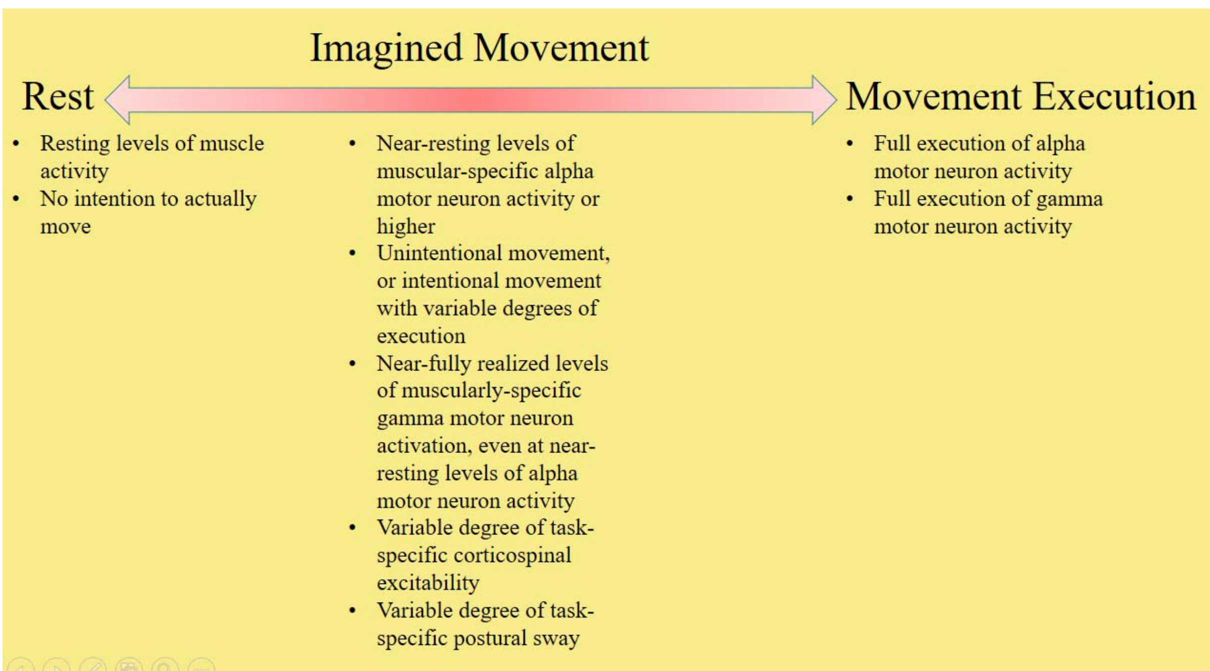
In chapter 5 I outline the research design and methodology employed in addressing these aims.

Table 4.1. A Taxonomy of Behaviorally Defined S-States.

Type of S-state	Degree of Awareness
Intended action	Conscious/non-conscious
Imagined action	Conscious
Prospective action judgments	Non-conscious
Perceptually based decisions	Non-conscious
Observation of graspable objects	Non-conscious
Observation of actions performed by others	Conscious/non-conscious
Action in dreams	Conscious

Source: Taken from Jeannerod, 2001, Table 1, p. S104.

Figure 4.1. The Action Continuum.



Source: Inspired by Gandevia et al., (1997).

Chapter 5: Research Design and Methodology

Overview

I have argued that falls are a huge problem in old age and that research into fall risk and prevention for older adults has been reductionist, including research completed to date evaluating Tai Chi training's effectiveness in falls prevention. I have postulated that postural instability in old age is at the root of the falls problem and that postural instability emerges from changes in a complex, dynamic postural control system.

Tai Chi training is a systems-oriented approach that promotes robust postural control throughout a person's life and extending into old age. The Tai Chi movement characteristic known as silk-reeling is described by experts as a spiraling force connecting and unifying the entire body such that it moves and functions as a single unit. This facilitates a high degree of postural stability (Yang et al., 2005). Based on a dynamic systems theoretical framework, I have hypothesized that silk-reeling is a class of postural control synergies that emerge from correctly performing a family of interacting Tai Chi movement principles. These principles function as constraints which shape and form postural control synergies. *Xin yi*/mind-intention is one of these interacting Tai Chi principles, a principle that can be reasonably categorized as motor imagery. If Tai Chi motor imagery is integral to the emergence of silk-reeling synergies that enable exceptional postural stability, then its effects should be detectable in Tai Chi experts, when compared to non-experts, through indicators of postural control system robustness.

Complexity-based, non-linear analyses of postural sway characteristics provide indicators of the robustness of a postural control system. Based on the loss of complexity theory of aging and disease, reduced complexity of postural sway characteristics associated with aging and disease is a sign of a dynamic system that is less adaptable to disturbances, and therefore more likely to fail (Goldberger et al., 2002; Lipsitz, 2002; Vaillancourt & Newell, 2002). Sample Entropy (SampEn) analysis of force platform center of pressure (COP) time series data provides a complexity index based on the degree of irregularity of postural sway variability (Kuznetsov, et al., 2013). SampEn analysis, as described by Ramdani et al. (2009), successfully detects reduced complexity of postural sway characteristics (at levels of significance) in eyes-closed conditions compared to eyes-open conditions during quiet standing in normal young adults (Ramdani, Seigle, Lagarde, Bouchara, & Bernard, 2009). This finding is consistent with a loss of complexity theory of aging and disease (Goldberger et al., 2002; Lipsitz, 2002; Ramdani et al., 2009; Vaillancourt & Newell, 2002). This is a relatively easy and inexpensive method of quantitatively evaluating the complexity, and therefore the robustness, of a postural control system.

The research design presented here is quasi-experimental; it used a matched control group to compare with a group of Tai Chi standing training experts. The purpose was to explore the effects of Tai Chi motor imagery on SampEn and other measures by addressing the specific aims listed at the end of Chapter 4.

Participant Recruitment

Enrollment began June 5, 2015 and ended September 25, 2016. Sixty-five participants were actually involved in the study (22 females and 43 males). I excluded one male participant's data because important information needed for matching a control was discovered to be missing after data collection and the participant could not be contacted. The outcome was that a total of 64 participants (22 females and 42 males) were included in the study.

This sample for the experimental component of this study included 32 individuals with extensive Tai Chi training and 32 individuals without such training as a control group (n=32 per group). A power analysis for ANOVA designs (Friendly, 2007) revealed that for a similar n=35 per group and $p < .05$, the probability of finding a main effect of size Delta = .500 (medium) is .835. The n used in this study was comparable to the n used in the power analysis, and therefore has a similar probability of finding a main effect of the same effect size. The high power of this study marks a strength of the study design, and indicates a relatively low probability that there were Type II errors (that is, concluding that there was no effect when there actually was one). Details of the power analysis are available in Appendix A.

Males and females of all ethnic groups who were 20 years of age or older and living independently in the community were eligible for the study. Exclusion criteria included self-reported inability to walk continuously for 15 minutes unassisted; inability to read, write, and speak English; and the presence of certain medical conditions. These conditions included vestibular disorder, dementia, mild cognitive deficit, stroke, neurological condition (e.g., Parkinson's disease, seizure disorder, or peripheral neuropathy), significant neuromuscular or musculoskeletal conditions or impairment, cardiovascular conditions (angina, myocardial infarction, atrial fibrillation, or presence of pacemaker), or any acute medical condition requiring hospital admission within six months prior to participation.

Each participant signed a University of Kentucky Institutional Review Board approved consent form prior to participation in the study (included as Appendix B). Participants consisted of two groups: experts in Tai Chi standing motor imagery, and persons naïve to Tai Chi standing motor imagery.

Experts in Tai Chi Standing Motor Imagery. I defined experts in Tai Chi standing motor imagery as individuals with five years or more experience with Tai Chi standing meditation training, also known as standing *wuji* meditation training. All participants in the expert group were recruited from a community of Tai Chi players who gather from around the United States and abroad to attend one to three, five-day-long Taiji and Qigong intensive training camps in Blowing Rock, NC, offered by the Center for Taiji Studies™ (Yang, 2016). Although these experts have a variety of Tai Chi training and instructional backgrounds, they share a common training experience of Tai Chi principles as taught by the particular curriculum at camps offered by the Center for Taiji and Qigong Studies™. Many of the experts use the same curriculum while training with their local Tai Chi communities. This is a curriculum that holds standing meditation as essential practice toward acquiring Tai Chi movement skill characteristics, including silk-reeling. It includes in its standing meditation training the Tai Chi motor imagery investigated here (Yang, 2007; Yang, 2016; Yang et al., 2005; Yang et al., 2007).

Recruitment of experts occurred during two six-day long Taiji and Qigong intensive training camps held at the Blowing Rock Conference Center in Blowing Rock, NC. One was held from June 5-10, 2015, and the other from August 9-14, 2016. Recruitment began at each camp after I spoke directly to the campers prior to the first training session. Recruitment continued through group announcements, and as I spoke individually to campers about the study during times between and after training sessions. Those who participated were asked to "spread the word" to other campers about the opportunity to be involved. Typically, potential participants were provided with the Informed Consent Form and Participant Intake Information Form (see Appendices B and C) at the time of scheduling an appointment for participation, in case they wished to examine them beforehand.

Persons Naïve to Tai Chi Standing Motor Imagery. This group was defined as persons with no experience with Tai Chi standing motor imagery training, and was designed to serve as a matched control to the expert group. Participants were recruited from communities in Kentucky including Lexington, Georgetown, Flemingsburg, and small communities in Northern Kentucky. One was a resident of Tennessee but was visiting Kentucky at the time of participation. I recruited participants in the naïve group to match as closely as possible those in the expert group on characteristics of sex, race and age.

Methods of recruiting the naïve group included directly speaking to individuals, emailing, telephoning, and handing-out or posting lists of the characteristics of individuals in the expert group for whom matches were needed. Persons recruited included family members, friends and acquaintances. Also participating were faculty and staff from the University of Kentucky Graduate Center for Gerontology and College of Public Health, and their families and friends. Several who participated helped recruit additional matching participants for the naïve group.

Procedures for Data Collection.

Data collection for each participant occurred at a mutually agreed upon place and time. For the expert group, all data collection occurred either in a lodge room or in a meeting room at the Blowing Rock Conference Center in Blowing Rock, NC. For the naïve group, data collection was conducted in an office in the University of Kentucky Graduate Center for Gerontology, at my home in Flemingsburg, KY, or in the participant's home. This required moving testing equipment (force platform, cords, connectors, and laptop computer) from place to place. The places of data collection were generally well lit, quiet, and at a comfortable temperature, and were chosen to facilitate minimal distraction.

Informed Consent. At the commencement of each data gathering session, I gave each participant an Informed Consent Form approved by the University of Kentucky Institutional Review Board (see Appendix A). Each participant was given as much time as they needed to read the form, ask questions, and demonstrate understanding. Usually this required fifteen minutes or less. I reviewed inclusion and exclusion criteria with each participant to ensure that they were qualified for the study. Each participant gave their informed consent by signing and dating the form. I then dated and signed the same form. A copy of the signed form was provided to each participant.

Participant Intake Information Form. Each participant completed a Participant Intake Information Form (see Appendix B) to self-report their years of experience with Tai Chi standing meditation training, and the following demographic and health-related information: age, sex, ethnicity, height, weight, history of diabetes, peripheral neuropathy, cardiovascular disease, chronic obstructive pulmonary disease and osteoarthritis, highest level of education attained, and average hours of exercise per week.

Postural Sway Test. This test required the participant to stand on a stationary force platform under four different conditions:

1. Eyes open while performing a Tai Chi motor imagery task;
2. Eyes open while performing a control motor imagery task;
3. Eyes closed while performing a Tai Chi motor imagery task;
4. Eyes closed while performing a control motor imagery task.

The Tai Chi motor imagery task consisted of three sub-tasks performed simultaneously. These were: (a) imagining a relaxed bodily feeling of peace and tranquility; (b) imagining growing an inch in an upward direction from the point at the center of the crown of the head; and (c) imagining standing in water while giving oneself permission to sway randomly, passively and slowly, as if there was a gentle current in the water. The control motor imagery task was imagining singing "Happy Birthday" throughout the duration of the task. The four conditions of the postural sway test are illustrated in Figure 5.1.

I explained to each participant that, in contrast to visual imagery in which one images the visual appearance of something, motor imagery involves imagining what a movement, exertion, or posture *feels like* in his or her body as if they were actually doing it. I also explained that, although visual imagery might be experienced during the test, the focus of attention was to be the motor imagery task. Similarly, during the control motor imagery of singing "Happy Birthday," I explained that imagining the melody would likely be experienced, but that one's attentional focus was to be on imagining the bodily (kinesthetic) feelings of the task.

Participants stood barefoot on the force platform (502 x 502 x 44.96 mm), facing a wall approximately one meter away, in a quiet stance with feet positioned comfortably at shoulder width apart, allowing their arms to suspend naturally along their trunk, and with their hips and knees very slightly and comfortably bent. Participants maintained this stance for three trials of up to 60 seconds for each of four different conditions performed in random order. I used a random number generator (RANDOM.ORG, 2016) to determine the sequence of trials. I asked participants to keep the same position of their feet on the platform throughout the duration of the test, but informed them that between trials they could move the rest of their body as they wished. If they needed to step off the platform prior to completing the activities in order to rest, they might do so after I had marked their foot positions. All participants were able to maintain their foot positions through the duration of this data collection. Using an AMTI Accusway system (Advanced Mechanical Technology, Inc., Watertown, Massachusetts) force platform, center of pressure coordinates were recorded with force signals sampled at a rate of 200 data points per second (200 Hz.).

After each trial, participants self-rated how easy, or difficult, it was to feel the imagined kinesthetic sensations. I used an ordinal scale of 1 to 7 developed by Hall & Martin (1997). In this scale, 7 is very easy to feel, 6 is easy to feel, 5 is somewhat easy to feel, 4 is neutral (not easy, not hard), 3 is somewhat hard to feel, 2 is hard to feel, and 1 is very hard to feel (Hall & Martin, 1997). I recorded each score immediately in a notebook.

After each participant completed all tasks, I exported center of pressure (COP) data to produce a text data file for each of the twelve trials (three trials for each of the four test conditions). At the sampling rate of 200 Hz, each 60-second trial produced a text file containing 12,000 data points described in two columns. In the chronological order that the 12,000 data points were collected, the first column contained the COP positions on the anterior-posterior (A-P) axis, and the second column contained the COP positions on the medial-lateral (M-L) axis of the force platform. Formatting COP data in this manner made it appropriate for further analysis. This step of the procedure required less than 10 seconds.

Once the text data files were saved, I told each participant that the test was completed and that they could step off the force platform. I thanked each participant for volunteering their time and effort on behalf of my study, and answered any questions that they wished to ask about the research. Participants were not compensated, monetarily or otherwise, for their participation. Typically, the entire postural sway test required thirty minutes or less.

Data Analyses

Postural sway results, scores of self-rated ease of kinesthetic imagery, and participant characteristics were entered and organized into Microsoft Office Excel 2016 spread sheets (Microsoft Corporation, Redmond, WA), and then converted into text files for subsequent statistical analysis.

Traditional Postural Sway Measures. Traditional postural sway measures include COP path length, and standard deviations of A-P and M-L COP displacement. These traditional measures offer static values indicating the magnitude of postural sway.

They do not provide insight into the variability of COP change across time, as do non-linear analyses of COP trajectories.

In this experiment, I performed analysis of path length and standard deviations of A-P and M-L COP displacement using MATLAB R2015b software (student version 8.6.0.2672246, the Mathworks, Inc., Natick, MA). This step of the analysis produced results that were saved in a CSV data format. I converted these to TXT data files in a format suitable for further statistical analysis.

Sample Entropy. A key advantage of this study was its use of a sophisticated non-linear method of measuring postural sway. Although traditional measures provide indications of postural sway magnitude, these measures cannot take into account how postural sway evolves and varies over time. The non-linear method of analysis used here known as Sample Entropy (SampEn) has advantages over traditional measures of postural sway because it can provide an indication of a postural control system's robustness.

In general, Sample Entropy (SampEn) analysis is a method used to quantify the degree of irregularity that occurs in a time series (Kuznetsov et al., 2013; Richman & Moorman, 2000). As applied to postural sway data, the higher the value of the SampEn statistic of a center of pressure (COP) time series, the greater the irregularity of the time series, indicating a more unpredictable, random, and therefore, more complex output of a postural control system. Reduced regularity of COP trajectories, as indicated by a lower SampEn value, has been documented in eyes closed versus eyes open conditions (Newell, 1998; Ramdani et al., 2009; Donker et al., 2007). These findings support a hypothesis that the loss of complexity in physiological systems associated with aging or disease indicates a reduction in the number of, or interaction among, subsystems, which renders the system less robust because of its smaller range of adaptive responses (Goldberger, 1996, 2002; Lipsitz, 2002).

SampEn analysis of human postural sway as described by Ramdani et al. (2009) employs a method of parameter selection that is able to detect lower SampEn in young adults in the eyes closed condition (versus eyes open condition) during quiet standing. Performing SampEn analysis of the same data, but with standard parameters failed to make this distinction. Neither did a similar method of analysis, known as Multi-Scale Entropy analysis (Ramdani et al., 2009). The method of SampEn described by Ramdani et al. (2009) was the chosen method of analysis because it was better able to distinguish a loss of complexity in a postural control system when the interacting visual component was removed.

I performed SampEn analysis of all COP time series data using MATLAB. Included in this procedure were mathematical transformations prior to the actual SampEn analysis to address two important properties of the time series that affect the validity of SampEn results. The first property is *sampling rate*. A sampling rate that is too high can lead to erroneous results. During the postural sway test, I collected data on center of pressure at a rate of 200 data points per second (200 Hz.). The sampling rate of time series was mathematically transformed to a lower rate, or *down sampled*, from 200 Hz to 20 Hz. in order to avoid an oversaturation of data points that could adversely affect the validity of SampEn results.

The second important property addressed was the *stationarity* of the time series. A stationary time series has a stable mean and variance, and is a requirement for valid

SampEn results. A mathematical transformation of the data known as differencing was performed to ensure that the data used for Samp En analysis was stationary (Kantz & Schreiber, 2004). This procedure standardizes the data in a way that removes temporal trends. The reader is referred to Kuznetsov et al. (2013) for detailed explanation of down sampling and differencing time series data for purposes of SampEn analysis (Kuznetsov et al., 2013).

SampEn analysis provides an index of the irregularity of a COP time series in which larger SampEn values are associated with greater irregularity, and therefore greater complexity, of postural sway. To accomplish this, SampEn analysis calculates the probability that a data point sequence pattern of length *m*, within a tolerance range *r*, will repeat itself for *m* + 1 points, without allowing self-matches (Kuznetsov et al., 2013). Using MATLAB R2015b software (student version 8.6.0.2672246, the Mathworks, Inc., Natick, MA), I used the method described by Ramdani et al. (2009) (partially derived from Lake et al., 2002) to select *m* and *r* parameters necessary for SampEn analysis. In accordance with the method, parameters *m* and *r* were chosen separately for A-P and M-L directions of COP displacement and kept constant for all statistical comparisons (Lake et al., 2002; Ramdani et al., 2009). The procedure resulted in selecting an *m* value of 1.0 and an *r* value of 0.10 as the parameters values appropriate for SampEn analyses of both A-P and M-L COP time series.

I performed SampEn analyses of A-P and M-L COP time series all postural sway test trials using MATLAB R2015b software (student version 8.6.0.2672246, the Mathworks, Inc., Natick, MA). This step of the analysis produced results that I saved as

CSV data files. I converted these to TXT data files in a format suitable for further statistical analyses.

Self-Reported Ease of Imagery. I organized all self-reported ease of imagery scores into an Excel spreadsheet, and then saved the scores in a CSV data file in a format suitable for further statistical analysis.

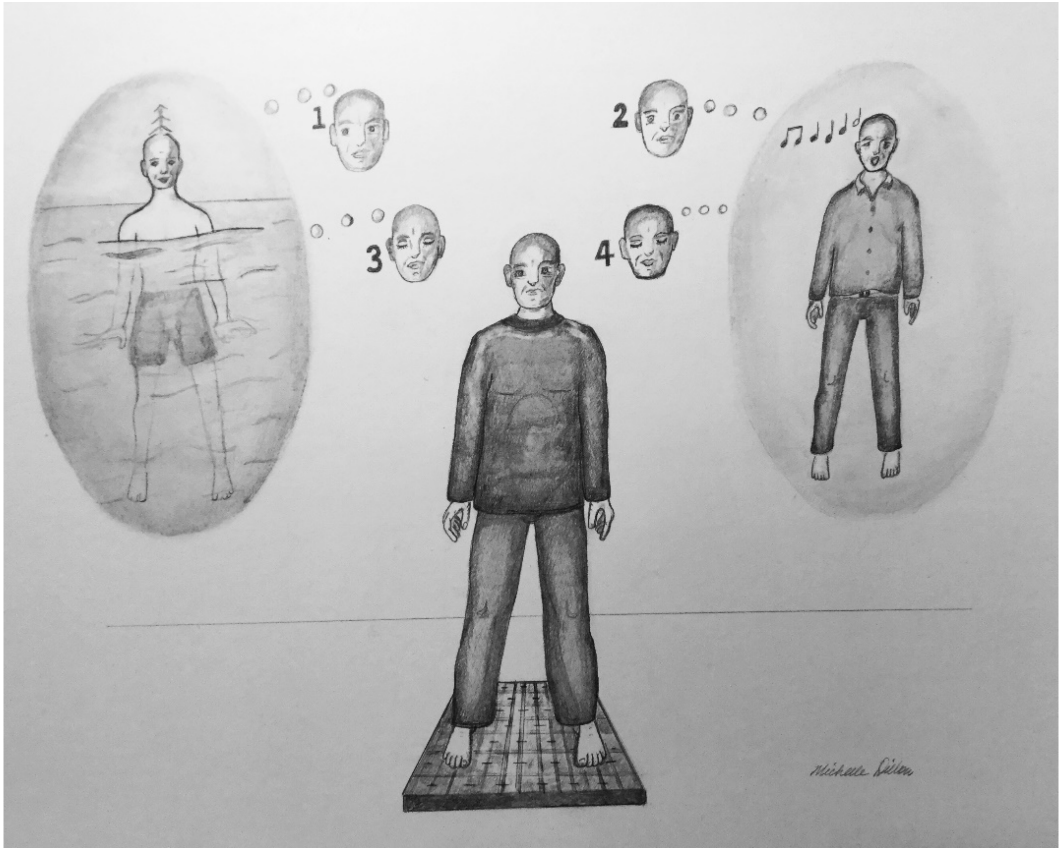
Analyses of Variance (ANOVAs). Group (expert or naïve), condition of eyes (open or closed), and type of imagery (Tai Chi or control) were the independent variables for ANOVAs. Using CSV data files produced as described above, Proc Mixed ANOVAs were used to make statistical comparisons describing the main and interacting effects of the independent variables on each of the following six dependent variables:

1. Anterior-Posterior (A-P) Sample Entropy (SampEn);
2. Medial-Lateral (M-L) SampEn;
3. A-P center of pressure (COP) displacement standard deviation (SD);
4. M-L COP displacement standard deviation (SD);
5. COP path length; and
6. Self-reported ease of imagery score

ANOVAs were performed using SAS software (SAS Institute, Inc., Cary, NC).

In this chapter I have described the research methodology and design of an empirical study in which I apply the systems-oriented approach to the problem of falls that was developed in chapters 2, 3 and 4. In chapter 6, I describe participant characteristics, and present results and findings of the ANOVAs as they pertain to each of the four specific aims. I also offer preliminary comment on salient features of those results and findings.

Figure 5.1. The Four Conditions of the Postural Sway Test.



Source: Dillon, 2016.

Chapter 6. Findings and Results from the Empirical Study

The findings of this dissertation are organized and presented in six sections. The first describes the characteristics of the sample. The next four sections present results as they pertain to each of the four Specific Aims and include findings of statistical comparisons generated by the Proc Mixed ANOVAs as described at the end of Chapter 5. A comprehensive report of statistical comparisons generated by the Proc Mixed ANOVAs is included as Appendix D. The final section offers an integrative overview of the chapter.

Participant Characteristics.

Table 5.1 describes participant characteristics separately for the group of experts in Tai Chi standing meditation and those naïve to Tai Chi standing meditation. The number of participants included in the study is 64 (22 females, 42 males). All participants in the naive group were recruited to match as closely as possible with an individual in the expert group according to sex, race and age. All in the naïve group were matched by sex, and all but two were matched by race. Age was matched to within +/- four (4) years. Notable exceptions were a pairing of males with 8 years' age difference, a pairing of females with 5 years' age difference, and a pair of females with 6 years' difference in age.

Experts had a mean ± SD = 13.6 ± 5.0 years of experience in standing meditation training. Both groups reported similarly high levels of education, although fewer in the expert group reported Master's or Doctoral levels of education than in the naïve group. This was a sample of convenience, and the high levels of education in both groups probably reflect the educational levels of people with whom I am acquainted. Despite similarities in height, the experts reported weighing less, mean ± SD = 161.3 ± 31.0 pounds in experts vs. 194.8 ± 41.1 pounds in the naïve group. Experts also reported engaging in more hours of exercise per week, mean ± SD = 9.9 ± 5.7 in experts vs. 5.3 ± 3.4 in the naïve, which may help explain the dissimilarity in weight between the two groups, despite their remarkable similarity in height. Another explanation may be that Tai Chi experts are more health-conscious and are motivated to maintain a lower body weight. Although the naïve group was recruited to match the expert group in sex, age and race, the two groups were well-matched in other characteristics overall.

The following four sections address each of the specific aims in order.

Specific Aim #1: To Develop a Methodology to Investigate Tai Chi Motor Imagery.

The methodology developed to investigate Tai Chi motor imagery contained aspects that worked well, and other aspects that were challenging. The method of recruitment of Tai Chi experts worked exceptionally well. Experts came from several disparate areas of the US. Recruiting this group as they gathered at a single location to attend two, six-day Tai Chi camps solved the challenging logistics of finding and recruiting enough experts to have a high-powered study. The location of the camps were within a six-hour drive from my home. The campers as a group were enthusiastic about the study and about participating. At one camp, all testing occurred in the same lodge room where I stayed. At the other camp, all testing occurred in a lodge conference room. Having a consistent place to test saved me from carrying and setting-up the testing equipment. It required only 12 total days to recruit and test the entire group of experts.

Recruiting a control group of those naïve to Tai Chi standing meditation was more difficult, particularly because they were recruited to match with the experts in age, sex and race. Several persons I had been recruiting were willing to participate but were not included because they did not match anyone in the expert group. Recruiting and testing the entire matched control group required several months, a much longer period of time than for experts. Testing the naïve occurred at several sites; University of Kentucky offices, my home, and in several homes of participants. Locations of testing controls were in Kentucky including Lexington, Flemingsburg, Georgetown, Edgewood and Villa Hills. Frequently this required loading, carrying, assembling and disassembling testing equipment between tests. Testing in a participant's home involved deciding upon and preparing a room that was free from distractions, well lit, and with access to power outlets.

Testing equipment was quickly and easily available from the University of Kentucky musculoskeletal lab throughout the testing periods. Participants scored their ease of motor imagery without exception or significant delay. All participants endured the entire postural sway test without needing to step off the force platform to rest. All participants maintained their balance throughout the test, and gave no indications that they felt unstable.

The test duration was a methodological concern after piloting. The pilot study had less stringent inclusion and exclusion criteria. Eligibility for the pilot required that participants did not use an assistive device to walk, and had the ability to walk unassisted for 15 minutes. As a result, some of the eligible pilot participants were unable to endure the postural sway test without interrupting the test to sit and rest. This required marking the position of the feet prior to stepping off the platform so that they might later resume the test in the same foot position. There were other related concerns. Pilot participants with low endurance gave indications that balance was significantly challenged in eyes closed conditions, and required close supervision during testing. There was also a concern that fear may be induced in a participant whose balance is significantly challenged during testing.

The development of inclusion and exclusion criteria for this study design were informed by concerns identified during piloting that, once addressed, provided a sample with a level of endurance to complete the postural sway test without interruption. The concerns recognized in piloting raise the question of how the methodology might be modified to include an older, frailer sample, especially since their likely increased risk for falling make them a study population of interest. Possible solutions are to consider shorter testing durations, and provide stable grab bars around the participant and/or closer standby supervision by one or more research personnel to facilitate a feeling of security.

Specific Aim #2: To Investigate People's Self-Rated Ability to Perform Motor Imagery.

Participants self-rated how easy, or difficult, it was to feel the imagined kinesthetic sensations after each trial on an ordinal scale of 1 to 7 developed by Hall & Martin (1997). In this scale, 7 is very easy to feel, 6 is easy to feel, 5 is somewhat easy to feel, 4 is neutral (not easy, not hard), 3 is somewhat hard to feel, 2 is hard to feel, and 1 is very hard to feel (Hall & Martin, 1997).

Table 6.2 presents the mean scores of self-reported ease of imagery. These results suggest that, on average, participants of both groups reported they were able to perform both the Tai Chi and control motor imagery tasks without difficulty.

For all imagery, greater ease of imagery was reported by experts vs. the naïve at a high level of significance, $F(1,62) = 29.84$, $p < 0.0001$. This is perhaps not surprising given that experts have had extensive training is standing motor imagery, though their training would not have included imagining singing Happy Birthday. For all participants, a significantly greater ease of imagery was reported with eyes closed vs eyes open, $F(1,62) = 23.58$, $p < 0.0001$, possibly because closing the eyes removed visual input that could distract from the task of focusing attention on the private bodily sensations related to the motor image.

Experts and the naïve participants differed in their rating with respect to the ease of performing Tai Chi vs. control imagery. Experts reported greater ease with Tai Chi vs. control motor imagery at a level of significance, $F(1,62) = 37.09$, $p < 0.001$. Conversely, the naïve participants reported greater ease with the control imagery, also at a level of significance, $F(1,31) = 6.74$ $p < 0.02$. One might expect that experts would have greater ease with the Tai Chi imagery given that they have had extensive training in its performance, but it is curious that the naïve found the control imagery easier to feel. One possible reason is because the Tai Chi motor imagery is a more complex task than the control imagery, and this made it relatively harder to feel by the naïve.

There was a significant interaction between eye condition and imagery type with respect to scores of imagery ability: In the eyes closed condition, participants rated significantly greater ease with Tai Chi imagery than with control imagery, $F(1,31) =$

11.01, $p < 0.0015$, but in the eyes open condition, no significant difference was found between the two types of imagery, $F(1,31) = 2.52$, $p < 0.1175$. Among all participants, this result suggests that closing the eyes facilitates greater ease of the Tai Chi motor imagery task to a degree that makes it significantly easier to feel than the control imagery, despite the greater complexity of the Tai Chi imagery task.

Specific Aim #3: To Explore the Effects of Tai Chi Motor Imagery on Postural Control.

Effects of Tai Chi Motor Imagery and Sample Entropy. The SampEn results represent the most important findings of the quasi-experiment because they relate directly to my hypothesis. No statistically significant differences were found between the two types of imagery on A-P or M-L SampEn values. Experts did, however, have lower M-L SampEn values during Tai Chi motor imagery compared to control motor imagery at a level that approached significance, $F(1,31) = 3.46$, $p < 0.07$, whereas the naïve group did not, $F(1,31) = 1.49$, $p < 0.25$.

These findings do not support my hypothesis that greater postural sway complexity, as measured by SampEn, is associated with Tai Chi motor imagery. My prediction that Tai Chi motor imagery would result in increased SampEn in this study may not have adequately considered the conditions during which other research has found Tai Chi-related increases in postural sway complexity. Detailed explanation about why I was wrong in my prediction, and how my overall hypothesis may still stand, is offered in the next chapter.

Effects of Tai Chi Motor Imagery on Traditional Postural Sway Measures of A-P COP Displacement SD, M-L COP Displacement SD, and COP Path Length. Participants demonstrated a main effect of greater A-P COP displacement SD during Tai Chi motor imagery compared to the control imagery at a level of significance, $F(1,62) = 16.49$, $p < 0.0001$. There were no main effects with respect to imagery type in M-L COP displacement SD, $F(1,62) = 1.09$, $p < 0.35$, or path length, $F(1,62) = 1.96$, $p < 0.20$.

The naïve group had significantly greater A-P COP displacement SDs with Tai Chi imagery than with control imagery, $F(1,31) = 19.85$, $p < 0.0001$, but among experts, the type of imagery made no significant difference in A-P sway, $F(1,31) = 0.71$, $p < 0.45$. The interaction between group and imagery type with respect to M-L sway was particularly curious. The naïve group produced significantly *higher* M-L displacement COP SDs during Tai Chi imagery than during the control imagery, $F(1,31) = 5.65$, $p < 0.025$. In contrast, experts had significantly *lower* M-L displacement during Tai Chi imagery than during control imagery, $F(1,31) = 6.74$, $p < 0.015$. Task-specific postural sway changes are known to occur as the result of performing motor imagery during quiet standing (Boulton & Mitra, 2013; Grangeon, Guillot, & Collet, 2011; Lemos, Rodrigues, & Vargas, 2014; Lemos et al., 2014; Rodrigues et al., 2010). Part of the Tai Chi motor imagery task, that was not included in the control task, was imagining standing in water with a gentle current. The greater sway found in the naïve during Tai Chi motor imagery may have been the result of task-specific sway modulations. An explanation of why an opposite result was found in experts may relate to their Tai Chi training. The discussion in the next chapter examines these possibilities more closely.

Specific Aim #4: To Compare Traditional Measures with a Complexity-Based Measure of Motor Imagery Effects on Postural Control.

This study employed the complexity-based measure, SampEn, and three traditional measures of postural sway in order to discern effects of Tai Chi motor imagery on postural control. When comparing the results of these two types of postural sway metrics as they relate specifically to effects of motor imagery, we find no main effects of imagery at levels of significance with respect to A-P or M-L SampEn. In contrast, a main effect of imagery was found with respect to A-P COP displacement SD, and there was significantly greater sway in this direction during Tai Chi motor imagery that during control imagery. The lack of statistically significant differences in SampEn with respect imagery type is unexpected, and not the result I predicted on the basis of my hypothesis. As intimated earlier, the equivocal SampEn results might be reasonably explained without rejecting my hypothesis, and are an important topic of discussion in Chapter 7.

No significant differences were found in SampEn values between Tai Chi and control imageries, or between eyes open and eyes closed conditions, in either the expert or the naïve groups. Using traditional measures, some of these differences were statistically significant. The naïve group had significantly *more* A-P displacement and M-L displacement, and experts had significantly *less* M-L displacement, during Tai Chi imagery compared to control imagery. As mentioned in the previous section, these are particularly interesting findings with plausible explanations to be covered in detail in the chapter that follows.

No significant main effect was found in A-P or M-L SampEn with respect to group, but experts did have lower A-P SampEn values than did the naïve at a level that approached significance, $F(1.62) = 2.81$, $p < 0.10$. My hypothesis is that Tai Chi motor imagery is associated with greater postural sway complexity as evidenced by higher SampEn values. The lower SampEn values were the opposite finding of that which I predicted. An explanation for the unexpected finding may lie in whether training effects of Tai Chi-related training are best captured in quiet standing during, or not during, motor imagery. If training effects of Tai Chi motor imagery are best detected in quiet-standing-alone, then testing this condition during future investigations of this sort is critical.

In contrast to the lack of significant effects found in SampEn, significant main effects were found in A-P COP displacement SD and COP path length. The expert group was found to sway with significantly higher A-P COP displacement SD, $F(1,62) = 4.93$, $p < 0.04$, and longer COP path length, $F(1,62) = 5.53$, $p < 0.025$, when compared to the naïve. These two findings are meaningfully related since path length is representative of movement that includes A-P, as well as M-L, directions.

SampEn measures detected no significant main effect with respect to eye condition (open versus closed). This is a surprising result given that method of SampEn analysis used in this study has been reported to detect lower Sampen values in eyes closed vs. eyes open conditions in young adults in quiet standing and without the added task of motor imagery (Ramdani, et al, 2009). The results suggest that these differences in sway complexity between eyes open and eyes closed condition disappear with the introduction of a motor imagery task. To my knowledge, these findings are new, and important for informing future research on effects of motor imagery on postural sway complexity measures.

In contrast to the equivocal results of SampEn, the use of traditional measures found significantly greater A-P COP displacement SD, $F(1,62)$ 16.88, $p < 0.0001$, M-L COP displacement SD, $F(1,62) = 128.98$, $p < 0.0001$) and COP path length, $F(1,62) = 62.40$, $p < 0.0001$, during eyes closed vs. eyes open conditions. Substantial increases in postural sway magnitude are typical in eyes closed vs. eyes open conditions, and results of these traditional metrics are not surprising (Latash, 2012). Overall, traditional measures were more sensitive in detecting main effects and interactions of the particular motor imageries of this study than were A-P or M-L SampEn measures.

Overview.

To summarize the description of the sample, characteristics of the expert and naïve groups were remarkably similar. A notable exception was the greater body weight reported by the naïve, despite the groups' very similar heights, a difference that may be explained by the greater number of hours of exercise per week reported by experts.

Recruitment and testing of the sample required much less time and trouble in the expert group, and is a strength of the study's design. Recruiting a naïve control group matching those in the expert group had challenges but was successful nonetheless. By all indications, the postural sway test and self-rating of imagery ability went smoothly for the entire sample in terms of understanding and performing the tasks, and enduring the postural sway test without evidence of excessive balance challenge. Piloting contributed to the success of this study's methodology in this respect.

According to self-reports, all imagery tasks performed by the sample were relatively easy. Experts reported greater ease than the naïve, and greater ease with the Tai Chi imagery compared to the control imagery. The naïve reported that the control imagery was easier to feel. Overall, the findings on motor imagery ability indicate that the measured effects of motor imagery are valid.

In sum, the ANOVAs show a number of interesting findings. The most important to the new approach being tested here is the lack of significant effects of Tai Chi motor imagery on SampEn measures of postural sway complexity. These findings do not support my hypothesis, and were not what I predicted, but neither do they defy an explanation by which my hypothesis still stands. The absence of significantly lower SampEn values in eyes closed vs. eyes open conditions was unexpected, given that SampEn detects these difference in quiet standing without an imagery task. Like the previous finding, these findings do not defy explanation, as will become apparent in the deeper discussion of the next chapter.

The traditional metrics of postural sway, compared to SampEn, were more sensitive to effects related to Tai Chi motor imagery, and to eyes open versus eyes closed conditions. I have already made preliminary comments about these differences in the previous section. In Chapter 7, I discuss these and other findings in depth. I conclude Chapter 7 by exploring innovations, implications, and future directions of the entire project.

Table 6.1. Participant Characteristics.

Characteristics	Experts	Naïve
N	32	32
Tai Chi Standing Meditation Training (years)	13.6 ± 5.0	0
Age (years)	56.8 ± 9.9	56.5 ± 10.4
Sex		
Female	11	11
Male	21	21
Race		
Asian	1	0
Black	1	0
White	30	32
Height (inches)	68.0 ± 3.0	67.8 ± 3.0
Weight (pounds)	161.3 ± 31.0	194.8 ± 41.1
Medical history		
Diabetes	0	2
Peripheral Neuropathy	0	0
Cardiovascular Disease	0	1
COPD*	0	0
Osteoarthritis	5	4
Educational level		
High school	3	1
Some college	2	0
Associate	2	1
Bachelor	12	8
Master	5	10
Doctor	8	11
Exercise per week (hours)	9.9 ± 5.7	5.3 ± 3.4

Data are N or means ± SD. *chronic obstructive pulmonary disease

Table 6.2. Mean Scores of Self-Reported Ease of Imagery.

	Tai Chi Motor Imagery	Control Motor Imagery	Both Imageries
Experts	6.32	5.83	6.08
Naïve	4.93	5.24	5.09
Both Groups	5.63	5.54	5.58

Chapter 7: Discussion

As noted at the outset, this dissertation is presented in two parts. Chapters 2 through 4 form the first part and constitute a critical philosophical and scientific exploration of developing a new approach to the problem of falls in old age. Why develop a new approach? Because the falls problem is enormously costly and disruptive for the older individual, others, and society, and its severity is likely to intensify along with the growing proportion of older persons in our population projected to occur over the next few decades. Chapters 5 and 6 form the second part of this dissertation: here, I describe an empirical study that was conducted to apply this new approach in a pragmatic manner. The purpose of this chapter is bring these two parts together by discussing findings and results of the empirical study, and by discussing the implications, innovations and future directions of the entire dissertation within the broader context of a new way of addressing the problem of falls.

The conceptual basis for the dissertation research discussed here is systems-oriented. This research takes a systems approach toward: 1) understanding the very nature of the problem of falls in old age; 2) presenting a strategy for developing optimal interventions, and; 3) selecting the type of analysis by which to test this strategy. I have postulated that postural instability in old age is at the crux of the falls problem, and that postural instability emerges from gradual changes occurring in a complex, dynamic postural control system. Realizing that falls arise from a complex system of interacting components of various levels and domains, and are not merely the sum of component risk factors, makes it imperative to investigate interventions that are aimed toward systemically fostering robust postural control in the long-term.

In Chapter 3, I explained how Tai Chi training is one such intervention. Tai Chi is a systems-oriented approach that promotes robust postural control throughout a person's life and extending into old age. The systemic nature of Tai Chi's effects on postural control is discerned by the holistic descriptors of the movement characteristics that Tai Chi training intends to develop. Silk-reeling is one Tai Chi movement characteristic that is a holistic descriptor of the motor coordination that Tai Chi training intends to develop. Silk-reeling is described by Tai Chi experts as a spiraling force connecting and unifying the entire body such that it moves and functions as a single unit, and as a result facilitates a high degree of postural stability (Yang et al., 2005).

Based on a dynamic systems theoretical framework, I have hypothesized that silk-reeling is a class of robust postural control synergies that emerge from correctly performing a family of interacting Tai Chi movement principles. These principles function as constraints which shape and form postural control synergies (Table 3.1). *Xin yi*/mind-intention is one of these interacting Tai Chi principles; a principle and constraint that is reasonably categorized as *motor imagery* (see Chapter 4). If Tai Chi motor imagery is integral to the emergence of silk-reeling synergies that enable exceptional postural stability, then its beneficial effects will hypothetically be detectable in Tai Chi experts, when compared to non-experts, through indicators of postural control system robustness.

SampEn is a complexity-based, non-linear analysis that provides an indication of the robustness of a postural control system. When applied to center of pressure (COP) time series data, higher SampEn values indicate greater complexity, and therefore greater robustness of a postural control system. I chose SampEn as the measure of postural control system robustness to serve to test my hypothesis. This study is a first step toward deeper understanding of how a systems-oriented intervention, such as Tai Chi training, may promote postural stability extending into old age. The approach has important implications for generating improved falls prevention strategies.

The first section of this chapter is devoted to reviewing the sample and study design. In the next four sections I discuss the findings with respect to each of the specific aims. Attention is paid to understanding how my experimental results inform the systems approach I have taken in researching the problem of postural instability in old age. Following these sections, I discuss limitations of the research. In the final section I discuss how the study is innovative, and reflect on implications and directions for future research and application.

Sample and Study Design.

This sample for the experimental component of this study included 32 individuals with extensive Tai Chi training and 32 individuals without such training as a control group. A power analysis for ANOVA designs (Friendly, 2007) of a comparable n reveals that this study is high powered for a medium effect size (see Appendix D for details). This high power represents a strength in the study's design, and indicates that the sample is large enough to find effects that are actually present.

The sample was part of a matched subjects design in which participants were assigned to groups based on expertise in Tai Chi standing meditation. That the expert group had an average ± SD = 13.6 ± 5.0 of years' experience in Tai Chi standing meditation represents a strength of this experimental group in terms of its level of expertise. But since the matched subjects design increases the probability that confounding variables are present, conclusions about causality are more guarded compared to a design in which participants are randomly assigned.

The validity of five years' experience in Tai Chi standing meditation as the criterion for expertise in Tai Chi motor imagery may be called into question. The group of experts had all attended Tai Chi camps, and local Tai Chi schools that share a common curriculum of training Tai Chi movement principles and standing meditation, which includes the Tai Chi motor imagery used in the study. This provides one measure of support for the validity of the criterion used to determine expertise. However, future study may consider a more direct and detailed account of the participants' experience of training in Tai Chi principles, and experience with any specific motor imagery being investigated.

The sample was one of convenience and this limits generalizability to a larger population. Any non-equivalence between the groups, apart from the independent variable of Tai Chi standing meditation expertise, also limits how results may generalize to a larger population. The control group was matched closely, though not perfectly, in characteristics of sex, race, age and height. There were notable differences between the expert and naïve groups in reported weight and hours of exercise per week. The non-equivalence in these characteristics between the two groups are possible threats to the external validity of the study. Otherwise, the two groups are remarkably well-matched and this supports the study's external validity.

The high levels of education reported in both expert and naïve groups may invoke caution when generalizing the results of this study to less educated populations. One possibility to consider is that motor imagery ability is associated with educational level. There does not appear to be any salient report of this association in the motor imagery research literature. However, one study found that motor imagery vividness does not abate with age, despite the markedly lower educational levels of the older age group that was compared (Malouin, Richards, & Durand, 2010).

The age range (29-80 years) of the sample precludes conclusions about whether the results of the study would differ or not in an older or younger sample. The methodology is sound (see next section) and seems appropriate for a broader age range. It would be useful in future investigations to explore the interactions of age with expertise and motor imagery type, and the degree to which relationships hold in samples of different age groups, such as 20-39, 40-59, and 60-80 years or older.

Specific Aim #1: To Develop a Methodology to Investigate Tai Chi Motor Imagery.

This research has demonstrated that the methodology developed here to investigate Tai Chi motor imagery can be successfully implemented with efficient and effective recruitment. This includes the logistically challenging recruitment of a group of Tai Chi standing meditation experts with common training experience in Tai Chi principles from a single instructor. It was also demonstrated that participants with a wide age range were successfully able to understand and complete the testing without difficulty.

Specific Aim #1 was achieved. The methodology developed in this dissertation serves as a model for future motor imagery and postural control studies designed to generate optimal strategies for addressing the problem of falling in old age. I suggest that future study take into account that the data collection in this study occurred at several different places and the conditions were not always exactly the same.

This inconsistency in testing conditions represents a limitation in the methodology, particularly regarding the visible field available to participants during postural sway testing with eyes open. During the eyes open conditions of the postural sway test, participants stared at a wall approximately three meters in front of them. Although the appearance of the walls varied between different testing sites, they were all free of wall hangings. The ways in which the walls varied were mainly in color, pattern and texture. For example, at one site the wall had a textured wall paper with red and brown tones, but it had clear a horizontal line in the pattern at about three feet from the floor. At another site, the wall was made of cinder blocks painted an off-white tone. Vertical and horizontal recessed lines were visible in this wall. Another site involved a wall with yellow tones, painted using a rag technique. At a different site, participants stared forward at a paneled door that was painted white, which provided visible horizontal and vertical lines.

This variation among test sites means that the available visual input at different sites varied during the postural sway test, and this could possibly confound comparisons and interpretations concerning eyes open conditions. Consistency in test conditions is important, but in order to make the eyes open conditions distinct from eyes closed conditions, it is desirable to have a visual field during all postural sway testing with eyes open that provides rich and relevant input to the postural control system, such as information about depth, horizon and verticality.

It is recommended that future study implements methods to reduce differences among testing site conditions. However, it should be noted that testing in a setting (even a consistent one) that is very different from that in which Tai Chi motor imagery training is typically performed could threaten the ecological validity of the study.

Overall, study of a systems-oriented intervention, such as Tai Chi training, appears worthwhile and appropriate given the nature of postural instability in old age as a failure in the complex and dynamic system that controls posture. The methodology presented here may serve to inform future systems-oriented research that strives to alleviate the pressing problem of falls in older adults.

Specific Aim #2: To Investigate People's Self-Rated Ability to Perform Motor Imagery.

This aim was achieved. Mean scores of self-reported ease of imagery indicate that both the experts and the naïve participants reported an ability to perform both Tai Chi and the control motor imagery tasks that fell on the "easy" end of the ordinal scale. The degree to which all participants rated their imagery ability suggests that motor imagery can be performed with relative ease, even in those without expertise. On the basis that experts and the naïve seem to be able to perform motor imagery with ease, motor imagery appears to have considerable potential as part of a falls prevention intervention worthy of further study.

Although the quasi-experimental design of the study makes conclusions about causation between subject groups less definitive than if the sample was randomized, the fact that experts reported significantly greater ease with the Tai Chi motor imagery (compared to the naïve participants who reported significantly greater ease with the control imagery) raises the reasonable possibility that increased Tai Chi motor imagery ability is a training effect of years of practice. This notion is reasonable because experts reported significantly greater ease with Tai Chi versus control motor imagery, even though the Tai Chi motor imagery was a more complex task in which three sub-tasks (as opposed to one with the control imagery) were performed simultaneously.

No participants mentioned during testing any difficulty with complying with instructions given beforehand to focus their attention on the motor image during the control motor imagery task, even when the auditory image of the Happy Birthday melody was likely experienced. This is an indication that my instructions on attentional focus prevented a problem in this regard. One participant reported a "bleed-over" effect in which motor images from one imagery task were being experienced during testing of the imagery task. In these cases, the participant was instructed to do their best to bring their attention on the motor imagery task being tested, which seemed to resolve the participant's concern.

Conclusions regarding the participants' imagery ability require caution because imagery ability was self-reported, and may or may not be an accurate measure of actual imagery ability. Furthermore, as with any self-reported measure, a self-reported imagery ability score is vulnerable to expectation bias. Until there is a "gold standard" for measuring motor imagery ability, these may be limitations with which future study must contend as it attempts to quantify motor imagery ability. As with pain, it remains unclear how motor imagery ability may be objectively quantified given the private nature of motor imagery as imagining first-person experiences of kinesthetic bodily sensations. Brain imaging may one day provide a quantitative measure of motor imagery ability by measuring the levels of activation in brain areas known to occur with motor imagery. Even if valid and reliable measures of motor imagery ability could be detected by brain imaging, cost and convenience would likely prohibit how extensively these measures would be used.

Specific Aim #3: To Explore the Effects of Tai Chi Motor Imagery on Postural Control.

Effects on Sample Entropy. The findings most relevant to my hypothesis are the *absence* of statistically significant differences between the Tai Chi motor imagery and the control imagery on A-P or M-L SampEn, and the *absence* of statistically significant differences in A-P or M-L SampEn between the interactions of the two imageries in either experts, or the naïve. These findings fail to support my hypothesis that greater SampEn values would be associated with Tai Chi motor imagery, or with expertise with Tai Chi standing meditation.

One interpretation of these results is that Tai Chi motor imagery training is *not* associated with the formation of more complex and more robust postural control synergies as hypothesized. This interpretation is perhaps bolstered by results of SampEn differences that approached a level of significance. Rather than showing an increase in SampEn associated with Tai Chi motor imagery, the differences approaching levels of significance revealed just the opposite. A-P SampEn was found *less* in experts than in the naïve participants ($p < 0.10$), and in experts, M-L SampEn was found *less* during Tai Chi motor imagery than during the control imagery ($p < 0.07$).

Another interpretation, and one consistent with my hypothesis, is that lack of an increase (or perhaps even a reduction) in the irregularity/complexity of COP trajectories is a phenomenon that occurs in quiet standing *during* intense cognitive training of Tai Chi motor imagery, but that a beneficial training effect of Tai Chi motor imagery of increased postural control complexity is better captured by entropy analysis during quiet standing *without* a cognitive task. My study did not include a test of quiet standing without an additional cognitive task, and therefore could not directly address this notion. Results from other studies suggest, in light of my findings, that this interpretation is plausible and worthy of future investigation (Manor, Lipsitz, Wayne, Peng & Li, 2013; Wayne, Gow, et al., 2014).

Tai Chi training is reportedly associated with increased postural sway complexity in quiet standing without a cognitive task. Wayne, et al. (2014) made cross-sectional comparisons between Tai Chi experts with an average of 24.6 years of Tai Chi training (N = 27, age 62.8 ± 7.5 years) and age-matched Tai Chi naïve participants (N = 60, age 64.5 ± 7.5 years). Using multi-scale entropy analysis to quantify the irregularity of COP trajectories, he found that during quiet standing, *without an additional cognitive task*, the experts exhibited significantly greater irregularity/complexity of sway in the A-P direction with eyes closed, and in the M-L direction in both eyes open and eyes closed conditions. Those naïve to Tai Chi participated in a six month, two-arm, wait-list randomized clinical trial of Tai Chi training. Post hoc analysis revealed that increases in irregularity/complexity of A-P and M-L COP trajectories with eyes closed were positively correlated with Tai Chi practice hours. Manor et al. (2013) found increases in irregularity/complexity in A-P COP trajectories during quiet standing with eyes closed in adults with peripheral neuropathy after 24 weeks of Tai Chi training. These results suggest that Tai Chi motor imagery training effects on postural control system complexity may also be captured using entropy analyses in quiet standing without the condition of an additional cognitive task.

Performing secondary cognitive tasks have effects of their own on postural sway complexity during quiet standing as detected in SampEn analysis. In both pre-adolescent dancers and non-dancers, quiet standing during a dual task of word memorization increased SampEn values when compared to quiet standing alone (Stins, Michielsen, Roerdink, & Beek, 2009). In healthy young adults with eyes closed, quiet standing during a dual task of pronouncing names spelled in reverse order increased SampEn compared to quiet standing alone (Donker, Roerdink, Greven, & Beek, 2007). In stroke patients, quiet standing while performing an arithmetic task produced higher SampEn values as compared to simply standing quietly (Roerdink et al., 2006). One explanation for these increases in postural sway complexity holds that dual tasking diverts attention away from cognitive monitoring of postural control, and allows more automaticity of postural control, as evidenced by the greater irregularity/complexity of postural sway (Donker et al., 2007). Yet, a study of adults over the age of 70 years seems to contradict this interpretation, wherein quiet standing while counting backwards by 3s resulted in *decreased* SampEn values when compared to quiet standing alone (Manor et al., 2010).

These studies demonstrate that an additional cognitive task is known to have (variable) effects on postural sway complexity in quiet standing. My study seems to be the first to investigate the effects of motor imagery during quiet standing. The dual task literature makes it unclear what to expect regarding effects of motor imagery on SampEn measures. Is Tai Chi motor imagery a dual task that diverts attention away from, or attracts attention toward, cognitive monitoring of postural control? If it attracts attention, then it may be expected to reduce complexity of postural sway, according to the interpretation of Donker et al., (2007). This interpretation may explain the decreases in SampEn found associated with Tai Chi motor imagery that approached levels of significance. If during the act of Tai Chi motor imagery training, the automaticity of postural control is being challenged to a greater degree in experts than in the naïve, then this may be reflected by lower SampEn values in experts.

How would this possible scenario fit with my hypothesis? It may be that Tai Chi motor imagery training is the path to, rather than the goal of, robust postural control synergies. The phenomenon of increased postural sway with eyes closed (which has been shown associated with reduced postural sway irregularity/complexity), seems to serve an information gathering function with the purpose of exploring stability limits in a more challenging condition (Donker et al., 2007; Riley & Clark, 2003; Sarabon, Panjan, & Latash, 2013) Tai Chi motor imagery may also be a condition during which information gathering plays a stronger role, which in turn reduces the automaticity of postural control, and is marked by decreased postural sway complexity. Tai Chi motor imagery may function as a cognitive constraint, that not only provides rich proprioceptive information during the training of movement and posture (Chapter 4), but also provides continual training and challenge to limited attentional resources associated with postural control (Chapter 3). In this sense, the practitioner is engaged in ongoing motor-related information gathering and learning during training, no matter the skill level, the goal of which is greater automaticity and system complexity of postural control that is made evident during the absence of intense cognitive training.

Taken together, the results of my study do not support my hypothesis that Tai Chi motor imagery in experts is associated with increased complexity and robustness of a postural control system, but the results do not disprove my hypothesis either. My prediction that SampEn values would be higher in experts *during* Tai Chi motor imagery may have been hasty, given the variability of dual cognitive task effects on, and the unknown effects (until now) of motor imagery on a postural sway complexity measure. It seems plausible that to capture the increased complexity I have hypothesized associated with Tai Chi motor imagery may require testing during quiet standing without an additional task of motor imagery. Including quiet-standing-only test conditions is critical to future investigation of Tai Chi motor imagery effects on postural control that seeks to deepen our understanding of how a systems-oriented intervention may contribute toward solutions to the problem of postural instability in old age.

Effects on Traditional Measures of Postural Sway. The main imagery effect of greater A-P COP displacement SD during Tai Chi motor imagery compared to the control motor imagery may be explained by a difference between the Tai Chi and control imagery tasks. The Tai Chi imagery task differed by its inclusion of a sub-task of "imagining standing in water while giving oneself permission to sway randomly, passively and slowly, as if there was a gentle current in the water" (see Chapter 5). Motor imagery has been reported in a number of studies to modulate postural sway in a manner that is specific to the motor imagery task (Boulton & Mitra, 2013; Grangeon et al., 2011; Lemos, Rodrigues, & Vargas, 2014; Lemos et al., 2014; Rodrigues et al., 2010). The increased A-P sway found during the Tai Chi imagery may be the result of induced sway changes that are specific to the motor imagery sub-task of standing in water.

This specific effect of a Tai Chi motor imagery task on postural sway is consistent with, and may help explain, significant interactions between imagery type and group. Postural sway during Tai Chi motor imagery was significantly greater among the naïve when compared to experts in both A-P and M-L COP displacement SD. If motor imagery falls on a continuum between rest and full execution as previously argued (see figure 4.1), then these results suggest that experts are performing the Tai Chi motor imagery with less imagery task-specific muscle activation than the naïve participants. This may represent a training effect of years practicing this specific motor image. This hypothesis is reasonable given that an essential Tai Chi training principle is to move and stand with as much relaxation as possible. Supporting this notion is the finding that experts had *significantly less*, and that the naïve participants had *significantly more*, M-L sway during Tai Chi motor imagery compared to the control imagery.

Tai Chi motor imagery seems to have no significant effects on path length. No main imagery effect, or significant interactions, with respect to COP path length were found.

Specific Aim #4: To Compare Traditional Measures with a Complexity-Based Measure of Motor Imagery Effects on Postural Control.

A main effect of group was found regarding COP path length. Path length was significantly greater among experts than the naïve participant group. This finding is consistent with a main group effect of significantly greater A-P COP displacement SD also found in experts. The typical clinical assessment of postural stability that is based on the magnitude of sway has a long history (Cavanaugh, Guskiewicz, & Stergiou, 2005; Romberg, 1853). Traditionally, those who are most stable are conceptualized to be able to stand with less sway, or so-called error, around a target position of equilibrium. Higher values of traditional sway measures have been recognized as risk factors for falling (Maki, Holliday, & Topper, 1994; Melzer, Benjuya, & Kaplanski, 2004; Pajala et al., 2008). Are these increases in traditional measures of sway magnitude found in Tai Chi standing meditation experts an indication of less postural stability?

The assumption that increased postural stability is marked by less postural sway magnitude has been called into question (van Emmerik & van Wegen, 2002), and has not always been supported by reported effects of Tai Chi training. Wolf et al., (1997) found that 15 weeks of Tai Chi training reduced risk of injurious falls in older adults, but that measures of sway magnitude either remained the same or increased (Wolf, Barnhart, Ellison, & Coogler, 1997). Other Tai Chi interventional studies report variable effects on traditional sway measures (Chen, Zhou, & Cartwright, 2011; Li & Manor, 2010; Wu, Zhao, & Zhou, 2002). These results explain why it may not be surprising that Tai Chi motor imagery by experts resulted in significant increases in the traditional measures of A-P COP displacement and COP path length when compared to naïve participants, as is the case here.

The Tai Chi research literature also suggests that increases in sway amplitude may not necessarily equate with less postural stability, and highlights the meaningfulness of non-linear, complexity-based analyses of postural sway trajectories (such as SampEn) that can assess the dynamic structure which underlies a postural control system (van Emmerik & van Wegen, 2002). This seems especially true for Tai Chi interventions. Using multiscale entropy analyses, cross-sectional comparisons by Wayne, Gow, et al. (2014) found greater complexity of postural sway trajectories, but trends toward *greater* sway magnitude and other related variables in seven (7) of eight (8) traditional sway measures, when compared to group naïve to Tai Chi. *Post hoc* analyses of a 6-month randomized clinic trial of Tai Chi training using a naïve group, found those who were exposed to Tai Chi had significant increases in postural sway complexity. Yet, this group showed trends toward *greater* values in all eight (8) of the traditional postural sway metrics tested, as compared to the wait-list control group (Wayne, Gow et al., 2014). This study by Wayne, Gow et al. (2014) demonstrates that a non-linear, complexity-based measure was able to capture beneficial Tai Chi training effects as seen through a dynamic systems lens, when traditional measures failed to do so on a conceptual basis that equates decreased sway magnitude with postural stability.

A significant main effect of eyes (open versus closed) was evident in all three traditional measures of postural sway used in my study in which there were significantly greater A-P and M-L COP displacement SDs, and COP path length with the eyes closed compared to the eyes open condition. It is a classic finding that closing the eyes produces substantial increase in traditional sway metrics, and so these finding are not surprising (Latash, 2012).

Surprising is that the SampEn analysis method used as described by Ramdani et al. (2009) did not find any significant main effect with respect to eye condition (open or closed) (Ramdani et al., 2009). This method of SampEn was reported to successfully differentiate (when similar methods did not) between eyes closed and eyes open conditions in young adults in quiet standing; there were significantly lower indices of complexity when eyes were closed (Ramdani et al., 2009). This finding is consistent with the loss of complexity hypothesis of aging and disease, and an important underpinning for my hypothesis (Goldberger et al., 2002; Lipsitz, 2002).

The conditions by which the SampEn method of analysis per Ramdani, et al. (2009) successfully differentiated between eyes open and eyes closed conditions did not include any additional cognitive task, as was the case in my study. Quiet standing during additional cognitive tasks have effects of their own on SampEn, and have already been covered in the discussion related to Specific Aim #3. Important here is that up until now, it has been unknown how motor imagery, when performed during quiet standing, affects SampEn. The absence of a main effect of eyes open versus eyes closed on SampEn in my study is a new finding that suggests that the differences in postural sway complexity normally detected by SampEn in quiet standing disappear with the addition of a motor imagery task. This new finding has important implications for future research of this kind that seeks to understand motor imagery's role in a systems-oriented falls prevention strategy, the most important of which is to include quiet-standing-only conditions when assessing Tai Chi-related effects on entropy measures of postural sway complexity.

Innovations, Implications and Future Directions.

The dissertation research presented here is innovative in several ways. First, it is innovative in its critical evaluation of a prevailing conceptual framework by which we understand falls research and falls prevention that potentially has powerful implications for the direction and funding of falls prevention research. Second, it is innovative in articulating the argument for a systems-oriented approach as a more suitable alternative to the conventional reductionist understanding of the falls problem using single variable and multi-variable analysis. It is innovative in that it critically examines the likely nature of postural control itself, and by extension, the nature of postural instability that underlies falling by older adults.

Third, this dissertation is innovative in its recognition of how postural instability parallels a holistic perspective on understanding aging as an emergent and gradual loss of homeodynamic buffering capacity. This perspective has implications for understanding the phenomenon of falls for both the older individual and society. The holistic nature of postural instability in old age calls for systems-oriented strategies of falls prevention.

Although the whole systems nature of Tai Chi's therapeutic value has previously been described (Wayne & Fuerst, 2013), this research is innovative in a fourth way. It has identified movement characteristics that are goals of Tai Chi training to be holistic descriptors related to robust postural control that seems to extend into old age as suggested by anecdotal evidence. Based on its dynamic systems theoretical perspective, this research has generated a new hypothesis that the Tai Chi movement characteristic, known as silk-reeling, is a class of robust postural control synergies that is developed by the systems-oriented practice of Tai Chi.

A fifth innovation of this research is the recognition that the Tai Chi movement principle of *xin yi*/mind-intention is reasonably understood as motor imagery, and that understanding its effects in an older adult may be informed by the large body of scientific motor imagery research. Related to this theme is this project's innovative articulation of a continuum of action within which motor imagery lies between rest and full execution of movement (see Figure 4.1). The use of this continuum to explain the effects of Tai Chi motor imagery training is new.

Finally, this research has introduced a novel methodology for investigating motor imagery effects that has implications for future investigation aimed at falls prevention. For example, the methodology serves as a model for future research regarding logistics of recruiting Tai Chi experts, and informs eligibility criteria that provide a sample with a level of endurance to complete postural sway testing without interruption.

Other implications of this research are both specific and broad. The most important specific implication is that future investigations of motor imagery's effect on postural sway complexity need to include quiet-standing-only conditions. This would allow important comparisons between quiet standing with, and without, a motor imagery task. This would also allow the research to inform, and be informed by, the substantial body of research that has investigated postural sway complexity changes associated with quiet standing with, and without, a dual cognitive task.

Another specific implication pertains to the novelty of motor imagery effects on complexity-based measures of postural sway. Until this study, the effects of motor imagery on measures of non-linear forms of analysis of postural control were unknown. In addition, the investigation of non-linear methods of analysis of postural sway complexity is a young enough field that there currently exists no single and agreed-upon method by which to successfully capture change in postural sway complexity in all conditions. This is evident in a survey of the literature by Riley et al., (2011) on effects related to constraints of individual, task and environment that demonstrates a wide-variety of non-linear measures being used to detect changes in postural sway complexity (Riley et al, 2011). It is possible that some other non-linear measure may have been able to capture changes in postural sway complexity in my study that were not captured by

SampEn. Since research on the effects of motor imagery on postural sway complexity is in its infancy, and there is no firm consensus on the best method to capture that complexity, a battery of non-linear analyses of complexity need to be considered in future investigations.

The broader implication of this dissertation's conceptual framework and the example of research adopting this framework presented here is that, in light of recognition of the holistic nature of falls in old age, there is an imperative toward systems-oriented approaches to falls prevention. What does this mean in practice? My research is one example of investigating the system-oriented practice of Tai Chi. There may be other mind-body interventions that would qualify in the expansion of this research including yoga or similar holistic arts. A move in the direction of more holistic systems-oriented interpretation is also consistent with, and may reinforce current societal changes in, a shifting emphasis of health care from treating disease to promoting whole-person wellness, and disease prevention. This would likely include changes in infrastructure and city planning that would facilitate long-term health-promoting behaviors, such as physical activity. There is plenty of room for creativity here, but progress begins with a change in the lens through which we look at the problem of falls in old age.

Chapter 8: Let Us Step Back

Below I have taken the opening passage by Waddell (2004) in Chapter 1, removed the phrases I had underlined relating to back pain and disability, and replaced them with “the problem of falls in old age:” The result is a concluding statement:

> We have looked at many aspects of the problem of falls in old age, and it is time to fit them all together. Let us step back and try to see the whole picture. It should be clear that the traditional disease model is inadequate to understand the problem of falls in old age. We need a new model…

Appendix A. Power Analysis

Power parameters:

- a = '2' (levels of factor for power)
- b = '2' (levels of factor(s) crossed with A)
- delta = '0.25 0.5 0.75 1.0 1.25' (effect size(s))
- alpha = '0.05' (significance level)

Power analysis for ANOVA designs
2x 2 layout Ha: T1=GM-Delta/2, T2=T3=...=T(k-1)=GM, Tk=GM+Delta/2 tested at Alpha= 0.050

DELTA (in units of sigma=Std. Dev.)

N	0.250	0.500	0.750	1.000	1.250
2	0.058	0.085	0.131	0.195	0.275
3	0.067	0.119	0.209	0.332	0.477
4	0.074	0.151	0.281	0.452	0.632
5	0.082	0.183	0.350	0.556	0.746
6	0.089	0.214	0.416	0.644	0.829
7	0.097	0.245	0.478	0.718	0.887
8	0.104	0.276	0.535	0.779	0.926
9	0.112	0.307	0.587	0.828	0.953
10	0.120	0.337	0.636	0.867	0.970
12	0.135	0.395	0.719	0.923	0.988
14	0.150	0.450	0.786	0.956	0.995
16	0.166	0.503	0.839	0.975	0.998
18	0.181	0.552	0.880	0.986	0.999
20	0.197	0.597	0.911	0.992	0.999
25	0.235	0.696	0.960	0.998	0.999
30	0.274	0.775	0.982	0.999	0.999
35	0.311	0.835	0.992	0.999	0.999
40	0.349	0.881	0.997	0.999	0.999
50	0.420	0.940	0.999	0.999	1.000
60	0.487	0.971	0.999	0.999	1.000
70	0.549	0.986	0.999	1.000	1.000
80	0.606	0.993	0.999	1.000	1.000
90	0.657	0.997	0.999	1.000	1.000

The sample size values given are those for each of the 2 levels of the factor called 'Factor A'. With 2 combinations of other factors at each level of Factor A, divide the sample size by 2 to determine the sample size per treatment cell.

Retrieved from Friendly, 2007.

Appendix B. Informed Consent Form

Consent to Participate in a Research Study

EFFECTS OF TAI CHI STANDING MOTOR IMAGERY ON STANDING POSTURAL CONTROL

WHY ARE YOU BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are being invited to take part in a research study about the effects of motor imagery on balance in adults. Simply put, motor imagery is imagining what it would feel like in your body if you were to do a particular movement but without actually doing it. You are being invited to take part in this research study because you are age 20 years or older, live independently in the community, and may or may not have expertise with motor imagery while in the standing position. If you volunteer to take part in this study, you will be one of about 100 people to do so nationally.

WHO IS DOING THE STUDY?

The person in charge of this study is Patrick A. Dillon of University of Kentucky Graduate Center for Gerontology He is a doctoral student and is being guided in this research by Graham Rowles, PhD.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to understand how a particular way of imagining movement affects balance in adults.

By doing this study, we hope to learn more about how to improve balance in older adults and prevent falls.

ARE THERE REASONS WHY YOU SHOULD NOT TAKE PART IN THIS STUDY?

You will not be eligible in this study if you are:

1. Are unable to walk continuously for 15 minutes without assistance or an assistive device
2. Are Unable to read, write and speak English.
3. Have any of the following chronic medical conditions: vestibular disorder, dementia, mild cognitive impairment, stroke, neurological condition (e.g., Parkinson's disease, seizure disorder, or peripheral neuropathy), significant neuromuscular or musculoskeletal conditions, cardiovascular conditions (angina, myocardial infarction, atrial fibrillation, or presence of pacemaker), or acute medical condition requiring hospital admission within the last six months.

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The research procedures will be conducted at the University of Kentucky Center for Gerontology. You will need to come to Suite 280 at the University of Kentucky Federal Credit Union at 1080 Export Street, Lexington, KY one time during the study for approximately one hour. One hour is the total approximate amount of time you will be asked to volunteer for this study.

If you prefer, and if you and the investigator agree to do so, the research procedures may instead be conducted in a suitable room either at your home or at the home of the investigator at 912 Secrest Crossing, Flemingsburg, KY 41041.

If you were recruited in Blowing Rock, NC you will need to come to a designated room one time at the Blowing Rock Conference Center at 1818 Goforth Road in Blowing Rock, NC 28605 for a total time of approximately one hour.

WHAT WILL YOU BE ASKED TO DO?

You are about one of 100 participants recruited for this study. After consent is obtained and you have completed the Participant Intake Information Form, you will be asked to perform the following test:

Standing Postural Sway Test: During this test you will be asked to stand barefoot with both feet on a force platform that is securely placed on the floor. You will be asked to stand quietly, have your arms suspended comfortably by your trunk, and have your knees and hips very slightly and comfortably bent. In this position you will be asked to stand for three trials of up to 60 seconds each in four different conditions (the order you do the tasks in will vary by chance):

1. Eyes open during Tai Chi motor imagery
2. Eyes open during a control motor imagery task
3. Eyes closed during Tai Chi motor imagery
4. Eyes closed during a control motor imagery task.

Again, motor imagery is imagining what it would feel like in your body if you were to do a particular movement but without actually doing it. Tai Chi is a very old martial art that uses motor imagery in its training. The Tai Chi motor imagery that you will be asked to do while standing on the platform consists of

1. Imagining the bodily feelings of peace and tranquility
2. Imagining that you are growing an inch upward from the point at the very top of your head
3. Imagining that you are standing safely and comfortably in water, and giving yourself permission to sway passively, slowly and randomly, as if the water you imagine standing in has a very gentle current.

After each trial of Tai Chi motor imagery you will be asked to rate how vivid your imagery experience was on a scale of 1 to 7.

The control motor imagery task is imagining singing happy birthday throughout the time of the trial.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

You have been told that the study may involve the following risks and/or discomforts: The Standing Postural Sway Test may be associated with temporary loss of balance, and could possibly result in a minor sprain of the ankle, fall or other injury. In order to minimize risk of injury during testing, the principal investigator will be standing close by you to provide physical support in case you lose your balance. If you become fatigued you are welcome to rest between trials as needed. There is always a chance that any scientific test can harm you, and the scientific tests in this study are no different. We will do everything we can to keep you from being harmed. In addition to these risks, your may experience another previously unknown or unforeseeable risk.

WILL YOU BENEFIT FROM TAKING PART IN THIS STUDY?

There is no guarantee that you will get any benefit from taking part in this study. Your willingness to take part, however, may, in the future, help society as a whole better understand this research topic.

DO YOU HAVE TO TAKE PART IN THE STUDY?
If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.
IF YOU DON'T WANT TO TAKE PART IN THE STUDY, ARE THERE OTHER CHOICES?
If you do not want to be in the study, there are no other choices except not to take part in the study.
WHAT WILL IT COST YOU TO PARTICIPATE?
The only cost you will experience is your time and travel expenses to the testing site.
WHO WILL SEE THE INFORMATION THAT YOU GIVE?
We will make every effort to keep confidential all research records that identify you to the extent allowed by law.
Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be personally identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.
We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. All data will be stored either in locked file cabinets and on secured password protected computers. You will be identified using only a study identification number and the investigators of this study will keep private all research records that identify you. Only personnel associated with this study will have access to the data and to keep information confined, all subject information will be kept under lock and key.
You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court or to tell authorities if you pose a danger to yourself or someone else. Finally, officials of the University of Kentucky may look at or copy pertinent portions of the records that identify you.
CAN YOUR TAKING PART IN THE STUDY END EARLY?
If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. You will not be treated differently if you decide to stop taking part in the study.
The individuals conducting the study may need to withdraw you from the study. This may occur if you are not able to follow the directions they give you, or if they find that your being in the study is more risk than benefit to you.
ARE YOU PARTICIPATING OR CAN YOU PARTICIPATE IN ANOTHER RESEARCH STUDY AT THE SAME TIME AS PARTICIPATING IN THIS ONE?
You may take part in this study if you are currently involved in another research study.
WHAT HAPPENS IF YOU GET HURT OR SICK DURING THE STUDY?
If you believe you are hurt or if you get sick because of something that is due to the study, you should call Patrick A. Dillon at (606) 584-0216 (email: pat.dillon@uky.edu) immediately.

It is important for you to understand that there are no funds set aside by the University of Kentucky, the Blowing Rock Conference Center, or the primary investigator to pay for the cost of any care or treatment that might be necessary because you get hurt or sick while taking part in this study. Also, the University of Kentucky will not, the Blowing Rock Conference Center will not, and the primary investigator will not pay for any wages you may lose if you are harmed by this study.

The medical costs related to your care and treatment because of research related harm will be your responsibility.

You do not give up your legal rights by signing this form.

WILL YOU RECEIVE ANY REWARDS FOR TAKING PART IN THIS STUDY?

You will not receive any rewards or payment for taking part in the study.

WHAT IF YOU HAVE QUESTIONS, SUGGESTIONS, CONCERNS, OR COMPLAINTS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions, suggestions, concerns, or complaints about the study, you can contact the investigator, Patrick A. Dillon at (606) 584-0216. If you have any questions about your rights as a volunteer in this research, contact the staff in the Office of Research Integrity at the University of Kentucky between the business hours of 8am and 5pm EST, Mon-Fri. at 859-257-9428 or toll free at 1-866-400-9428. We will give you a signed copy of this consent form to take with you.

WHAT IF NEW INFORMATION IS LEARNED DURING THE STUDY THAT MIGHT AFFECT YOUR DECISION TO PARTICIPATE?

If the researcher learns of new information in regards to this study, and it might change your willingness to stay in this study, the information will be provided to you. You may be asked to sign a new informed consent form if the information is provided to you after you have joined the study.

WHAT ELSE DO YOU NEED TO KNOW?

There is a possibility that the data collected from you may be shared with other investigators in the future. If that is the case the data will not contain information that can identify you unless you give your consent or the UK Institutional Review Board (IRB) approves the research. The IRB is a committee that reviews ethical issues, according to federal, state and local regulations on research with human subjects, to make sure the study complies with these before approval of a research study is issued.

____ ____________
Signature of person agreeing to take part in the study Date

____
Printed name of person agreeing to take part in the study

____ ____________
Name of [authorized] person obtaining informed consent Date

____
Signature of Principal Investigator or Sub/Co-Investigator

Appendix C. Participant Intake Information Form

Study Identification #: ________________________
Number of years' experience with Tai Chi *wuji* Standing Training______
Age: ____ DOB: _____________
Sex: Male Female
Ethnicity: Caucasion African-American Hispanic Asian
Other:___________________
Height:____________ Weight:____________

Medical History
Diabetes: Y N
Peripheral Neuropathy: Y N
Cardiovascular Disease: Y N
Chronic Obstructive Pulmonary Disease: Y N
Osteoarthritis: Y N
Other: ____

Highest level of education attained: ___________________________________
Average hours of exercise per week:___________________________________

Appendix D. Proc Mixed ANOVAs Results

Key:
APSampN = Anterior-Posterior Sample Entropy
MLSampN = Medial-Lateral Sample Entropy
APDisp = Anterior-Posterior Center of Pressure Displacement Standard Deviation
MLDisp = Medial-Lateral Center of Pressure Displacement Standard Deviation
PL = Center of Pressure Path Length
Score = Self-Rated Ease of Motor Imagery Score
Grp = Group
- 0 = Expert Group
- 1 = Naïve Group

Eyes = Eyes Condition
- 0 = Eyes Open
- 1 = Eyes Closed

Imagery = Imagery Type
- 0 = Tai Chi Motor Imagery
- 1 = Control Motor Imagery

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	APSampN
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	399.93030146	
1	1	-410.91767284	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
UN(1,1)	Subj	0.07173

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	APSampN
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	399.93030146	
1	1	-410.91767284	0.00000000

Convergence criteria met.

Covariance Parameter Estimates

Cov Parm	Subject	Estimate
UN(1,1)	Subj	0.07173

Residual		[illegible]

Fit Statistics	
-2 Res Log Likelihood	-410.9
AIC (Smaller is Better)	-406.9
AICC (Smaller is Better)	-406.9
BIC (Smaller is Better)	-402.6

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	810.85	<.0001

Solution for Fixed Effects

Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.7896	0.04994	62	35.84	<.0001
Grp	0			-0.1002	0.07062	62	-1.42	0.1610
Grp	1			0	.	.	.	.
Eyes		0		-0.00359	0.02247	62	-0.16	0.8734
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		-0.00786	0.03177	62	-0.25	0.8054
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	0.01638	0.02247	62	0.73	0.4686
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	-0.03092	0.03177	62	-0.97	0.3343
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.02453	0.03177	62	-0.77	0.4431
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	0.02292	0.04494	62	0.51	0.6118
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	2.81	0.0986
Eyes	1	62	1.57	0.2155
Grp*Eyes	1	62	0.03	0.8732
Imagry	1	62	0.25	0.6195
Grp*Imagry	1	62	0.75	0.3899
Eyes*Imagry	1	62	0.34	0.5630
Grp*Eyes*Imagry	1	62	0.26	0.6118

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			1.6760	0.04801	62	34.91	<.0001
Grp	1			1.7899	0.04801	62	37.28	<.0001
Eyes		0		1.7259	0.03441	62	50.16	<.0001
Eyes		1		1.7400	0.03441	62	50.57	<.0001
Grp*Eyes	0	0		1.6699	0.04866	62	34.32	<.0001
Grp*Eyes	0	1		1.6821	0.04866	62	34.57	<.0001
Grp*Eyes	1	0		1.7820	0.04866	62	36.62	<.0001
Grp*Eyes	1	1		1.7978	0.04866	62	36.95	<.0001
Imagry			0	1.7301	0.03441	62	50.28	<.0001
Imagry			1	1.7358	0.03441	62	50.45	<.0001
Grp*Imagry	0		0	1.6684	0.04866	62	34.29	<.0001
Grp*Imagry	0		1	1.6837	0.04866	62	34.60	<.0001
Grp*Imagry	1		0	1.7919	0.04866	62	36.83	<.0001
Grp*Imagry	1		1	1.7878	0.04866	62	36.74	<.0001
Eyes*Imagry		0	0	1.7199	0.03531	62	48.70	<.0001
Eyes*Imagry		0	1	1.7320	0.03531	62	49.05	<.0001
Eyes*Imagry		1	0	1.7404	0.03531	62	49.29	<.0001
Eyes*Imagry		1	1	1.7395	0.03531	62	49.26	<.0001
Grp*Eyes*Imagry	0	0	0	1.6618	0.04994	62	33.28	<.0001
Grp*Eyes*Imagry	0	0	1	1.6780	0.04994	62	33.60	<.0001
Grp*Eyes*Imagry	0	1	0	1.6749	0.04994	62	33.54	<.0001
Grp*Eyes*Imagry	0	1	1	1.6894	0.04994	62	33.83	<.0001
Grp*Eyes*Imagry	1	0	0	1.7779	0.04994	62	35.60	<.0001
Grp*Eyes*Imagry	1	0	1	1.7860	0.04994	62	35.76	<.0001
Grp*Eyes*Imagry	1	1	0	1.8060	0.04994	62	36.16	<.0001
Grp*Eyes*Imagry	1	1	1	1.7896	0.04994	62	35.84	<.0001

The SAS System

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	MLSampN
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	123.03775392	
1	1	-390.16053438	0.00000000

Convergence criteria met.

Fit Statistics	
-2 Res Log Likelihood	-390.2
AIC (Smaller is Better)	-386.2
AICC (Smaller is Better)	-386.1
BIC (Smaller is Better)	-381.8

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	513.20	<.0001

Solution for Fixed Effects

Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				1.9888	0.03912	62	50.84	<.0001
Grp	0			-0.01913	0.05533	62	-0.35	0.7307
Grp	1			0	.	.	.	.
Eyes		0		0.003276	0.02337	62	0.14	0.8890
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		-0.00657	0.03305	62	-0.20	0.8431
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	0.04420	0.02337	62	1.89	0.0633
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	-0.07048	0.03305	62	-2.13	0.0369
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.04539	0.03305	62	-1.37	0.1746
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	0.04080	0.04674	62	0.87	0.3861
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	0.85	0.3603
Eyes	1	62	1.15	0.2887
Grp*Eyes	1	62	0.35	0.5562
Imagry	1	62	0.09	0.7631
Grp*Imagry	1	62	4.59	0.0361
Eyes*Imagry	1	62	1.14	0.2891
Grp*Eyes*Imagry	1	62	0.76	0.3861

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			1.9537	0.03641	62	53.66	<.0001
Grp	1			2.0012	0.03641	62	54.96	<.0001
Eyes		0		1.9712	0.02640	62	74.66	<.0001
Eyes		1		1.9837	0.02640	62	75.14	<.0001
Grp*Eyes	0	0		1.9509	0.03734	62	52.25	<.0001
Grp*Eyes	0	1		1.9565	0.03734	62	52.40	<.0001
Grp*Eyes	1	0		1.9915	0.03734	62	53.34	<.0001
Grp*Eyes	1	1		2.0109	0.03734	62	53.86	<.0001
Imagry			0	1.9757	0.02640	62	74.83	<.0001
Imagry			1	1.9792	0.02640	62	74.97	<.0001
Grp*Imagry	0		0	1.9394	0.03734	62	51.95	<.0001
Grp*Imagry	0		1	1.9680	0.03734	62	52.71	<.0001
Grp*Imagry	1		0	2.0119	0.03734	62	53.89	<.0001
Grp*Imagry	1		1	1.9904	0.03734	62	53.31	<.0001
Eyes*Imagry		0	0	1.9632	0.02766	62	70.97	<.0001
Eyes*Imagry		0	1	1.9792	0.02766	62	71.55	<.0001
Eyes*Imagry		1	0	1.9882	0.02766	62	71.87	<.0001
Eyes*Imagry		1	1	1.9792	0.02766	62	71.55	<.0001
Grp*Eyes*Imagry	0	0	0	1.9355	0.03912	62	49.47	<.0001
Grp*Eyes*Imagry	0	0	1	1.9664	0.03912	62	50.26	<.0001
Grp*Eyes*Imagry	0	1	0	1.9434	0.03912	62	49.67	<.0001
Grp*Eyes*Imagry	0	1	1	1.9697	0.03912	62	50.35	<.0001
Grp*Eyes*Imagry	1	0	0	1.9909	0.03912	62	50.89	<.0001
Grp*Eyes*Imagry	1	0	1	1.9921	0.03912	62	50.92	<.0001
Grp*Eyes*Imagry	1	1	0	2.0330	0.03912	62	51.97	<.0001
Grp*Eyes*Imagry	1	1	1	1.9888	0.03912	62	50.84	<.0001

The SAS System

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	APDisp
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-6624.48113060	
1	1	-7935.12243395	0.00000000

Convergence criteria met.

Residual		[illegible]

Fit Statistics	
-2 Res Log Likelihood	-7935.1
AIC (Smaller is Better)	-7931.1
AICC (Smaller is Better)	-7931.1
BIC (Smaller is Better)	-7926.8

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	1310.64	<.0001

Solution for Fixed Effects

Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.01096	0.000517	62	21.18	<.0001
Grp	0			0.001859	0.000732	62	2.54	0.0135
Grp	1			0	.	.	.	.
Eyes		0		-0.00013	0.000154	62	-0.83	0.4072
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		-0.00006	0.000217	62	-0.29	0.7708
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	0.000761	0.000154	62	4.96	<.0001
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	-0.00059	0.000217	62	-2.71	0.0087
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.00044	0.000217	62	-2.02	0.0472
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	0.000257	0.000307	62	0.84	0.4053
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	4.93	0.0300
Eyes	1	62	16.88	0.0001
Grp*Eyes	1	62	0.18	0.6730
Imagry	1	62	16.49	0.0001
Grp*Imagry	1	62	8.97	0.0039
Eyes*Imagry	1	62	4.10	0.0472
Grp*Eyes*Imagry	1	62	0.70	0.4053

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			0.01276	0.000509	62	25.09	<.0001
Grp	1			0.01117	0.000509	62	21.95	<.0001
Eyes		0		0.01181	0.000362	62	32.64	<.0001
Eyes		1		0.01212	0.000362	62	33.51	<.0001
Grp*Eyes	0	0		0.01262	0.000512	62	24.67	<.0001
Grp*Eyes	0	1		0.01290	0.000512	62	25.23	<.0001
Grp*Eyes	1	0		0.01099	0.000512	62	21.49	<.0001
Grp*Eyes	1	1		0.01134	0.000512	62	22.17	<.0001
Imagry			0	0.01212	0.000362	62	33.51	<.0001
Imagry			1	0.01181	0.000362	62	32.64	<.0001
Grp*Imagry	0		0	0.01280	0.000512	62	25.03	<.0001
Grp*Imagry	0		1	0.01272	0.000512	62	24.87	<.0001
Grp*Imagry	1		0	0.01144	0.000512	62	22.36	<.0001
Grp*Imagry	1		1	0.01089	0.000512	62	21.30	<.0001
Eyes*Imagry		0	0	0.01188	0.000366	62	32.49	<.0001
Eyes*Imagry		0	1	0.01173	0.000366	62	32.06	<.0001
Eyes*Imagry		1	0	0.01236	0.000366	62	33.78	<.0001
Eyes*Imagry		1	1	0.01189	0.000366	62	32.50	<.0001
Grp*Eyes*Imagry	0	0	0	0.01262	0.000517	62	24.39	<.0001
Grp*Eyes*Imagry	0	0	1	0.01263	0.000517	62	24.41	<.0001
Grp*Eyes*Imagry	0	1	0	0.01299	0.000517	62	25.11	<.0001
Grp*Eyes*Imagry	0	1	1	0.01282	0.000517	62	24.78	<.0001
Grp*Eyes*Imagry	1	0	0	0.01115	0.000517	62	21.56	<.0001
Grp*Eyes*Imagry	1	0	1	0.01083	0.000517	62	20.94	<.0001
Grp*Eyes*Imagry	1	1	0	0.01172	0.000517	62	22.66	<.0001
Grp*Eyes*Imagry	1	1	1	0.01096	0.000517	62	21.18	<.0001

The SAS System

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	MLDisp
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-6381.22262929	
1	1	-7210.08019133	0.00000000

Convergence criteria met.

Fit Statistics	
-2 Res Log Likelihood	-7210.1
AIC (Smaller is Better)	-7206.1
AICC (Smaller is Better)	-7206.1
BIC (Smaller is Better)	-7201.8

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	828.86	<.0001

Solution for Fixed Effects								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				0.01374	0.000578	62	23.76	<.0001
Grp	0			0.000643	0.000818	62	0.79	0.4349
Grp	1			0	.	.	.	.
Eyes		0		-0.00217	0.000256	62	-8.48	<.0001
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		0.001648	0.000362	62	4.55	<.0001
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	0.000623	0.000256	62	2.43	0.0179
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	-0.00076	0.000362	62	-2.11	0.0388
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.00004	0.000362	62	-0.12	0.9042
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	-0.00034	0.000512	62	-0.67	0.5084
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	1.61	0.2090
Eyes	1	62	128.98	<.0001
Grp*Eyes	1	62	33.31	<.0001
Imagry	1	62	1.09	0.3007
Grp*Imagry	1	62	13.33	0.0005
Eyes*Imagry	1	62	0.70	0.4063
Grp*Eyes*Imagry	1	62	0.44	0.5084

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			0.01395	0.000557	62	25.07	<.0001
Grp	1			0.01295	0.000557	62	23.27	<.0001
Eyes		0		0.01273	0.000399	62	31.91	<.0001
Eyes		1		0.01418	0.000399	62	35.56	<.0001
Grp*Eyes	0	0		0.01359	0.000564	62	24.11	<.0001
Grp*Eyes	0	1		0.01431	0.000564	62	25.38	<.0001
Grp*Eyes	1	0		0.01186	0.000564	62	21.03	<.0001
Grp*Eyes	1	1		0.01405	0.000564	62	24.91	<.0001
Imagry			0	0.01352	0.000399	62	33.90	<.0001
Imagry			1	0.01339	0.000399	62	33.57	<.0001
Grp*Imagry	0		0	0.01378	0.000564	62	24.45	<.0001
Grp*Imagry	0		1	0.01412	0.000564	62	25.04	<.0001
Grp*Imagry	1		0	0.01325	0.000564	62	23.50	<.0001
Grp*Imagry	1		1	0.01265	0.000564	62	22.44	<.0001
Eyes*Imagry		0	0	0.01274	0.000409	62	31.15	<.0001
Eyes*Imagry		0	1	0.01271	0.000409	62	31.09	<.0001
Eyes*Imagry		1	0	0.01430	0.000409	62	34.97	<.0001
Eyes*Imagry		1	1	0.01406	0.000409	62	34.38	<.0001
Grp*Eyes*Imagry	0	0	0	0.01333	0.000578	62	23.05	<.0001
Grp*Eyes*Imagry	0	0	1	0.01386	0.000578	62	23.96	<.0001
Grp*Eyes*Imagry	0	1	0	0.01424	0.000578	62	24.62	<.0001
Grp*Eyes*Imagry	0	1	1	0.01438	0.000578	62	24.87	<.0001
Grp*Eyes*Imagry	1	0	0	0.01215	0.000578	62	21.00	<.0001
Grp*Eyes*Imagry	1	0	1	0.01157	0.000578	62	20.00	<.0001
Grp*Eyes*Imagry	1	1	0	0.01436	0.000578	62	24.83	<.0001
Grp*Eyes*Imagry	1	1	1	0.01374	0.000578	62	23.76	<.0001

The SAS System

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	PL
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	4892.60917860	
1	1	3228.34181089	0.00000000

Convergence criteria met.

Fit Statistics	
-2 Res Log Likelihood	3228.3
AIC (Smaller is Better)	3232.3
AICC (Smaller is Better)	3232.4
BIC (Smaller is Better)	3236.7

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	1664.27	<.0001

Solution for Fixed Effects								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				22.7386	1.0284	62	22.11	<.0001
Grp	0			3.1996	1.4543	62	2.20	0.0315
Grp	1			0	.	.	.	.
Eyes		0		-1.0713	0.2322	62	-4.61	<.0001
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		0.5997	0.3284	62	1.83	0.0727
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	0.3247	0.2322	62	1.40	0.1670
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	-0.03288	0.3284	62	-0.10	0.9206
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.1022	0.3284	62	-0.31	0.7568
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	-0.3789	0.4644	62	-0.82	0.4177
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	5.53	0.0218
Eyes	1	62	62.40	<.0001
Grp*Eyes	1	62	3.12	0.0822
Imagry	1	62	1.96	0.1666
Grp*Imagry	1	62	0.92	0.3421
Eyes*Imagry	1	62	1.58	0.2139
Grp*Eyes*Imagry	1	62	0.67	0.4177

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			25.7280	1.0185	62	25.26	<.0001
Grp	1			22.3398	1.0185	62	21.93	<.0001
Eyes		0		23.5753	0.7225	62	32.63	<.0001
Eyes		1		24.4925	0.7225	62	33.90	<.0001
Grp*Eyes	0	0		25.3720	1.0218	62	24.83	<.0001
Grp*Eyes	0	1		26.0841	1.0218	62	25.53	<.0001
Grp*Eyes	1	0		21.7786	1.0218	62	21.31	<.0001
Grp*Eyes	1	1		22.9010	1.0218	62	22.41	<.0001
Imagry			0	24.1152	0.7225	62	33.38	<.0001
Imagry			1	23.9527	0.7225	62	33.15	<.0001
Grp*Imagry	0		0	25.7537	1.0218	62	25.20	<.0001
Grp*Imagry	0		1	25.7024	1.0218	62	25.15	<.0001
Grp*Imagry	1		0	22.4766	1.0218	62	22.00	<.0001
Grp*Imagry	1		1	22.2030	1.0218	62	21.73	<.0001
Eyes*Imagry		0	0	23.5837	0.7272	62	32.43	<.0001
Eyes*Imagry		0	1	23.5670	0.7272	62	32.41	<.0001
Eyes*Imagry		1	0	24.6467	0.7272	62	33.89	<.0001
Eyes*Imagry		1	1	24.3384	0.7272	62	33.47	<.0001
Grp*Eyes*Imagry	0	0	0	25.2774	1.0284	62	24.58	<.0001
Grp*Eyes*Imagry	0	0	1	25.4666	1.0284	62	24.76	<.0001
Grp*Eyes*Imagry	0	1	0	26.2300	1.0284	62	25.51	<.0001
Grp*Eyes*Imagry	0	1	1	25.9382	1.0284	62	25.22	<.0001
Grp*Eyes*Imagry	1	0	0	21.8899	1.0284	62	21.29	<.0001
Grp*Eyes*Imagry	1	0	1	21.6673	1.0284	62	21.07	<.0001
Grp*Eyes*Imagry	1	1	0	23.0633	1.0284	62	22.43	<.0001
Grp*Eyes*Imagry	1	1	1	22.7386	1.0284	62	22.11	<.0001

The SAS System

The Mixed Procedure

Model Information	
Data Set	WORK.DATA1
Dependent Variable	Score
Covariance Structure	Unstructured
Subject Effect	Subj
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Between-Within

Class Level Information

Class	Levels	Values
Grp	2	0 1
Subj	64	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 33 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82
Eyes	2	0 1
Imagry	2	0 1

Dimensions	
Covariance Parameters	2
Columns in X	27
Columns in Z per Subject	1
Subjects	64
Max Obs per Subject	12

Number of Observations	
Number of Observations Read	768
Number of Observations Used	768
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	2459.36618201	
1	1	2300.71770111	0.00000000

Convergence criteria met.

Fit Statistics	
-2 Res Log Likelihood	2300.7
AIC (Smaller is Better)	2304.7
AICC (Smaller is Better)	2304.7
BIC (Smaller is Better)	2309.0

Null Model Likelihood Ratio Test		
DF	Chi-Square	Pr > ChiSq
1	158.65	<.0001

Solution for Fixed Effects

Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept				5.3021	0.1549	62	34.24	<.0001
Grp	0			0.5833	0.2190	62	2.66	0.0098
Grp	1			0	.	.	.	.
Eyes		0		-0.1042	0.1437	62	-0.72	0.4713
Eyes		1		0	.	.	.	.
Grp*Eyes	0	0		-0.01042	0.2032	62	-0.05	0.9593
Grp*Eyes	0	1		0	.	.	.	.
Grp*Eyes	1	0		0	.	.	.	.
Grp*Eyes	1	1		0	.	.	.	.
Imagry			0	-0.04167	0.1437	62	-0.29	0.7728
Imagry			1	0	.	.	.	.
Grp*Imagry	0		0	0.7396	0.2032	62	3.64	0.0006
Grp*Imagry	0		1	0	.	.	.	.
Grp*Imagry	1		0	0	.	.	.	.
Grp*Imagry	1		1	0	.	.	.	.
Eyes*Imagry		0	0	-0.5521	0.2032	62	-2.72	0.0085
Eyes*Imagry		0	1	0	.	.	.	.
Eyes*Imagry		1	0	0	.	.	.	.
Eyes*Imagry		1	1	0	.	.	.	.
Grp*Eyes*Imagry	0	0	0	0.1458	0.2874	62	0.51	0.6137
Grp*Eyes*Imagry	0	0	1	0	.	.	.	.
Grp*Eyes*Imagry	0	1	0	0	.	.	.	.
Grp*Eyes*Imagry	0	1	1	0	.	.	.	.
Grp*Eyes*Imagry	1	0	0	0	.	.	.	.
Grp*Eyes*Imagry	1	0	1	0	.	.	.	.
Grp*Eyes*Imagry	1	1	0	0	.	.	.	.
Grp*Eyes*Imagry	1	1	1	0	.	.	.	.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Grp	1	62	29.84	<.0001
Eyes	1	62	23.58	<.0001
Grp*Eyes	1	62	0.19	0.6651
Imagry	1	62	1.52	0.2225
Grp*Imagry	1	62	31.96	<.0001
Eyes*Imagry	1	62	11.12	0.0014
Grp*Eyes*Imagry	1	62	0.26	0.6137

Least Squares Means								
Effect	Grp	Eyes	Imagry	Estimate	Standard Error	DF	t Value	Pr > |t|
Grp	0			6.0755	0.1274	62	47.68	<.0001
Grp	1			5.0911	0.1274	62	39.95	<.0001
Eyes		0		5.4089	0.09701	62	55.76	<.0001
Eyes		1		5.7578	0.09701	62	59.35	<.0001
Grp*Eyes	0	0		5.9167	0.1372	62	43.13	<.0001
Grp*Eyes	0	1		6.2344	0.1372	62	45.44	<.0001
Grp*Eyes	1	0		4.9010	0.1372	62	35.72	<.0001
Grp*Eyes	1	1		5.2813	0.1372	62	38.50	<.0001
Imagry			0	5.6276	0.09701	62	58.01	<.0001
Imagry			1	5.5391	0.09701	62	57.10	<.0001
Grp*Imagry	0		0	6.3229	0.1372	62	46.09	<.0001
Grp*Imagry	0		1	5.8281	0.1372	62	42.48	<.0001
Grp*Imagry	1		0	4.9323	0.1372	62	35.95	<.0001
Grp*Imagry	1		1	5.2500	0.1372	62	38.27	<.0001
Eyes*Imagry		0	0	5.3333	0.1095	62	48.70	<.0001
Eyes*Imagry		0	1	5.4844	0.1095	62	50.08	<.0001
Eyes*Imagry		1	0	5.9219	0.1095	62	54.08	<.0001
Eyes*Imagry		1	1	5.5938	0.1095	62	51.08	<.0001
Grp*Eyes*Imagry	0	0	0	6.0625	0.1549	62	39.15	<.0001
Grp*Eyes*Imagry	0	0	1	5.7708	0.1549	62	37.26	<.0001
Grp*Eyes*Imagry	0	1	0	6.5833	0.1549	62	42.51	<.0001
Grp*Eyes*Imagry	0	1	1	5.8854	0.1549	62	38.00	<.0001
Grp*Eyes*Imagry	1	0	0	4.6042	0.1549	62	29.73	<.0001
Grp*Eyes*Imagry	1	0	1	5.1979	0.1549	62	33.56	<.0001
Grp*Eyes*Imagry	1	1	0	5.2604	0.1549	62	33.97	<.0001
Grp*Eyes*Imagry	1	1	1	5.3021	0.1549	62	34.24	<.0001

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Vita

Patrick A. Dillon, PT

October 25, 2016

Education

Doctoral Candidate and inaugural Susan Lee Fellow, University of Kentucky, Graduate Center for Gerontology.

Dissertation Research: *A Systems Approach to the Problem of Falls in Old Age.* December 6, 2016 (defended). Doctoral Committee: Graham D. Rowles, Ph.D. (chair), John F. Watkins, Ph.D., Lawrence R. Gottlob, Ph.D., John Patterson, M.D.

Master of Arts in Theology, Lexington Theological Seminary, Lexington, KY. Masters Thesis: *Emergence: A New Paradigm for Understanding God.* Thesis Adviser: David Sharrard, Ph.D. May, 2010.

Bachelor of Health Science in Physical Therapy, with High Distinction, University of Kentucky, Lexington, KY. October, 1988.

Bachelor of Science in Microbiology, with High Distinction, University of Kentucky, Lexington, KY. May, 1985.

Certifications

Board Certified Clinical Specialist in Orthopedic Physical Therapy, American Board of Physical Therapy Specialties, 1996 to 2016.

Evidence-Based Taiji and Qigong Teacher Certification, Center for Taiji and Qigong Studies, New York, NY, August 2012 to August 2014.

Certified in Mechanical Diagnosis and Therapy, McKenzie Institute, USA, 1991.

Licensure

Physical Therapist, State of Kentucky, License Number PT 001627, 1988 to present.

Professional Experience

PRN Home Health Physical Therapist, St. Claire Regional Medical Center, Morehead, KY. April 2016 to present.

Part-Time Staff Physical Therapist, Johnson-Mathers Nursing and Rehabilitation Center, Carlisle, KY. April, 2013 to present.

Part-Time Staff Physical Therapist, Pioneer Trace Nursing and Rehabilitation Center, Flemingsburg, KY. April, 2013 to April, 2015.

Clinical Instructor, Physical Therapy Curriculum, University of Kentucky, Lexington, KY, 1990 to 2013.

Co-Founder, President, and Co-Owner of Progressive Therapeutics, PSC, Maysville, KY. March 1991 to June 2012.

Home Health Physical Therapist, Saint Claire Regional Medical Center, Morehead, KY. October 2008 to March, 2010.

Staff Physical Therapist, Saint Joseph Hospital, Lexington, KY. March 1989 to March, 1991.

Staff Physical Therapist, Central Baptist Hospital, Lexington, KY. October 1988 to March 1989.

Clinical Laboratory Technician, Microbiology, University of Kentucky Medical Center, circa December, 1985 to March, 1988.

Teaching Experience

Full Responsibility

2016 Spring: University of Kentucky, Primary Instructor, Falls and Aging, (CPH 365), Enrollment 30

2015, Fall: University of Kentucky, Primary Instructor, Aging in Today's World (GRN 250) – Enrollment: 75

Publications

Dillon, P.A., and T.L. Overman. 1988. Effect of Prompt inoculator on results of Sceptor system minimal inhibitory concentration determinations for *Listeria monocytogenes.* Arch Pathol Lab Med. 112: 163-165.

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Presentations

Dillon, P.A. 2016. *Tai Chi Motor Imagery: A Strategy of Motor Coordination for Postural Stability into Old Age*. Poster presented at the 26th Annual Southeastern Student Mentoring Conference in Gerontology and Geriatrics, Pensacola, FL.

Dillon, P.A., S.B. Overman, and T.L. Overman. 1986. Effect of Prompt inoculator on results of *Listeria monocytogenes* MIC determinations. Abstr. Annu. Meet. Am. Soc. Microbiol. p. 392.

Overman, T.L., and P.A. Dillon. 1986. False resistance of *Listeria monocytogenes* to penicillin-G with the Autobac AIS test. Abstr. Annu. Meet. Am. Soc. Microbiol. p. 392.