EFFECT OF THE LONG-TERM HEALTH PRACTICES OF TAI CHI, MEDITATION AND AEROBICS ON ADULT HUMAN EXECUTIVE ATTENTION: A CROSS-SECTIONAL STUDY

by

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DISSERTATION ABSTRACT

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Title: Effect of the Long-term Health Practices of Tai Chi, Meditation and Aerobics on Adult Human Executive Attention: A Cross-sectional Study

Meditation, Tai Chi, and moderate aerobic exercise have been shown to positively affect executive attention. We compared the executive attention efficiency and aerobic capacity of long-term Tai Chi, meditation plus exercise, aerobic fitness, and sedentary participants. We hypothesized that because meditation and Tai Chi include moderate aerobic exertion and executive attention training, these groups would show significantly greater executive attention efficiency compared to aerobic exercisers or sedentary control groups. Our results support this. Tai Chi and meditation but not aerobic fitness practitioners significantly outperformed sedentary controls on key executive measures: percent switch costs and P3b ERP switch amplitude (Tai Chi, $p = .001$; $p = .031$, respectively; meditation, $p = .006$; $p = .003$, respectively). This suggests participation in chronic health practices requiring moderate aerobic exertion and attentional focus may offset declines in aerobic, neuromotor, and executive attention capacity often seen in normal aging.

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CHAPTER I

GENERAL INTRODUCTION

Maintaining cognitive function across the human lifecycle is a public health concern (Verghese et al, 2003). Cognitive health contributes to quality of life as well as economic stability. Public health entities (i.e. NIH, Centers for Diseases Control, local hospitals, members of the various health-care professions) are tasked with developing and implementing programs that positively impact cognitive health in the United States. This presents a number of research challenges for providers of evidence of cognitive training regimens that can be applied in clinical settings (Murdaugh, 1997).

Many variables affect human health outcomes. Those include age (Salthouse 2003; Hillman et al, 2006), genetic influences (Rueda et al, 2005; Posner, 2005; Agjewski et al, 2011), nutrition, education, environmental safety, socio-economic status, personal experience, and adherence to health regimens (Patrick, 1996; Kramer, 2007; Metzler et al, 2008; Freeman, 2009). A further challenge is that new health-care protocols must integrate well with the extant health-care system. This is important due to complex efficacy, logistical, and resource allocation goals (Hogan, 1996; Patrick, 1997). Additionally, many health-care clients find it difficult to select and adhere to a health regimen, be it therapeutic or preventative. Thus, practitioner self-efficacy is a major concern for health-care providers (Bogg, 2008; Nigg et al, 2011).

Research taking these issues into account is crucial for development of effective treatment and prevention protocols (Patrick, 1996). Additionally, different physiological systems interact during output of human behavior (i.e., cardiovascular, neuromotor, and cognitive) (Guyton & Hall, 2000; Kandel, et al 2004; Gazzaniga, 2004). This suggests that in human subjects research these systems should be tested simultaneously in order to understand their contribution to the outcomes we measure. Indeed, after decades of research, large normative databases have been assembled on cardiovascular, neuromotor, and cognitive measures (NIH eRA Commons) as well as methods for evaluating performance (psychophysical and physiological). These can be used when comparing similarly collected data (Powers & Howley, 2004; Shadish et al, 2002; NIH Toolbox).

In the laboratory, this enables us to use a multivariate approach to compare the effect sizes explained by each IV or covariate during cognitive and motor behavior observed under carefully designed experimental conditions (Shadish, et al, 2002). Cardiovascular system capacity can be easily assessed with simple, field-tested measures like the Rockport 1-mile walk (Kline, 1987). Neuropsychological tests reliably assess cognitive capacity (Reisberg, 2005; Banich, 1997), including executive attention function (Fan et al, 2002; Salthouse, 2003; Etnier & Chang, 2007). Skill assessment instruments can be custom-designed to laboratory, clinical, or training setting needs (Butler et al, 2010, Berg et al, 1989; Blasing et al, 2010; Chatfield, 2009). These readily available tests allow us to effectively compare system contributions to human cognitive health across subjects and carefully defined groups (Shadish et al, 2002).

The overall purpose of this study was to investigate the cognitive and cardiovascular benefits of three readily available health regimens (Tai Chi, meditation plus exercise, aerobic exercise) in normally aging adults with a focus on executive attention, a key component of cognitive capacity (Salthouse, 2003; Gilbert, 2008). The following sections review the literature on executive attention, neuropsychological tests of executive attention function, and the effects of Tai Chi, meditation, and aerobic fitness practice on attention function.

Attention Function

Attention assists the implementation of system-wide goals in the awake, behaving mammal. Attention effects include increases in firing rate of single units when a monkey attends to a location in space (Leopold & Logothetis, 1996), enhancement of information processing (Corbetta & Shulman, 2002; Oken, Salinsky, & Elsas, 2006), including holding items in working memory (Awh, 2001, Corbetta, 2002; Courtney, 2004; Luck, Vogel, & Shapiro, 1996), doing mathematical calculations (Ishii, Shinosaki, Ukai, Inouye, Ishihara, Yoshimine, Hirabuki, 1991; Mizuhara, Wang, Lobayashi, & Yamaguchi, 2004), planning motor operations (Rushworth, Ellison, & Walsh, 2001; Rushworth, Johansen-Berg, Gobel, Devlin, 2003; Serrien, Ivry, & Swinnen, 2007), maintaining postural control (Huxhold O, Li S-C, Schmiedek F & Lindenberger U, 2006; Silsupadol P, Lugade V, Shumway-Cook A, van Donkelaar P, Chou LS, Mayr U, Woollacott MH, 2009), and resolving response conflicts (Chan & Woollacott, 2007; Milham, 2002; Rushworth, Walton, Kennerley, & Bannerman, 2004a).

The executive control microcircuit arrays in the forebrain have been shown to be activated during conflict resolution, processing of novel stimuli, and error detection (Desimone, 1995; Raz, 2004; Milham et al, 2003; Fan, 2002) This key attention component has many outputs, including selection of relevant stimuli or processes and inhibition of irrelevant ones (Knight; 1995; Milham, 2003).

Executive control has been localized to the anterior areas of the frontal cortex, including the anterior cingulate and dorsolateral and mediolateral prefrontal cortices (Chan, 2001; Fretwald, 2004; He, 2007; Herd, 2006; Humphries, 2004; Rushworth, 2007; Rushworth, 2004b; Taylor, 2007). The anterior cingulate is thought to mediate response-related processes, while bilateral dorsolateral prefrontal cortex is thought to mediate coordination of information relevant to choice of response (Milham, 2003). The left dorsolateral pre-frontal cortex has been found to be activated during tasks requiring regulation of shifts of attention (Callejas, 2005).

Three main executive attention components have been identified for neuropsychological tests: 1) Inhibition, 2) Shifting, and 3) Updating (Miyake, et al, 2000). Working memory is often included as a component of executive function (Gilbert, 2008). Coordinated whole system output includes moving percepts, plans, and goals into and out of working memory (Rowe et al, 2002; Rounis et al, 2007; Rafal et al, 2002; Gevins & Smith, 2000; Miller et al, 1996), appropriate gating of relevant sensory-association and motor re-entrant processing, goal-setting and up-dating, and action implementation (Rushworth, 2001a; 2001b; 1998; 1997).

Neuropsychological Tests of Executive Attention Function

Neuropsychological tests are used to probe attention function. These tests can be combined with neuroimaging (fMRI, PET, EEG) to correlate cognitive output with circuit activation patterns (Poulson et al, 2005; Luck, 1996).

Neuropsychological tests of executive function combine working memory requirements with percept identification, rule memorization and task-specific rule deployment followed by a motor response. Response time and accuracy are the behavioral measures of interest (Carillo-Reid, Tecuapetla, Tapia, Hernandez-Cruz, Galarraga, Drucker-Colin, & Bargas, 2008; Grillner & Graybiel, 2006; Reisberg, 2006; Banich, 1997). These include: Pure perceptual report combined with working memory-aided single (Deco, 2005); dual (Siu, Chou, Mayr, van Donkelaar, & Woollacott,2008), variable (Silsupadol, 2009), or switch tasks (Altmann, 2008); and variants of the Erikson flanker tasks such as the Attentional Network Task (ANT) (Fan, 2002; 2009).

Task switch paradigms evaluate the ability to memorize sets of response rules and switch between them during stimulus presentation (Mayr, 2001; Monsell, 2003a. Altmann, 2008). Stimuli can be auditory, semantic, or visual (Banich, 1997). Switch of response rule can be exogenously or endogenously cued (Kiesel et al, 2003). Rule switches can be predictable or random (Tornay, 2001). In a randomized runs procedure, stimuli are randomly presented one after the other in runs (AABB) for blocks of varying trial lengths (36 trials/block, 24 trials/block, etc). For the switch condition, subjects must switch the response-rule every other trial. Working memory and strategizing are both necessary. On these kinds of tests reaction times on switch trials are consistently longer for all age groups (Mayr, 2001). Percent cost for switching between rules in heterogeneous blocks of stimulus-response mappings has been shown to index executive efficiency (Monsell et al, 2000; Wylie & Allport, 2000; Milan et al, 2006; Pesce, 2011).

EEG recordings in combination with task switch tests have provided evidence for consistent event-related potential (ERP) magnitudes and latencies by electrode during specific attention tasks. This suggests common source generator circuits across subjects output the behavior we measure during the execution of specific tasks. The P300 complex has been under active investigation for decades (Polich, 2007). This is a positive-going waveform appearing at central electrode sites during tasks requiring stimulus identification and working memory updates during the time window 300 to 800 msec post-stimulus presentation. This complex has been dissociated into two main components: P3a (centered around electrode Fz) and P3b (centered around electrode Pz) (Pontifex et al, 2009; Polich, 2007). The whole complex is thought to index inhibitory processes occurring in the fronto-parietal attention circuit during task performance. The frontal pole of this circuit is thought to engage in stimulus discrimination for gating into working memory (P3a) (Light et al, 2007). The parietal pole of this circuit is thought to update working memory for the purpose of successful goal-directed responses during cognitive operations (P3b) (Wylie et al, 2003; Polich, 2007). The amplitude and latency of these two ERPs are sensitive to stimulus and presentation type (Gonsalvez & Polich, 2002), and aging (Adrover-Roig & Barcelo, 2010). A growing body of evidence suggests these amplitude and latency patterns are predictive of executive attention capacity and prefrontal circuit functionality.

Exercise Effects on Attention

Decades of research has shown exercise positively benefits cardiovascular capacity (Powers & Howley, 2004). Cardiovascular capacity is easily measured in the field, clinical, and research settings with estimated VO_2max tests (Kline, 1987; American College of Sports Medicine, 2009). These tests reliably report aerobic capacity in $ml^{-1}/kg^{-1}/min^{-1}$ O_2 (uptake and utilization of oxygen by working tissues). Moderate exercise has also been shown to have beneficial effects on cognition (Davranche, 2004; Hillman, 2003; Kawai, 2007), including 1) speed of information processing as indexed by visual and auditory P300 latency and reaction time decreases, and correlated accuracy increases in oddball tasks (Kamijo, 2004; Zhou, 1984); 2) enhancement of executive attention processes as indexed by reaction time and accuracy on Erikson flanker tasks in older adults who take up aerobic exercise (Hatta, 2005); 3) enhanced memory and neurogenesis in animal models (Ding, 2006; Trejo, 2007); and 4) upregulation of brain-derived neurotrophic factor (BDNF) and insulin-like growth factor which stimulate synaptogenesis, neurogenesis and memory performance in human and animal models. (Cotman, 2002; 2007; Tang, 2008). Additionally, aerobic exercise regimens have been documented to increase the thickness of frontal, parietal and temporal cortices in human subjects (Kramer, 2005). Importantly, a recent meta-analysis showed superior aerobic fitness as quantified by standard cardiovascular measures is not required in order to accrue cognitive benefits from exercise. Light to moderate exercise and dose frequency seem to be the keys (Etnier, 2006; Kamjito, 2004).

Importantly, exercise has been shown to preferentially affect executive attention processing throughout the adult human life cycle (Ratey & Loehr, 2011; Scisco et al, 2008; Hillman et al, 2006; Colcombe & Kramer, 2003). Many of these studies divide exercise types into those requiring cardiovascular training alone or cardiovascular training in combination with strength or resistance training. There are few studies which divide exercise types into those requiring cardiovascular exertion alone and cardiovascular exertion plus consistent mental exertion. Those that do find that exercise requiring constant mental challenge produces greater executive attention benefits than cardiovascular exertion with low mental challenge (Voss, 2009; Pesce, 2011). A high degree of variability is seen in studies of exercise effect on executive function. This could be due to differences in methodology (types of executive tasks used in testing) and confounds from different intensities, types, and durations of exercise practice.

Meditation Effects on Attention

Concentrative meditation involves sustained, exclusive focus on a specific sensation, image, or syllable(s) for extended periods of time (i.e. 30 minutes – 18 hours) (Lutz, 2007; Joshi, 2007; Kubota, 2001). The goal of this practice is sustained, nonjudgmental awareness of all thoughts and sensations, as well as the ability to resist engagement with such (Bishop, 2007). Meditation came under scrutiny by neuroscientists because meditators claim the ability to reliably sustain attention. If this can be shown to be true, this may work in the laboratory setting to shed light on human cognitive processes (Lutz, 2007).

A recent fMRI study of novices, and medium- and long-term concentrative meditators revealed that long-term meditators showed the greatest ability to regulate circuit and behavioral responses to auditory distractor stimuli while resting or meditating. (Brefczynski-Lewis, 2007). Specifically, individuals with > 37,000 lifetime hours of practice showed less activation in sensory processing areas during distractor presentation in both rest and meditation conditions, and less activation in frontal, parietal, and occipital regions dedicated to executive and visuo-spatial processing than either novices or medium-term concentrative meditators. This suggests meditation practice may result in a reliable ability to suppress irrelevant stimuli. If so, we would expect to see plastic changes to specific microcircuits in the brain that are active during this kind of cognitive output.   A cross-sectional study of matched meditators vs. non-meditator controls revealed significantly larger grey matter volume in brain circuits known to subserve response control and affect regulation. Regions with greater grey-matter volume were right orbito-frontal cortex, right thalamus, left inferior temporal gyrus, and right hippocampus (Luders, 2008; Lazar, 2005). Importantly, this study recruited meditators from a number of meditation schools (i.e., Vipassana, Samatha, with between 5-49 years of practice) to test for any significant differences between meditation practices on grey-matter volume. None were found, suggesting that the attentional control required to perform various meditation practices recruits similar sets of specialized circuits across meditation styles.

Cognitive state and trait training effects are reported for executive function (Chan, 2007), orienting (Jha, 2007), and management of attentional resources (Kubota, 2001) in long-term meditators. Meditators showed greater theta phase locking to stimulus onset than non-meditators in a demanding attentional blink paradigm, suggesting sharper, more efficient stimulus encodement. Theta frequency in frontal circuits has been shown to be positively correlated with performance on attentionally demanding tasks (Kubota, 2001; Tsujimoto, 2006). Meditators also showed reduced P3bs in an attentional blink paradigm. This was correlated with a high accuracy rate for target identification, suggesting more efficient percept encodement. These studies suggest concentrative meditation training enhances coordination of attention resources at the circuit level (Slagter, 2007; 2008).

A study by Srinivasan, 2007 showed meditators but not controls demonstrated enhanced mismatch negativities (MMN), an ERP reliably correlated with pre-attentive sensory processing. This suggests meditation enhances very early processing of percept formation. The reader may note that in one study a reduced ERP indicated more efficient processing and in another study an enhanced ERP indicated the same thing. Why is less activation in one task and more activation in another considered efficient? The key to this apparent discrepancy may be where the task is in the serial or parallel distributed sequence of steps necessary to output the behavior being tested (Sigman, 2006; Milham, 2002; Floyer-Lea, 2004). Automated tasks require less activation in subserving circuits than novel tasks, or tasks in the process of encodement. Thus, at the circuit level, meditation training seems to affect early sensory and visuo-spatial association processes in the direction of a greater signal to noise ratio. Output from both of these processes are key inputs to attention circuits engaged in encodement (frontal lobes), engagement (parietal), disengagement (frontal and parietal), and choice (dorso- and medio-lateral prefrontal cortices, anterior cingulate).

Physiology of Tai Chi

Tai Chi is equivalent in physiological exertion to aerobic walking (Li, 2001; Powers, 2004; Zhou, 1984). Importantly Tai Chi requires coordination of 1) movements of arms, legs, head, and trunk positions in single and double-leg stance, 2) shifts of visual focus, 3) control of breath relative to movement, and 4) memorization of complex specific movement sequences (Gatts, 2008; Kerr, 2008; Wolf, 1997).

Tai Chi has been shown to affect the neuromotor system. Tai Chi practice changes muscle recruitment patterns pre-post training (Gatts, 2006; Fong, 2006; Wu, 2004). This suggests motor learning. Motor learning requires encodement of serial and distributed parallel motor unit recruitment commands. Automated activation patterns in serial and parallel distributed motor circuits are defined as motor programs (Rushworth et al, 1998; Kandel, 2000; Shumway-Cook, 2007).

Motor programs are calculated by the basal ganglia, cerebellum, pre-supplementary motor area, premotor area, and dorso-lateral prefrontal cortex bilaterally (Grillner & Greybiel, 2006; Kandel, 2000; Shumway-Cook, 2007). Dorsolateral prefrontal cortex is especially implicated in the recruitment and organization of 1) salient memories, 2) motor programs, and 3) somatosensory information for output to online motor and cognitive interactions in humans (Milham, 2003; Rushworth, 2007; 2004a; 2004b). The anterior cingulate cortex seems to participate in calculating goal-driven system responses (Altmann, 2008; Milham, 2003; Corbetta 1998; 2002) that are based on cost-benefit assessments (Grillner, 2006). Practitioners of Tai Chi are required to set and achieve complex cognitive and motor performance goals that must be endogenously cued throughout long movement sequences (10 minutes – 1 hour) (Gatts, 2008).

With respect to circuit activations during motor learning, Floyer-Lea (2004) showed that during the early motor learning stage, activity in the prefrontal cortex, sensori-motor association areas, parietal cortex, caudate, and ispilateral cerebellum increases. As the behavior approaches automaticity, however, those circuits quiet. A different set of circuits is then activated during movement performance. That includes the thalamus, putamen, and cerebellar dentate (Floyer-Lea, 2004). This suggests feedback processes necessary to correct online movement or sensory integration errors decrease as encodement of the motor program is completed. As a complex motor skill, Tai Chi, requires constant application of executive attentional control, and thus could be expected to result in plastic changes to executive circuits in the prefrontal cortex.

A study by Audette 2006 investigated Tai chi versus brisk walking in elderly women in a randomized controlled trial. They found a significant increase in aerobic power, as measured by VO_2 max in elderly women who did Tai Chi vs. brisk walking. VO_2 max indexes efficiency of oxygen transport and utilization during exertion. Changes in VO_2max are positively correlated with changes in cardiac stroke volume (Powers, & Howley, 2004), and thus the amount of blood per minute circulating through the vascular system. Stroke volume is mediated by parasympathetic and sympathetic signals to specialized receptors on cardiac atrial node cells. (Silverthorn, 2004). Changes in stoke volume are correlated with changes in autonomic signals to the heart. These kinds of changes suggest autonomic adaptation to the practice of Tai Chi.

Gatts and Woollacott, (2006, 2007) investigated the neural and biomechanical mechanisms underlying Tai Chi's effect on control of center of mass during gait perturbations. Gait perturbations probe dynamic balance control (Shumway-Cook, 2007). In randomized, controlled trials they found Tai Chi enhanced reactive postural responses. Especially affected was motor recruitment at the ankle. Improvement of ankle management is a consistent pattern in kinematic and EMG studies of Tai Chi. Their results confirmed that Tai Chi training enhanced subjects' abilities to make quick, accurate adjustments in posture and swing leg response during a gait perturbation. This suggests plasticity in neural circuits integrating multi-modal sensory information, motor plans, and mechanisms correcting for error signal. These include motor-related prefrontal cortical modules, the basal ganglia, cerebellum, and spinal locomotor targets (Kandel, 2000; Shumway-Cook, 2007).

Comparison of Tai Chi and Meditation Training Effects

Evidence suggests both Tai Chi and sitting forms of meditation require executive attention circuit activation to learn and to perform (Halsband, 2006; Lutz et al, 2007; Gatts, 2008; Luders, 2008). As such, we might expect to see similar training effects in executive networks of long-term Tai Chi practitioners and sitting meditators.

Practice of Tai Chi has been shown to produce long-term changes in the muscle recruitment patterns required for dynamic balance control during its performance in as little as 3 weeks (Gatts and Woollacott, 2007). This suggests learning-related changes have occurred in motor and attention networks (Halder, 2005).

Sedentary meditation training has been shown to produce changes in executive and autonomic function in five days if trainees are highly motivated or self-selected (Tang, 2007; Zeidan, 2010).

What are the differences between Tai Chi and sitting meditation training regimens? Tai Chi is a form of moderate exercise requiring between 4-8 METs (Li et al, 2001; Powers & Howley, 2004). Sitting meditation requires only 1 MET (Powers & Howley, 2004). However, the meditators we tested uniformly self-reported chronic aerobic fitness activities and demonstrated an aerobic capacity similar to long-term aerobic fitness practitioners. The key difference between our Tai Chi and sitting meditation groups is in relation to the attentional focus instructions specific to each of these regimens. Tai Chi requires that attention be focused simultaneously on the achievement of multiple, inter-related goals and the ability to memorize and independently perform complex motor sequences (Gatts, 2008).

In sitting meditation, whether one practices a single focus (the breath, a mantra, or an image) or mindfulness (non-engagement with sensory, cognitive, or affective stimuli)(Lutz, et al 2007), there is a single goal which is implemented, monitored, and achieved by the executive attention network . Thus, it is hypothesized Tai Chi trains motor attention (Rushworth, 2001a; 1997), and sitting meditation trains the inhibition and self-monitoring components of executive attention (Lutz et al, 2007; Lutz et al, 2008; Smallwood, 2008; Luders, 2009).

Would these two types of chronic executive attention exertion produce different outcomes on a demanding neuropsychological executive attention test? Evidence suggests the motor and executive networks interact but are dissociable (Rushworth, 2003; 2004b). If so, would Tai Chi practitioners outperform meditators and aerobic fitness practitioners with no Tai Chi training on motor responses because they have trained the greater motor attention network? By this logic, would meditators outperform all other groups on inhibition and self-monitoring because that is an important part of meditation training (Lutz et al, 2007)? Would these two training regimens requiring specialized attentional exertion produce greater benefits to executive function than moderate aerobic exertion with its more relaxed attentional focus? Recent work by Chan & Woollacott (2007), Voss (2009), and Pesce (2011) suggest they might.

Purpose of This Study

Successful cognitive aging is a public health concern (Verghese et al, 2003). Executive attention may mediate cognitive function (Salthouse, 2003). Moderate aerobic exertion has been shown to positively benefit human executive attention function. Mental exertion has been shown to affect executive function (Chan & Woollacott, 2007; Slagter et al, 2007, Tang, 2007).We tested the hypothesis that long-term practice of Tai Chi, and meditation would produce greater executive attention training benefits than aerobic fitness alone. Generally sedentary participants who had never trained in Tai Chi or meditation served as baseline controls for the effects of long-term moderate exercise on cardiovascular and executive attention function. Because these controls had never undertaken Tai Chi or meditation training, cognitive effects of long-term motor or concentrative attention training could be compared across all groups.

Bridge

To assess long-term health regimen training effects on executive attention function, we measured estimated VO_2max (described in Chapters II and VI) (Kline et al, 1987; Colcombe et al 2004), Tai Chi skill (experiment described in Chapter III), simple inhibition and self-monitoring function (described in Chapters IV and V) (Smallwood, 2008), visuo-spatial task switch reaction time and percent local switch costs (experiment described in Chapter V (Mayr, 2001), and P3b amplitude and latency correlated with switch trial events (experiment described in Chapter VI (Polich, 2007). General methodology is described in Chapter II.

CHAPTER II

GENERAL METHODOLOGY

Participants

Participants were recruited by word of mouth, local Craigslist and newspaper ads, and flyers posted throughout the communities of Eugene and Springfield, Oregon. Inclusion criteria were 1) no neurological or physical disorders, and 2) aged 20-75. Sedentary participants were required to have 1) a generally inactive lifestyle for five or more years, and 2) no prior experience with meditation or Tai Chi. Health regimen practitioners were required to 1) have practiced at least five years or more, three times per week, 30 minutes per session. All participants had self-selected into their preferred level and type of exercise activity. Fifty-nine participants responding to a health regimen recruitment campaign agreed to four hours of testing scheduled at their convenience. Because acute exercise has been shown to positively affect cognitive performance (Pesce, 2011; Davranche, 2004) we scheduled the cognitive and exercise testing separately. If the participants preferred to do the testing in one day, the cognitive testing was done first followed by the exercise testing. Two Tai Chi participants who could not use a computer effectively were excluded since our key executive attention tests were administered via PC computer. Two subjects did not complete the testing. One subject who presented with bipolar disorder and presently off medication was excluded. Thus, 54 subjects completed all tests and were included in this analysis (female = 27). Final group composition was 1) 10 Tai Chi (female = 3), 2) 16 meditation plus exercise (female = 6), 3) 16 aerobic fitness (female = 8), and 4) 12 generally sedentary (female = 10) participants. Final group composition for the Tai Chi Skill Assessment was 13 (female = 6). Body mass index (BMI) was calculated for each participant (http://www.nhlbisupport.com/bmi/) Participant characteristics are presented in Table II.1.

Table II.1

Participant Characteristics

Group	*n*	Female	Age	BMI
Tai Chi	10	3	55.4 ± 12.99	29.3 ± 3.77
Meditation	16	6	48.63 ± 15	23.3 ± 3.53
Aerobic Fitness	16	8	44.09 ± 16.2	23.78 ± 2.62
Sedentary	12	2	46.92 ± 12.81	27.93 ± 6.37

Subject recruitment and experimental protocol were approved by the University of Oregon Institutional Review Board. Subjects signed Informed Consent and were compensated for their participation. Informed Consent Forms are presented in Appendix A.

Multivariate Cross-sectional Design

In multivariate designs multiple dependent variables are measured on subjects who are assigned membership in carefully defined groups (Stevens' 2002) (see Figure II.1). We asked if we could isolate executive attention training effects by comparing scores on aerobic capacity (VO_2max) and key executive attention variables on three training groups: 1) Tai Chi, 2) meditation, and 3) aerobic fitness. Our fourth group was composed of generally sedentary participants who had not engaged in Tai Chi or meditation training. Our original design specified that Tai Chi and meditation practitioners would differ on lifetime hours of aerobic exertion, thus we could compare the training effects of moderate exercise plus motor attention exertion to no moderate exercise plus concentrative attention exertion. However, in this study we found no sedentary meditators. All of our long-term health regimen volunteers reported a similar number of lifetime hours of aerobic activity as our aerobic fitness group Thus, the difference between our training groups was the type of attention required to perform each health regimen (Pesce & Audiffren, 2011; Voss et al, 2009). The control group allowed us to assess training effects on cardiovascular and attention measures relative to a no-training population. Because normal aging is associated with degradation of cognitive and physiological function, age was included as a covariate.

Health Behavior	System Requirements		
	Exertion*	Cognitive Focus**	Motor Function***
Tai Chi	Moderate	Complex	Complex Coordination
Meditation Exercise	Moderate	Concentrated	Simple Coordination
Aerobic Fitness	Moderate	Relaxed	Simple Coordination
Inactive	Random	Random	Random

Figure II.1. Study Design. *Cardiovascular/respiratory requirements (Powers & Howley, 2004); **In CNS requirements (Halsband & Lange, 2006; Rushworth); ***Neuromotor/skeleto-motor requirements (Powers & Howley, 2004; Shumway-Cook & Woollacott, 2007; Castaner et al, 2009; Blasing et al, 2010).

<u>Testing</u>

Aerobic Capacity --Rockport 1-mile Walk (Kline et al, 1987; American College of Sports Medicine, 2009). Subjects were fitted with an Athletic Connection Polar E600 heart rate monitor (Polar Electro-USA). A chest strap with heart sensor sent information on heart rate and walk time to a wrist recorder. Subjects walked 1 mile as fast as they were able. Estimated VO_2Max and METs were calculated by entering subject's age, weight, gender, walk time, and ending heart rate in a java applet located at http://www.exrx.net/Calculators/Rockport.html (see Figure II.2).

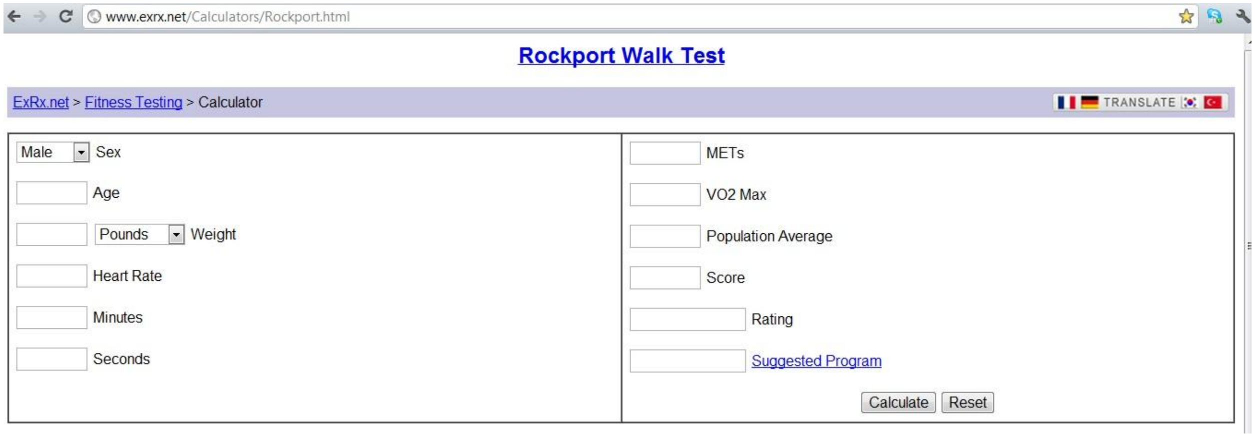


Figure II.2. VO_2max and MET java applet.

Tai Chi Skill. A Tai Chi leg kick sequence was selected from a 10-form Tai Chi sequence developed for the laboratory by Wolf (1997). An international Tai Chi champion was selected as a professional exemplar. Video of this exemplar was downloaded and the 11 seconds which depicted the Tai Chi leg kick sequence was extracted. The 11 second clip was not used in any commercial ventures nor reproduced in any other form. This video was used to train participants to independently and safely perform the Tai Chi Leg Kick (see Figure II.3).

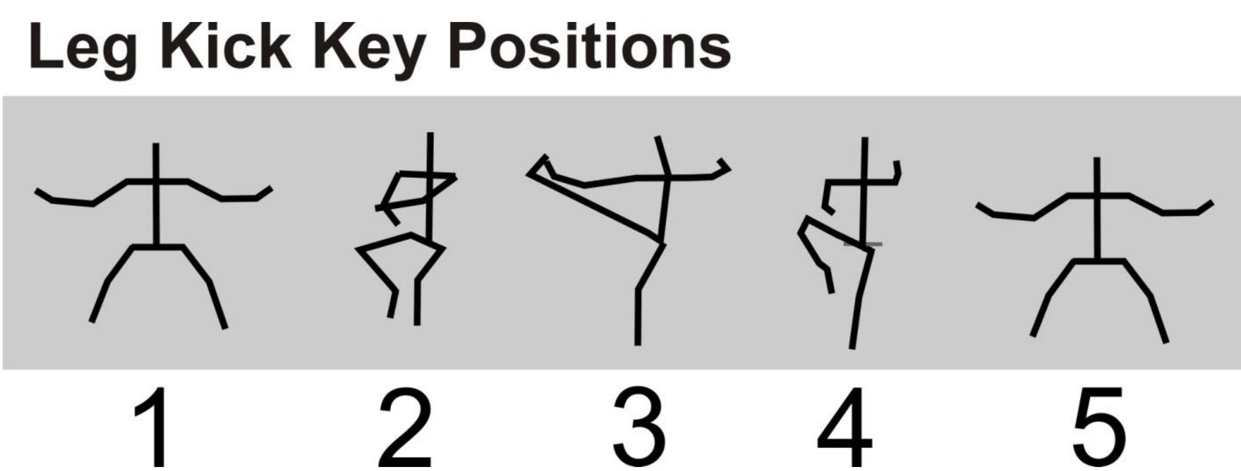


Figure II.3. Key positions in the Tai Chi leg kick.

Motion Analysis Data Collection. Subject height and weight were recorded. Subjects wore a tight-fitting dance unitard and swim cap. 31 Markers were placed on bony landmarks per a modified-Helen Hayes marker set (Motion Analysis Corporation, 2009). An eight-camera system captured whole body motion at 60 Hz (Motion Analysis Corporation, Santa Rosa, CA).

Subjects were warmed up with the following sequence: 1) one minute of stationary horse stance, 2) one minute of moving horse stance (Powers & Howley, 2004). Subjects then viewed the exemplar video as many times as they wished. They were then instructed in the movement sequence, and given feedback on performance until they felt they could perform the movement safely and independently. Subjects performed 12 separate trials of the Leg kick form.

Motion data analysis. Marker trajectories were filtered with a low-pass, fourth order Butterworth filter at a cutoff frequency of 8 Hz. Thirteen-segment anatomical models were derived. Mp4 recordings of Trial 12 of each subject performing the Tai Chi Leg Kick from the same angle as the grand master were recorded.

Tai Chi skill rating. Six blinded expert raters scored subject Mp4 recordings using the Tai Chi Skill Assessment. Instrument development and testing are described in Chapter III. Rater scores were averaged by participant. Rater average was recorded as subject Tai Chi skill score.

Concentrative Meditation Skill -- Sustained Attention Go No-go (Smallwood, 2008). Subjects were seated ~ 24 inches in front of a computer monitor. A fixation cross appeared in the center of the screen. Subjects were directed to focus on this point. An X or 0 appeared there. Zeros were non-targets and required a button press response. X's were targets and required the subject to withhold the button press response (see Figure II.4).

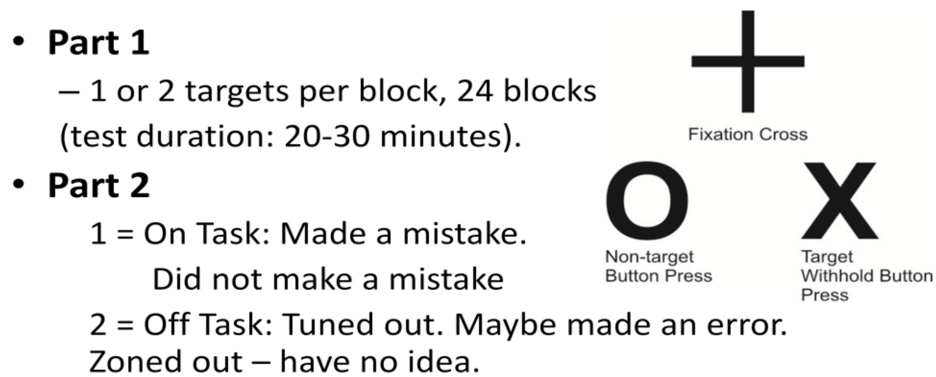


Figure II.4. Sustained attention go no-go paradigm .(Smallwood et al, 2008).

Subjects were allowed to practice until they felt comfortable with the test. They then completed 24 blocks of trials. There were two block types: 1) An 11-trial block with one X, and 2) A 31-trial block with two X's. Twelve blocks were 11-trial blocks and twelve blocks were 31-trial blocks. Block type presentation was randomized. Appearance of the X was randomized within blocks. At the end of each block, subjects were asked to rate their own performance. Their options were: 1) On Task. Fully attentive to performing the task with two performance sub-categories): a) Sure you made no mistakes; b) Sure you made a mistake. 2) Off Task with two performance sub-categories: a) Tuned out. Off-task and suspect you may have made a mistake; b) Zoned out. Off-task and unsure if you made a mistake. The dependent variables were accuracy withholding target responses (inhibition), and self-reported performance (self-monitoring). This test was programmed in E-Prime (Psychology Software Tools, Inc.), and delivered from a PC-laptop to a monitor with a two-button mouse input (Logitech, Apples, Switzerland).

Complex Executive Attention Test. Visuo-spatial task switch (VSTS) with dense array EEG (Mayr Laboratory, University of Oregon). This task required working memory, inhibition, updating, and shifting (Miyake, 2000; Gilbert, 2008). Participants were trained in two different response rules (Rule 1 and 2) to indicate the spatial location of a randomly appearing dot within a fixation rectangle. For Rule 1, the button press response was compatible with the dot's location in space. For Rule 2 the button press was incompatible with the dot's location in space. For the Switch test (Rule 3) participants switched between Rule 1 and 2 on every other trial. Trials in which a switch of response rule was required were designated switch trials (see Figure II.5).

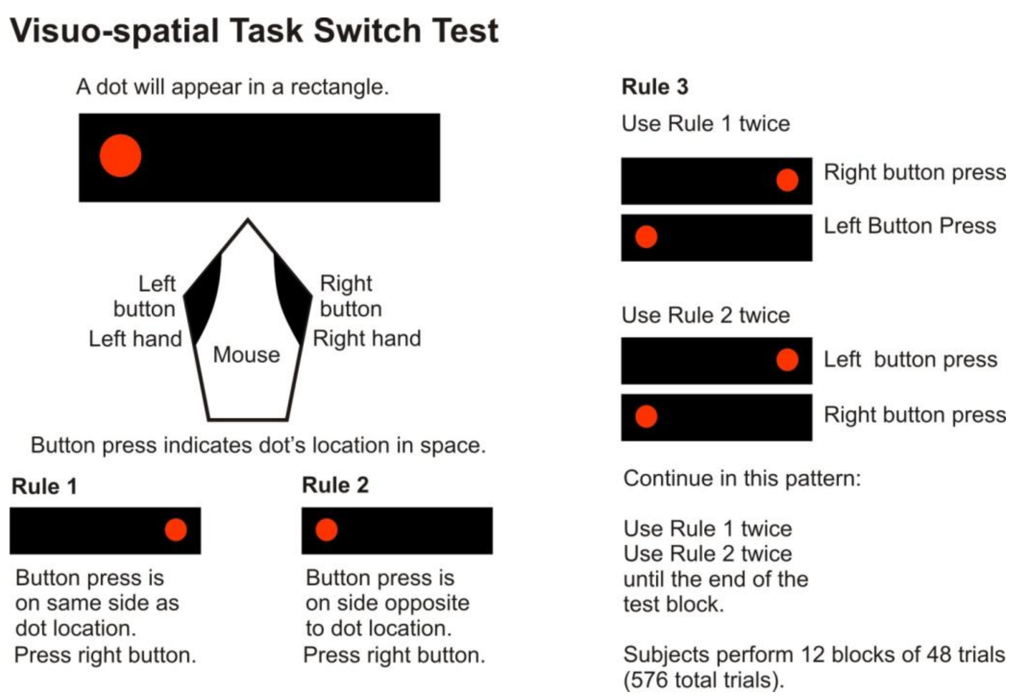


Figure II.5. Mayr Visuo-spatial task switch paradigm.

Trials when the response rule remained the same as the previous trial were designated no-switch trials. The test was coded in E-Prime for use with dense array EEG (Electrical Geodesics, Eugene, Oregon). Coded events in the EEG data stream and the VSTS raw data output were: 1) stimulus type (Congruent Right, Congruent Left; Incongruent Right, Incongruent Left); 2) Trial type (Congruent switch, congruent no-switch, Incongruent switch, incongruent no-switch); and response (correct or incorrect). Trial and stimulus type coding allowed us to precisely identify reaction time associated with each type of trial and stimulus. For this analysis, switch and no-switch trials were collapsed onto means. Switch costs were calculated thus: Switch RT – No-switch RT/No-switch RT. This controlled for any possible speed accuracy trade-off. Dependent variables were switch reaction time and switch costs.

Stimuli were displayed on a computer monitor located ~ 24 inches in front of the participant. Participants were trained to respond as quickly and accurately as possible to stimulus appearance using a two button mouse. For Rule 3 participants were provided with visual feedback in the case of erroneous responses. They corrected their error and continued the trial block. Participants practiced each Rule until they achieve 85% accuracy. Rules 1 and 2 consisted of 48 trials in two blocks. Rule 3 (the actual task switch) consisted of twelve blocks of 48 trials. All tests were administered from the same instruction script on the same PC computer.

Participant instructions are presented in Appendix D. Data Collection workflow is presented in Appendix C.

Expertise Questionnaire. This questionnaire is modified from one used by Joshi, 2007. This quantifies in minutes and hours by year the amount of time each subject self-reported practice of aerobic activities, sitting meditation, and/or Tai Chi.

The Adult Temperament Questionnaire, Short Form – Version 1.3 (ATQ)(Derryberry & Rothbart, 1988). This 77-question assay was developed by Derryberry and Rothbart. It evaluates effortful control (test-retest reliability= .78), negative affect (test-retest reliability=.78), extraversion/surgency (test-retest reliability = .75), and orienting sensitivity (test-retest reliability = .85). Text of questionnaires is presented in Appendix D.

Data Analysis

To protect against alpha slippage, one multivariate analysis of variance (MANOVA) was performed on the data set from the overall study. Levene's test for homogeneity of variance was performed. Sidak correction (a variation of Bonferroni) was used for post hoc analyses. All results reported here are from that one procedure (Stevens, 2002). Our independent variable was health training modality. Overall study dependent variables were lifetime hours of aerobic, meditation, or Tai Chi practice, simple inhibition, simple self-monitoring, body mass index (BMI), VO_2max, metabolic equivalents (METs) of effort expended during the Rockport 1-mile walk, Tai Chi Skill, no-switch RT, switch RT, switch costs, VSTS post-error RT, VSTS accuracy, fractal dimension of VSTS RT time series, P3b switch amplitude, P3a switch amplitude, P3b no-switch amplitude, P3a no-switch amplitude, P3b switch latency, P3a switch latency, P3b no-switch latency, P3a no-switch latency, and the thirteen temperaments from the Adult Temperament

Questionnaire (ATQ): fear, sadness, discomfort, frustration, sociability, positive affect, high intensity pleasure, attention control, inhibitory control, activation control, neutral perceptual sensitivity, affective perceptual sensitivity, and associative sensitivity. Key outcome measures were 1) estimated VO_2max, 2) self-monitoring capacity, 3) Tai Chi skill, 4) VSTS switch reaction time, 5) VSTS percent local switch costs, 6) P3b switch amplitude, and 7) P3b switch latency. VSTS switch trials were collapsed onto means. Because we were evaluating whole system functionality, error trials were included in these means. *Alpha* was set at .05 for the main MANOVA. A bivariate correlation was run on all variables. To control for *alpha* slippage for multiple analyses (PCA and cluster analyses not reported here), a Bonferroni correction was applied and *alpha* set at 0.0125. Groups were numerically coded thus: Tai Chi, 1; Meditation plus exercise, 2; Aerobic fitness, 3; and sedentary control, 4. We matched this numbering system with our hypothesis that Tai Chi and meditation practitioners, would outperform aerobic fitness practitioners, and all training groups would outperform sedentary controls on our executive function variables. This made correlations between group members and our numerical variables interpretable. All analyses were run with PSAW Statistics 19 (IBM, Chicago, Illinois).

Bridge

The purpose of this study was to investigate the effects of three readily available, long-term health regimens on executive attention function in normal adults across the lifespan: Tai Chi, meditation, and aerobic fitness. Executive attention function in our training groups was compared to generally sedentary controls who had never engaged in

Tai Chi or meditation training. To confirm aerobic capacity, all participants underwent the Rockport 1-mile walk (Kline, 1987) which yields an estimated VO_2max score. This indexes aerobic capacity. We expected Tai Chi and aerobic fitness practitioners to outperform meditators and sedentary controls on this measure. To document meditation training effects, a sustained attention go no-go with self-monitoring (Smallwood et al, 2008) was administered to all subjects (results reported in Chapter VI). We expected meditators to outperform all other groups on the self-monitoring measure. To document Tai Chi training effects, a Tai Chi Skill Assessment was developed and administered to all participants. This is described in detail in Chapter VI. We expected Tai Chi practitioners to outperform all other groups on this measure.

CHAPTER III

PRELIMINARY DEVELOPMENT OF A TAI CHI SKILL ASSESSMENT INSTRUMENT

Introduction

Movement instructors routinely design and implement movement training programs for the average person, as well as dancers, athletes, and martial artists. Each movement program requires specific motor and cognitive skills (Castaner, 2009; Blasing et al, 2010). Examples of movement training programs include folk dance, discus throwing, rowing, weight-lifting, ballet, gymnastics, yoga, bowling, shooting, and martial arts. Training-related adaptations occur in the cardiovascular-respiratory, neuro-motor, skeleto-motor, and cognitive systems as a result of movement training (Powers & Howley, 2007; Voss, 2009; Blasing et al, 2010).

Training benefits to system function typically occur within normative timeframes. It has been hypothesized that cognitive adaptation occurs quickly, often within minutes, while neuromotor programs form within days. Muscle adaptation occurs over weeks (Powers & Howley, 2004). Total time required to become moderately skilled in any movement program depends on the complexity of the required neuromotor tasks and the ability and commitment of the participant (Blasing et al, 2010). Assessing skill acquisition is an integral part of movement instruction. While it is true casual observers can distinguish between excellent and novice movement skills, can they say why? Can they put a reliable number on these differences? In research, clinical, training, and competitive settings we need to identify skills required of performers and put numbers on these differences. Indeed, not just anyone can be a judge at a sporting competition. Just so, in the clinical and research settings, not just anyone can deliver an assessment of performer skill which can be used across subjects and groups.

Typically, experts develop criteria for evaluating expertise in a skill based on the motor and cognitive skills required to perform the particular sport or movement style (Berg et al, 1989; Gatts, 2008; Chatfield, 2009; Krasnow, 2009; Blasing et al, 2010; Butler et al, 2010). These criteria are selected to differentiate novice from skilled practitioners. Since movement programs require specific contributions from the cardiovascular, respiratory, cognitive, neuromotor, and skeleto-motor systems (Castaner et al, 2009), assessments of training effects must include measures of expected gains in strength, balance, flexibility, endurance, aerobic capacity, and cognitive skill (Blasing et al, 2010). Skill assessments in Olympic sports (i.e., figure skating, gymnastics) are carefully codified, and experienced judges work from established guidelines when rating performances. US Figure Skating guidelines list skating skills, transitions, performance and execution, choreographic excellence, and performer interpretation as key criteria. (US Figure Skating, 2011).

Skill assessments that can be tested for reliability, sensitivity and specificity are being developed for use in the movement research setting. Ability to report accurate representations in long-term memory of the basic action sequence required to perform a pirouette was used to differentiate novice through advanced ballet dancers (Blasing, et al, 2010, p. 75-98). Chatfield et al, 2009 developed a modern dance proficiency test which rated 1) overall dance skill, 2) use of space, time, energy, and phrasing, and 3) presence. This instrument successfully differentiated between non-dancing controls and, beginner, intermediate, advanced, or professional modern dancers (Chatfield, 2009). The goal of these specialized instruments was to accurately differentiate between individuals with no training and practitioners, rate practitioner performance level, detect performance deficiencies, and enhance training methods in specific training and laboratory settings. Thus, development of specialized movement program assessment instruments has a place in the clinical, training, and research settings (Riddle & Stratford, 1999; Castaner, 2009).

This study was part of a larger project evaluating the effects of long-term training in Tai Chi, meditation plus exercise, aerobic fitness, and general sedentary lifestyle on executive attention function. In order to evaluate these effects, Tai Chi skill needed to be assessed by subject and group. Tai Chi is a martial art that is equivalent in physiological exertion to aerobic walking (Li, 2001; Powers, 2004; Zhou, 1984). Tai Chi requires coordination of 1) movements of arms, legs, head, and trunk positions in single and double-leg stance, 2) shifts of visual focus, 3) control of breath relative to movement, and 4) memorization of complex movement sequences (Gatts, 2008; Wolf, 1997). The goal of this study was to develop a Tai Chi skill assessment capable of detecting Tai Chi training effects in long-term practitioners of Tai Chi compared to meditation plus exercise, aerobic fitness, and generally sedentary individuals.

Methods

Participants. Participants were recruited by word of mouth, local Craigslist and newspaper ads, and flyers posted throughout the communities of Eugene and Springfield, Oregon. In order to participate, subjects were required to have no neurological or physical disorders and be aged 20-75. Sedentary participants were required to have a generally inactive lifestyle for five or more years and no prior experience with meditation or Tai Chi. Health-regimen practitioners were required to 1) have practiced at least five years or more, three times per week, 30 minutes per session. All participants had self-selected into their preferred level and type of exercise activity. Fifty-nine participants responded to word of mouth, Craigslist, and newspaper advertisements. All participants were tested at their convenience. Final group composition was 1) 13 Tai Chi (female = 6), 2) 16 meditation plus exercise (female = 6), 3) 17 aerobic fitness (female = 9), and 4) 12 generally sedentary (female = 10) participants. Body mass index (BMI) was calculated for each participant (U.S. Department of Health & Human Services, 2012). Subject recruitment and experimental protocol were approved by the University of Oregon Institutional Review Board. Subjects gave Informed Consent and were compensated for their participation.

Lifetime Tai Chi Practice Self-report. Participants self-reported average daily and weekly Tai Chi practice, and total number of years of that intensity of practice. Lifetime hours of practice were calculated.

Tai Chi Skill Assessment Development. A Tai Chi leg kick sequence was extracted from the 10-form Yang-style Tai Chi sequence developed by Wolf, 1997 for use the clinical and community settings. This leg kick sequence required smooth weight shift between single and double limb support, one leg balance with leg extension, coordination of upper and lower body movements, and ability to memorize and independently perform the sequence. An international Tai Chi tournament champion was downloaded from Youtube. Eleven seconds of that video edited to highlight the Tai Chi leg kick sequence we had chosen (see Figure II.3).

This video was used to train participants to independently and safely perform the Tai Chi Leg Kick. The Tai Chi skill assessment instrument was based on the structure used by Chatfield (2009). Guided by this instrument, judges evaluated general skill and specific skill items according to relevant modern dance criteria. For the Tai Chi Skill Assessment instrument, skills outlined in a proposed Tai Chi training model by Gatts, 2008 were used as the judging criteria (see Table III.1). Three professional Tai Chi instructors reviewed and approved this assessment instrument. These instructors also later served as professional raters. Rating categories included general Tai Chi skill level (no experience through professional) and nine specific skill items: 1) head and trunk verticality, 2) accurate foot positions, 3) accurate postures and transitions, 4) rotation of movement about spine and waist, 5) smooth, even limb velocity, 6) relaxed muscle activity, 7) control of whole body center of mass, 8) movement flow, and 9) slowness of movement. Ratings included 1) below average for level, 2) average for level, and 3) above average for level.

Table III.1

Tai Chi Skill Scoring Form

General Skill Level	Score	Criteria
No Experience	0	Displays little or no familiarity and skill with sequence

Table III.1 (continued)

General Skill Level	Score	Criteria
Beginner	9	Displays limited familiarity and skill
Intermediate	18	Displays familiarity and skill with sequence
Advanced	27	Displays familiarity, skill, and confidence with sequence
Professional	36	Displays complete command of skills

Individual Tai Chi Skills

Rank	Score
Below average for level	1
Average for level	2
Above average for level	3

Skill	Judging Criteria
Head and trunk verticality	Subject's trunk and head remain in a line perpendicular to the floor throughout the movement sequence,
Accurate foot positions	Subject places feet in same floor pattern as exemplar.
Accurate postures and Transitions	Subject accurately reproduces exemplar key postures and transitions.
Movements rotate around spine and waist	Subject twists around spinal column rather than abducting the torso.
Limb velocity smooth and even	Subject's arm and leg movements seem smooth, not jerky.

Table III.1 (continued)

Skill	Judging Criteria
Relaxed muscle activity	Subject's movements are not rigid.
Control of whole body center of mass (COM)	Subject never loses balance, nor has to keep balance by rapid arm or leg compensatory movements.
Sequential flowing pattern	Subject performs the movement sequence accurately.
Slow movement	Subject moves at a consistently slow pace.

Experimental Protocol

Motion Analysis Data Collection. Subject height and weight were recorded. Subjects wore a tight-fitting dance unitard and swim cap. Thirty-one reflective markers were placed on bony landmarks per a modified-Helen Hayes marker set (Motion Analysis Corporation, 2009). An eight-camera system captured whole body motion at 60 Hz (Motion Analysis Corporation, Santa Rosa, CA). Subjects were warmed up with the following sequence: 1) one minute of stationary horse stance, 2) one minute of moving horse stance (Powers & Howley, 2004). Subjects viewed the exemplar video as many times as they wished. Subjects were instructed in the movement sequence by the experimenter and research assistant. The Research assistant had two years of training in Tai Chi. The experimenter had studied dance, yoga, Kung-fu, and Tai Chi for 35 years and trained the assistant to demonstrate the form. Subjects were given feedback on performance until they felt they could perform the movement safely and independently. Subjects performed 12 separate trials of the Leg kick form. The 12th trial was used to generate Mp4 recordings for rating. This served two purposes: 1) to test the subject's mastery of the movement, and 2) to test the subject's endurance.

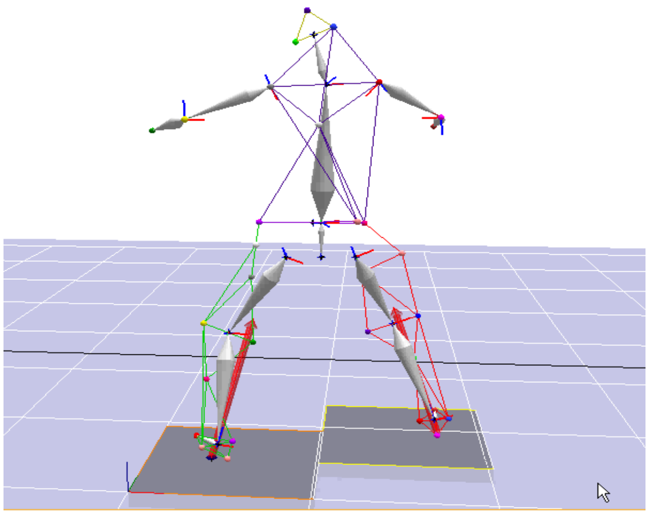


Figure III.I. Motion analysis skeleton model.

Motion data analysis. Marker trajectories were filtered with a low-pass, fourth order Butterworth filter at a cutoff frequency of 8 Hz. Thirteen-segment anatomical models were derived with KinTools Software (Santa Rosa, CA)(see Figure III.1). Mp4 recordings of Trial 12 of each subject performing the Tai Chi Leg Kick from the same angle as the grand master were created.

Rater Blinding. Subjects were assigned a number when they joined the overall study. For the Tai Chi skill assessment, a different, random number was assigned to each subject's Mp4 recording. A list of original and blinding numbers was kept separately for use in matching each subject with their score subsequent to rating. Subject group information, original subject number, and subject identity were not available to raters.

Raters. Six raters evaluated each subject on Tai Chi skill. Rater 1 was a Ph.D. candidate in the Department of Human Physiology, University of Oregon, professional yoga and dance instructor with 35 years of training in ballet, modern dance, yoga and martial arts and two years of intensive training in Yang and Chen style Tai Chi. Rater 2 was a Research Assistant with three years of training in Yang style Tai Chi. Rater 3 was a Research Associate who had trained in Aikido, Karate, Tae Kwon Do, Systema and fencing for eight years, but had no experience with Tai Chi. Rater 4 is a professional Tai Chi instructor and Ph.D. neuroscientist. Rater 5 is Co-Director of the United States branch of the World Chinese Internal Martial Arts Association, and honorary president of the Tsang Cheuk Yi Chen Style Tai Chi Association of Hong Kong. Rater 5 has taught Tai Chi for 35 years. Rater 6 is a Tai Chi instructor and researcher with the Oregon Research Institute, and a Tai Chi instructor with the University of Oregon.

Tai Chi Skill Assessment Rating. The six raters were trained to use the Tai Chi Skill Assessment. Professional raters were compensated for their time. Raters were familiarized with the criteria described in Table III.1, and then proceeded with subject rating when comfortable with the rating criteria. Raters scored the Mp4 recording of each subject performing the Tai Chi Leg Kick. Mp4s were displayed on a 27 inch iMAC. Raters were able to compare the Mp4 of the professional exemplar to the recording of each subject. Rater scores were averaged by subject. This average was recorded as Tai Chi skill raw score. Our six raters agreed that the professional exemplar’s score was 63, the maximum possible score. Participant Tai Chi skill was recorded as a percent of the professional's score.

Data Analysis

Validity indices. A two-way intra-class correlation was performed which evaluated consistency across raters on single and averaged measures of subject general Tai Chi skill level and specific Tai Chi skill items. Cronbach's Alpha was calculated (McGraw & Wong, 1996). A multivariate analysis of variance (MANOVA) was performed for the overall study. Levene's test for homogeneity of variance was performed. Sidak correction (a form of Bonferroni correction) was used for post hoc analyses. Our independent variable was health training modality. Because normal aging is associated with degradation of cognitive and physiological function, age was included as a covariate. Only Tai Chi skill results are reported here. Other results are reported in Chapters IV, V, and VI. All analyses were run with PSAW Statistics 19 (IBM, Chicago, Illinois).

Results

Reliability of the Tai Chi Skill Assessment. Agreement of raters on Tai Chi skill was high. Cronbach's Alpha was 0.915 indicating the internal consistency among raters was high. The two-way ICC single measures outcome was 0.641, $p < 0.001$, indicating some degree of disagreement among raters on individual measures. However, the averaged measures outcome was 0.915, $p < 0.001$, indicating a high degree of agreement among raters when scores were averaged. Rater scores, means, standard deviations, and group are presented in Table III.2.

Table III.2

Tai Chi Skill Assessment Rater scores by Subject.

Subj.	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6	Mean	SD	Group
1	36.51	41.27	34.92	23.81	43.75	46.03	37.72	8.01	SED
2	65.08	61.9	41.27	46.03	69.84	85.71	61.64	16.23	TC
3	66.67	61.9	26.98	17.46	15.87	15.87	34.13	23.77	AF
4	41.27	38.1	41.27	53.97	60.32	66.67	50.27	11.78	TC
5	80.95	55.56	46.03	28.57	82.54	42.86	56.09	21.69	TC
6	28.57	23.81	17.46	25.4	14.29	14.29	20.64	6.10	MED
7	28.57	23.81	33.33	36.51	52.38	17.46	32.01	12.06	AF
8	23.81	26.98	26.98	39.68	28.57	17.46	27.25	7.27	AF
9	41.27	57.14	41.27	61.9	41.27	68.25	51.85	12.11	TC
10	28.57	23.81	38.1	23.81	38.1	14.29	27.78	9.24	AF
11	55.56	66.67	57.14	55.56	69.84	100	67.46	17.06	TC
12	20.63	22.22	19.05	38.1	14.29	14.29	21.43	8.80	MED
13	28.57	39.68	38.1	23.81	28.57	31.75	31.75	6.11	SED
14	22.22	15.87	19.05	20.63	17.46	14.29	18.25	2.97	SED
15	30.16	28.57	22.22	39.68	22.22	23.81	27.78	6.72	AF
16	39.68	26.98	42.83	22.22	39.68	61.9	38.88	13.90	SED
17	22.22	17.46	17.46	31.75	14.29	14.29	19.58	6.63	AF
18	17.46	17.46	23.81	23.81	14.29	14.29	18.52	4.34	SED
19	26.98	22.22	26.98	42.86	52.38	44.44	35.98	12.16	MED
20	26.98	26.98	39.68	39.68	50.79	22.22	34.39	10.80	MED
21	20.63	14.29	31.75	25.4	14.29	14.29	20.11	7.29	MED
22	55.56	57.14	42.86	58.73	85.71	85.71	64.29	17.52	TC
23	14.29	14.29	15.87	19.05	1.59	14.29	13.23	6.00	SED
24	25.4	20.63	39.68	41.27	49.21	58.73	39.15	14.29	MED
25	52.38	36.51	39.68	53.97	53.97	66.67	50.53	10.97	MED
26	52.38	61.9	39.68	76.19	82.54	85.71	66.40	18.22	TC
27	19.05	17.46	22.22	23.81	36.51	14.29	22.22	7.78	AF
28	33.33	17.46	20.63	25.4	14.29	14.29	20.90	7.40	SED
29	41.27	26.98	41.27	39.68	47.62	39.68	39.42	6.77	MED
30	28.57	19.05	38.1	30.16	41.27	36.51	32.28	8.07	AF
31	28.57	17.46	41.27	25.4	57.14	20.63	31.75	14.92	TC
32	20.63	15.87	20.63	34.92	30.16	14.29	22.75	8.14	AF
33	17.46	20.63	46.03	36.51	68.25	36.51	37.57	18.47	AF

Table III.2 (continued)

Subj.	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6	Mean	SD	Group
35	66.67	26.98	58.73	57.14	39.68	80.95	55.03	19.22	MED
36	25.4	19.05	38.1	39.68	39.68	46.03	34.66	10.21	AF
37	14.29	14.29	14.29	23.81	14.29	14.29	15.88	3.89	SED
38	26.98	20.63	39.68	49.21	82.54	19.05	39.68	23.99	MED
39	19.05	15.87	17.46	28.57	28.57	14.29	20.64	6.35	SED
40	20.63	15.87	36.51	55.56	33.33	14.29	29.37	15.74	MED
41	60.32	60.32	42.86	76.19	84.13	85.71	68.26	16.68	AF
42	17.46	14.29	19.05	25.4	33.33	14.29	20.64	7.44	MED
43	57.14	55.56	41.27	61.9	85.71	85.71	64.55	17.78	AF
44	19.05	20.63	20.63	22.22	19.05	14.29	19.31	2.73	AF
45	23.81	31.75	20.63	41.27	36.51	47.62	33.60	10.31	AF
46	55.56	39.68	53.97	53.97	58.73	80.95	57.14	13.39	TC
47	25.4	20.63	36.51	42.86	41.27	20.63	31.22	10.22	AF
48	14.29	14.29	17.46	34.92	17.46	14.29	18.79	8.06	MED
49	39.68	36.51	39.68	58.73	65.08	41.27	46.83	11.95	TC
50	58.73	58.73	71.43	63.49	61.9	85.71	66.67	10.43	MED
51	20.63	28.57	36.51	25.4	46.03	14.29	28.57	11.36	SED
52	19.05	15.87	17.46	39.68	23.81	14.29	21.69	9.40	AF
53	15.87	14.29	17.46	22.22	15.87	14.29	16.67	2.97	MED
54	15.87	17.46	19.05	34.92	15.87	14.29	19.58	7.69	SED
55	60.32	33.33	38.1	39.68	14.29	63.49	41.54	18.22	TC
56	57.14	41.27	39.68	26.98	68.25	71.43	50.79	17.62	TC
57	80.95	55.56	46.03	58.73	66.67	100	67.99	19.58	TC
58	85.71	61.9	71.43	33.33	50.79	100	67.19	24.00	None

Data met MANOVA requirements. MANOVA results showed that membership in group significantly affected Tai Chi skill ($p < .001$, *partial eta-squared* = .401). Tai Chi practitioners reported significantly more lifetime hours of Tai Chi practice than mediation ($p = 0.002$), aerobic fitness (($p = 0.003$) practitioners, and sedentary controls ($p = 0.004$) (see Figure III.2). A scatterplot shows Tai Chi practitioners all reported a similar number of hours of lifetime practice (see Figure III.3); thus we expected them to perform at similar levels of skill. This is what was observed.

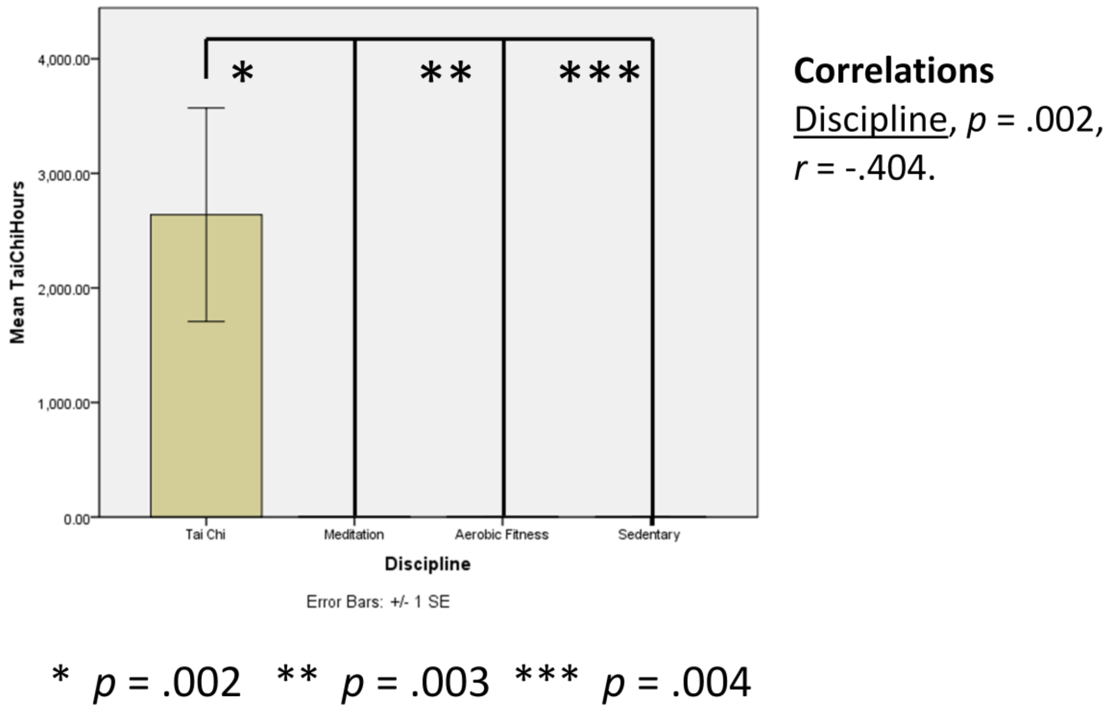


Figure III.2. Post-hoc comparison of self-reported Tai Chi practice in lifetime hours.

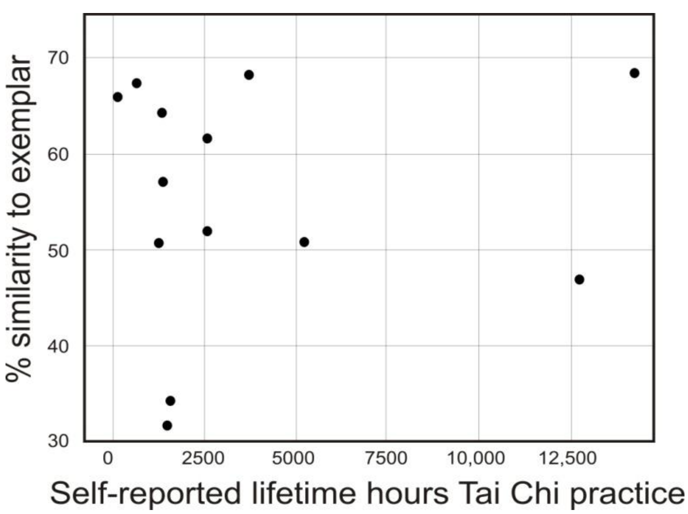


Figure III.3. Self-reported Tai Chi practice plotted against Tai Chi skill.

A post-hoc comparison showed Tai chi practitioners outperformed meditators ($p < 0.001$), aerobic fitness practitioners ($p < 0.001$), and sedentary controls ($p < 0.001$) on Tai Chi skill (see Figure III.4 and Table III.3), indicating the Tai Chi skill assessment successfully identified participants who self-reported long-term practice of Tai Chi.

Table III.3

Tai Chi Skill Post Hoc Comparison

Groups	**Mean Difference**	**Std. Error**	**95% CI Lower**	**95% CI Upper**
TC Skill				
TC vs Med	22.558*	5.255	8.152	36.965
TC vs AF	23.671*	5.375	8.935	38.406
TC vs Sed	31.691*	5.610	16.311	47.070

TC = Tai Chi, Med = meditation, AF = aerobic fitness, Sed = Sedentary

*$p < .001$

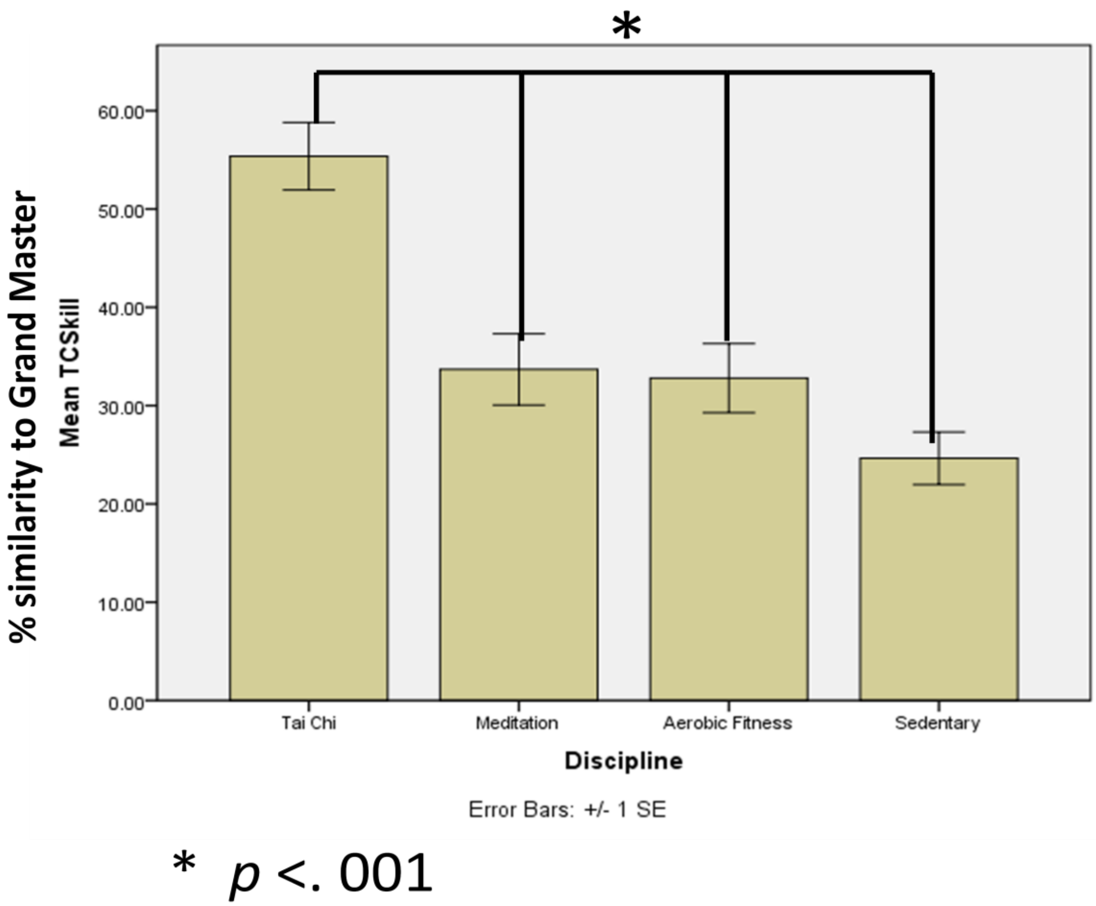


Figure III.4. Post-hoc comparison of Mean Tai Chi skill.

Ten of 13 Tai Chi practitioners scored > 50% similarity to the professional exemplar. Only 3 of 16 meditation and 3 of 17 aerobic fitness practitioners scored > 50% similarity to the professional exemplar (see Table III.4). There is a clear progression of means by group, with Tai Chi outperforming meditation and aerobic practitioners by 20 points, and meditation and aerobic fitness practitioners outperforming sedentary controls by ~10 points.

Table III.4

Tai Chi skill means, standard deviations, range, ratio of scores over 50% by Group

	n	Mean	SD	Low	High	> 50%
Tai Chi	**13**	54.92	10.91	31.75	67.99	10
Med	**16**	33.68	14.49	16.67	66.67	3
AF	**17**	35.36	15.89	19.31	68.26	3
Sed	**12**	24	8.4	13.23	38.88	0

Discussion

This study sought to adapt a dance-proficiency instrument (Chatfield, 2009) for the purpose of assessing Tai Chi skill acquisition subsequent to long-term Tai Chi training. Skill assessment instruments measure specific system configurations required for movement program output (Chatfield, 2009). Some programs like cycling or running require more effort than others (croquet, fencing) (Powers & Howley, 2007). Some require more complex motor patterns, flexibility, and finely controlled balance than others (i.e., classical ballet vs. aerobic walking). Tai Chi requires developing the ability to 1) shift weight from double to single leg stance smoothly, 2) extend the legs to the side or front at a 90^o or larger angle, 3) sustain moderate aerobic exertion, and 4) learn and perform a long and complex movement sequence requiring coordination of the upper and lower bodies (Wolf, 1997; Gatts, 2008).

To test long-term effects of this training, we selected a Tai Chi movement requiring weight shift from double to single leg stance, rotation of torso as weight is shifted from double to right single leg stance, extension of the left leg to the side while simultaneously executing coordinated arm movements (Wolf, 1997). The skill assessment we developed was based on the rating protocol used in a recent dance proficiency instrument. This included a rating of overall skill level, and proficiency with selected specific skills (Chatfield, 2009).

Our criteria were guided by skills listed in a Tai Chi training proposal by Gatts, 2008: head and trunk verticality, accurate foot positions, accurate postures and transitions, rotation of movement about spine and waist, smooth even limb velocity, relaxed muscle activity, control of whole body center of mass , movement flow, and slowness of movement during performance of the Tai Chi Leg Kick. Three Tai Chi students and three professional Tai Chi Instructors served as raters. Though rater agreement on single measures showed more variability than averaged measures, the instrument successfully differentiated between long-term Tai Chi practitioners and participants who had never practiced Tai Chi (p =< .001). This evidence suggests this instrument has successfully identified key skills trained in Tai Chi.

A limitation of this present study is that motion analysis reconstruction of subject movement was utilized. This method of recording subject movement, though useful for providing kinematic data for comparison across subjects, and providing protection for subject identity during data analysis, is expensive to use in the research or clinical settings. More economical video recordings could be substituted in future studies. Additionally, during the training and testing sessions, the professional raters felt that the metric (1-3) for rating individual skill items was not sufficient to truly capture differences in skill levels. If this instrument is developed further, this issue must be addressed. A third limitation to the study is that it only differentiates between experts and those who have never practiced Tai Chi. This is something that could probably be successfully performed by an observer without any assessment tool or skill in observation, as skill differences between non-practitioners and experts are generally very large. However, now we have a number to quantify these impressions, and this can be useful given careful validation for use in future studies.

It should be noted that our Tai Chi practitioners all reported a similar mean number of lifetime hours of practice; thus if practice effects are correlated with acquired skill, we would expect to see similar skill levels in these participants. This is what we saw. To determine if this instrument is sensitive enough to detect skill level differences between practitioners of Tai Chi, a cross-sectional study would need to be conducted in a large metropolitan area with a more diverse socio-economic and racial demographic. In such a research setting the subject pool of volunteers is potentially much larger. It might be possible to find volunteers with a wider range of lifetime hours of practice.

However, the raters did successfully differentiate those participants with long-term Tai Chi training from those with no such training, a key aim of this study, suggesting this instrument may be sufficiently sensitive for distinguishing between Tai Chi practitioners and those who have never studied Tai Chi. It is interesting to note that the aerobic and meditation groups performed similarly and superiorly to sedentary controls. A careful examination of rater scores for individuals in these groups showed a small number of scores in the Tai Chi practitioner range (> 50% similarity to professional exemplar). Field notes were taken during data collection. Several aerobic fitness and meditation practitioners self-reported chronic practice of competitive sports, dance, or yoga. These are complex movement skills which may be similar to Tai Chi. This suggests that this particular skill assessment instrument can identify individuals with complex gross motor training and differentiate them from individuals with long-term Tai Chi training. Because this instrument assesses ability to coordinate upper and lower body movements, shifts from double to single leg stance, leg extension, balance, and return to double leg stance, a future study could adapt this Tai Chi Skill Assessment for use in assessing general gross motor skill in normal adults.

Bridge

The purpose of this study was to develop a skill assessment instrument capable of detecting Tai Chi training effects during performance of a typical Tai Chi movement sequence. A recent dance proficiency instrument was used as the template (Chatfield, 2009). Tai Chi training effects were defined as percent similarity to a professional exemplar performing the same movement sequence. Tai Chi practitioners did significantly outperform each of our other groups. Ten of 13 Tai Chi practitioners scored > 50% similarity to the professional exemplar. Only 3 of 16 meditation and 3 of 16 aerobic fitness practitioners scored > 50% similarity to the professional exemplar. This allowed us to include Tai Chi skill score in our overall analysis. Additionally, because Tai Chi training effects were detected, we expected the benefits derived from such practice to be evidenced in practitioner executive attention measures. These benefits include faster reaction times, lower percent local switch costs, larger P3b switch amplitudes, and shorter P3b switch latencies. Experiments gathering that evidence are described in Chapters IV and V.

CHAPTER IV

EFFECT OF LONG-TERM TAI CHI, MEDITATION AND AEROBIC PRACTICE VS. AN INACTIVE LIFESTYLE ON A NEUROPSYCHOLOGICAL MEASURE OF ADULT HUMAN EXECUTIVE ATTENTION FUNCTION

Introduction

As human life expectancy has lengthened in the developed world, successful aging has become a public health concern. Health-related quality of life, cognitive capacity, and physiological status are all dependent on healthy aging (Murdaugh, 1997). Aging effects include decreasing cardiovascular, neuro-motor, and cognitive capacities. VO_2max, a proxy for cardiovascular-respiratory health, declines at a rate of 1% per year after the age of 20 (Powers & Howley, 2004, p. 335). Reaction time on neuropsychological tests declines by a factor of 1.5 during the 25-65th years of life (Verhaegen & Carella, 2002). By the age of 65, walking and other locomotor skills required for daily living require increasing amounts of cognitive capacity to perform adequately (Shumway-Cook & Woollacott, 2007). A key component of cognitive capacity is executive attention function (EF) (Miyake, 2000; Gilbert, 2008). Executive function may mediate aging effects on other cognitive resources (i.e. orienting, planning, and goal-setting) (Salthouse, 2003). Investigation of health training regimens which may counteract the effects of aging on executive function are currently underway (Ratey & Loehr, 2011; Etnier & Chang, 2009). Of particular interest are regimens that may extend mid-life (30-65 years) cognitive capacity into the seventh and eighth decades of life. Meditation and aerobic fitness are two readily available health regimens (Lutz et al, 2007; Powers & Howley, 2004) that have been shown to positively affect executive function in young and older adults (Ratey & Loehr, 2011; Tang et al, 2008; Chan & Woollacott, 2007; Brefczynski-Lewis et al, 2007).

Executive function (EF) benefits resulting from chronic aerobic fitness training include faster reaction time and greater accuracy on flanker and go no-go tasks in older adults (Hatta et al, 2005: Latey, 2011). Reaction time (RT) is thought to represent the time course of central (cognitive) and peripheral (motor) operations required to perform a neuropsychological response (Verhaeghen & Cerella, 2002). This body of evidence suggests that moderate exercise benefits executive function processing speed and accuracy during tasks requiring inhibition and working memory. This may be due to upregulation of neurotrophic factors and neural metabolism efficiency (Vaynman and Gomez-Pinilla, 2006). Further, new evidence suggests that the type of moderate exercise may be important for EF training benefits. Exercise can require relaxed or focused attention. Moderate exercise requiring constant application of attentional focus, such as orienteering or soccer, has been correlated with greater benefits to EF processing speed and accuracy (Voss et al, 2009; Pesce, 2011).

Meditation has been shown to train executive function. Meditation is defined as concentrated mental focus on a sound, image, sentence (chant or mantra), or activity (walking, sitting). All conflicting stimuli are pushed out of awareness (Lutz et al, 2007). Many meditation practitioners also engage in yoga and other moderate exercise activities. Indeed, one of the most utilized and studied meditation practices, Mindfulness-based Stress Reduction, explicitly incorporates yoga into its training regimen (Smith et al, 2008). Not surprisingly, during subject recruitment for this study, we found no sedentary meditators. All meditation practitioners reported chronic participation in moderate exercise of some kind. Thus, a contributing factor in meditation's benefit to EF function might be cardiovascular and metabolic modifications resulting from chronic moderate exertion. Additionally, the mental effort of inhibiting distracting thoughts or sensations suggests meditation may train the EF inhibition component. Chan & Woollacott, 2007 found that long-term practitioners of meditation showed less interference on the Stroop incongruent condition than non-practicing controls. This suggests executive function tests of inhibitory capacity may isolate a key executive function affected by chronic meditation training.

Another health training regimen that shows promise for benefiting EF is Tai Chi. Tai Chi is a form of moderate exercise (Li et al, 2001) that has been shown to be superior to aerobic walking for cardiovascular function (Audette, et al, 2006). Tai Chi is also a form of moving meditation (Luskin, 2004) that requires memorization of complex movement sequences, and thus motor learning. Motor learning requires EF (Halsband & Lange, 2006). Tai Chi also requires constant application of attention for optimal performance (Gatts, 2008; Voss, 2009; Pesce, 2010). Because Tai Chi requires moderate exercise, motor learning, and application of attention, would chronic practice yield similar or greater benefits to executive function compared to aerobic exercise and meditation? A recent uncontrolled study showed that 10 weeks of Tai Chi training benefited task switch performance in community dwelling, normally aging elders (Matthews & Williams, 2008).

Executive function processes which have been routinely identified include the ability to respond appropriately to novel situations, make choices, set goals, coordinate task sequences, inhibit inappropriate responses, update ongoing task sequences, and switch between tasks appropriately (Salthouse et al, 2003; Gilbert & Burgess, 2008). Three key executive function components that may underlie these operations are 1) inhibition, 2) updating, and 3) shifting (Miyake, 2000). Working memory is often included as a major component of executive function (Gilbert, 2008). Importantly, Salthouse, 2003 found that degradation of the inhibition and updating components of executive function may mediate age-related cognitive decline. Indeed, both simple and complex executive tests have been shown to reliably differentiate between older and younger adult executive capacity (Salthouse et al, 2003; Colcombe & Kramer, 2003). Longer reaction times are thought to index less efficient processing (Banich, 1997; Mayr, 2001; Chan & Woollacott, 2007; Altmann, 2008). Tests which isolate the inhibition component of executive function include the flanker, Stroop, and go no-go. The *n*-back task evaluates updating capacity (Miyake, 2000). Tests of complex executive function include the many variants of task switching (Altmann, 2008; Verhaegen & Carella, 2002). Task switch tests require four main executive function components: inhibition, updating, shifting and working memory. These components are subserved by the dorsolateral and mediolateral prefrontal, and anterior cingulate cortices (Rushworth et al, 2007; Rushworth et al, 2005, Rushworth et al, 2002). If integrated microcircuits in the prefrontal cortex mediate inhibition, updating, shifting, and working memory operations, then a complex test requiring these circuits may be a reliable measure of executive function coordination of these components.

This study utilized a complex visuo-spatial task switch (VSTS) (Mayr Laboratory, University of Oregon, 2009) to assess executive function of long-term Tai Chi, meditation plus exercise, or aerobic fitness practitioners compared to generally sedentary individuals. This test required working memory, inhibition, shifting, and updating (Miyake, 2000), was noncued and included alternating runs of two rules (Altmann, 2008). Our measures were switch reaction time and switch capacity (% local switch costs). We expected our training groups would outperform sedentary controls on aerobic capacity. We predicted that long-term Tai Chi and meditation plus exercise training would produce the greatest benefits to our executive function measures (switch reaction time and capacity) followed by aerobic fitness training. We predicted all three training groups would significantly out-perform sedentary controls on our executive function measures. Further, we hypothesized that age effects on health regimen practitioners would be less than those for sedentary controls.

Methods

Participants. Participants were recruited by word of mouth, local Craigslist and newspaper ads, and flyers posted throughout the communities of Eugene and Springfield, Oregon. Inclusion criteria were 1) no neurological or physical disorders, and 2) aged 20-75. The large age range was chosen so we could document the effects of normal aging on our key measures across the lifecycle. We expected to see less than normal aging effects in our health regimen groups compared to sedentary controls (Mayr, 2000; Bryan & Luszcz, 2000; Hillman et al, 2002; Verhaegen, 2002; Colcombe, 2004; Etnier & Chang, 2009). Sedentary participants were required to have 1) a generally inactive lifestyle for five or more years, and 2) no prior experience with meditation or Tai Chi. Health regimen practitioners were required to 1) have practiced at least five years or more, three times per week, 30 minutes per session. All participants had self-selected into their preferred level and type of exercise activity. Fifty-nine participants responding to a health regimen recruitment campaign agreed to four hours of testing scheduled at their convenience. This test was administered as part of a four-hour battery of tests, two of which required moderate aerobic exertion. Because acute exercise has been shown to improve cognitive performance (Pesce, 2011; Davranche, 2004) we scheduled the cognitive and exercise testing separately. If the participants preferred to do the testing in one day, the cognitive testing was done first followed by the exercise testing. Two Tai Chi participants who could not use a computer effectively were excluded since our key executive attention tests were administered via PC computer. Two subjects did not complete the testing. One additional subject who presented with bipolar disorder and presently off medication was excluded due to that psychological abnormality. Thus, 54 subjects completed all tests and were included in this analysis (female = 27). Final group composition was 1) 10 Tai Chi (female = 3), 2) 16 meditation plus exercise (female = 6), 3) 16 aerobic fitness (female = 8), and 4) 12 generally sedentary (female = 10) participants. Body mass index (BMI) was calculated for each participant (U.S. Department of Health & Human Services, 2012). BMI is mass (kg)/(height (m))^2 (see Table II.1). Subject recruitment and experimental protocol were approved by the University of Oregon Institutional Review Board. Subjects gave Informed Consent and were compensated for their participation.

Testing

Aerobic Capacity --Rockport 1-mile Walk (Kline et al, 1987; American College of Sports Medicine, 2009). Subjects were fitted with an Athletic Connection Polar E600 heart rate monitor (Polar Electro-USA). A chest strap with heart sensor sent information on heart rate and walk time to a wrist recorder. Subjects walked 1 mile as fast as they were able. Estimated VO_2Max was calculated by entering subject's age, weight, gender, walk time, and ending heart rate in a java applet located at http://www.exrx.net/Calculators/Rockport.html. VO_2max indexes aerobic capacity – the body's ability to transport and utilize oxygen during exercise in ml/kg/min O_2 (Powers & Howley, 2004).

Executive Attention Test. Executive attention test structure has been shown to affect reaction time. More complex tests produce longer reaction times (Bryan, 2000). Non-cued paradigms have been shown to be more difficult than cued paradigms (Monsell et al, 2003; Koch, 2003). Response-stimulus interval (RSI) is important as well. Short RSIs have been shown to produce greater switch costs than longer ISIs (Karayanidis et al, 2003). To optimize separation between our groups on our executive measures, a randomized runs, no-cue, short (10 *msec*) response to stimulus interval, visuo-spatial task switch (VSTS) with dense array EEG (Mayr Laboratory, University of Oregon) was selected. This VSTS maximized interaction of working memory load, past response updating, and present response selection. Finally, we selected local switch costs after controlling for the speed accuracy trade-off as our measure of executive capacity. Local switch costs index the capacity to switch tasks quickly and accurately (Monsell et al, 2000; Wylie & Allport, 2000; Milan et al, 2006). Lower switch costs index greater switch capacity (Pesce & Audiffren, 2011).

Paradigm. Participants were trained in two different response rules (Rule 1 and 2) to indicate the spatial location of a randomly appearing dot within a fixation rectangle (Figure II.5) For Rule 1, the button press response was compatible with the dot's location in space. For Rule 2 the button press was incompatible with the dot's location in space. For the Switch test (Rule 3) participants switched between Rule 1 and 2 on every other trial. Trials in which a switch of response rule was required were designated switch trials. Trials when the response rule remained the same as the previous trial were designated no-switch trials. The test was coded in E-Prime (Psychology Software Tools) for use with dense array EEG (Electrical Geodesics, Eugene, Oregon). Methods and results for the EEG component of this test are reported in Chapter V. Switch costs were calculated thus: Mean Switch RT – Mean No-switch RT/Mean No-switch RT. This controlled for any possible speed accuracy trade-off. Dependent variables were switch reaction time and local switch costs.

Stimuli were displayed on a computer monitor located ~ 24 inches in front of the participant. Participants were trained to respond as quickly and accurately as possible to stimulus appearance using a two button mouse. The stimulus appeared immediately subsequent to each response (screen refresh rate was 10 *msec*). For Rule 3 participants were provided with visual feedback in the case of erroneous responses. They corrected their error and continued the trial block. Participants practiced each Rule until they achieve 85% accuracy. Rules 1 and 2 consisted of 48 trials in two blocks. Rule 3 (the actual task switch) consisted of twelve blocks of 48 trials/block. All tests were administered from the same instruction script on the same PC computer.

Multivariate Cross-sectional Design. In multivariate designs multiple dependent variables are measured on subjects who are assigned membership in carefully defined groups (Stevens, 2002). The overall study, of which this analysis is a part, included three health training groups: 1) Tai Chi, 2) meditation plus exercise, and 3) aerobic fitness. We contrasted those with generally sedentary controls who had never engaged in any of our training modalities. Each training group reported similar lifetime hours of moderate aerobic exertion (Li, 2001; Powers & Howley, 2007) (see Figure II.1). This allowed us to control for physical exercise effects. Covarying age allowed us to assess its effects on our dependent measures. Our effect size measure was *partial eta-squared.*

We expected to see all chronic moderate aerobic exercisers outperform sedentary controls on estimated VO_2max (Powers & Howley, 2004,p. 335). As a result, we also expected they would outperform sedentary controls on our executive function measures (Ratey & Loehr, 2011; Dishman et al, 2006; Vaynman & Comez-Pinilla, 2006). It is key to note that the difference between our training groups was the attentional focus required to perform their respective health regimens (Pesce & Audiffren, 2011; Voss et al, 2009) (See Figure 2). Both Tai Chi (Gatts, 2008; Voss, 2009; Pesce, 2011) and meditation (Lutz et al, 2007) require constant attentional focus. This is in contrast to aerobic exercise, which permits more generally relaxed attention (Voss, 2009; Pesce, 2011). This allowed us to examine the effect of chronic executive function training in combination with moderate aerobic exertion on our key executive function outcome measures: switch reaction time and % local switch costs.

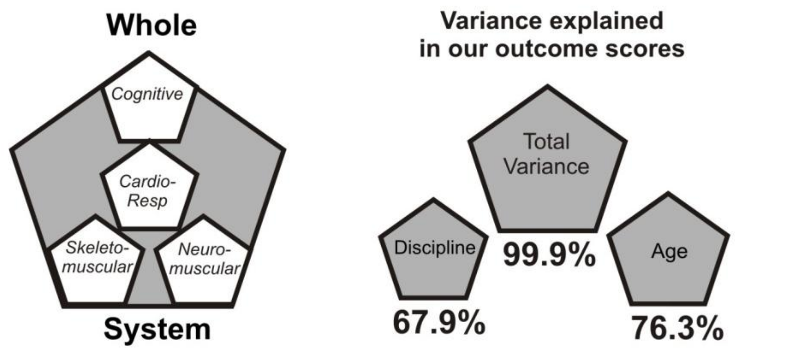
Data Analysis

A multivariate analysis of variance (MANOVA) and Levene's test for homogeneity of variance was performed. Sidak correction was used for post hoc analyses. Sidak is a variation on Bonferroni adjustment. *Alpha* was set at 0.05 for the main MANOVA. A bivariate correlation was run. To control for *a* slippage for multiple analyses (PCA and cluster analyses reported elsewhere), a Bonferroni correction was applied and *alpha* was set at 0.0125. Our independent variable was group. Because normal aging is associated with degradation of cognitive and physiological function, age was included as a covariate. Our Discriminant Variable was Group (Tai Chi, Meditation, Aerobic Fitness, and Sedentary Control). Dependent variables were estimated VO_2max, switch reaction time, and percent switch costs. Because we were evaluating whole system functionality, error trials were included in our reaction time means. Groups were numerically coded thus: Tai Chi, 1; Meditation plus exercise, 2; Aerobic fitness, 3; and sedentary control, 4. We coded this numbering system in line with our hypothesis that Tai Chi, then meditation practitioners, would outperform aerobic fitness practitioners on our executive function variables. We predicted all training groups would outperform sedentary controls on executive function and aerobic capacity. This made correlations between group members and our numerical variables interpretable. All analyses were run with PSAW Statistics 19 (IBM, Chicago, Illinois).

Results

Overall results. As expected, training group and age both significantly affected our key outcome measures. Levene's statistic revealed eight variables with unequal error variances (Appendix G). These variables were either compound numbers (i.e. % switch costs) or discriminant variables in the data set (lifetime hours of health regimen practice). MANOVA can be forgiving of such deviations from normalcy (Stevens, 2002). The main MANOVA omnibus was significant (Wilk's lambda (Λ) ($F(24, 26) = 1417.561$, $p <$ .001.) Our overall *partial eta square* was .999, indicating we have explained 99.9% of the variance in our outcome measures. Since we included two key variables shown to affect executive function: aerobic capacity and age, this is not surprising. Group membership explained ~68% of this variance (Wilk's lambda (Λ) ($F(72, 78.562) = 2.321$, $p < .001$, *partial eta square* = .679), indicating the presence of possible training effects. Though our groups do not differ on age ($p = .295$), age explained 76% of total variance (Wilk's lambda (Λ) $F(24, 26) = 3.488$, $p = .001$, *partial eta square* = .763), suggesting normal aging was a key factor affecting our outcome. Clearly these two have overlapping variance, as would be expected, since the cell populations that produce the output are affected by both age and fitness training effects (Hillman et al, 2002; Vaynman, 2006; Ratey & Loehr, 2011). Age and group membership have similar effect sizes on switch reaction time (group, 34.3%; age, 31.2%) and VO_2max (group, 49.6%; age, 39.3%), but not on percent switch costs (group, 28%; age, 9%). Means, standard deviations, and variance explained for key factors and variables are presented in Figure IV.1.

Interacting Systems



***Total variance explained* = 99.9%**

Variance explained by Group and Age Covariate

Group	*p* < .001	*ES* = 67.9 %	Age	*p* = .001	*ES* = 76.3%
Switch RT	*p* < .001	*ES* = 34.3%	Switch RT	*p* < .001	*ES* = 31.2 %
Switch Costs	*p* = .001	*ES* = 28.2%	Switch Costs	*p* = .030	*ES* = 9.3 %
P3b S Amp	*p* = .003	*ES* = 25 %	P3b S Amp	*p* = .075	*ES* = 6.3 %
P3b S Lat	*p* = .157	*ES* = 10 %	P3b S Lat	*p* = .591	*ES* < 1 %
TC Skill	*p* < .001	*ES* = 41 %	TC Skill	*p* = .678	*ES* = < 1%
VO_2max	*p* < .001	*ES* = 49.6%	VO_2max	*p* < .001	*ES* = 39.3%
Self-monitoring	*p* = .388	*ES* = 5.9 %	Self-monitoring	*p* = .004	*ES* = 15.4%

	M	*SD*
Switch (msec)		
TC	453.94	110.95
Med	477.41	188.88
AF	489.63	96.89
Sed	654.30	154.56
Sw Costs (%)		
TC	14.13	11.97
Med	17.07	9.74
AF	22.66	14.34
Sed	32.14	11.82
P3b Sw Amp (μv)		
TC	3.94	2.43
Med	4.38	1.85
AF	3.13	1.45
Sed	2.08	.76
P3b Sw Lat (msec)		
TC	256.4	122.48
Med	264.00	72.40
AF	269.50	82.70
Sed	203.33	42.09

	M	*SD*
VO_2max (ml/kg/min)		
TC	34.14	6.34
Med	41.83	9.04
AF	45.66	9.67
Sed	28.68	5.76
TC Skill (% similarity)		
TC	55.88	11.01
Med	33.68	14.49
AF	32.80	14.06
Sed	24.64	9.22
Self-monitor (% correct)		
TC	92.54	7.81
Med	91.35	14.32
AF	86.77	22.17
Sed	86.44	26.59

Notes

TC = Tai Chi, Med = meditation, AF = Aerobic Fitness, Sed = Sedentary
Sw Costs = switch costs, Sw Amp = switch amplitude, Sw Lat = switch latency
ES = Effect size is *partial eta squared.*

Figure IV.1. Variance explained, means and standard deviations.

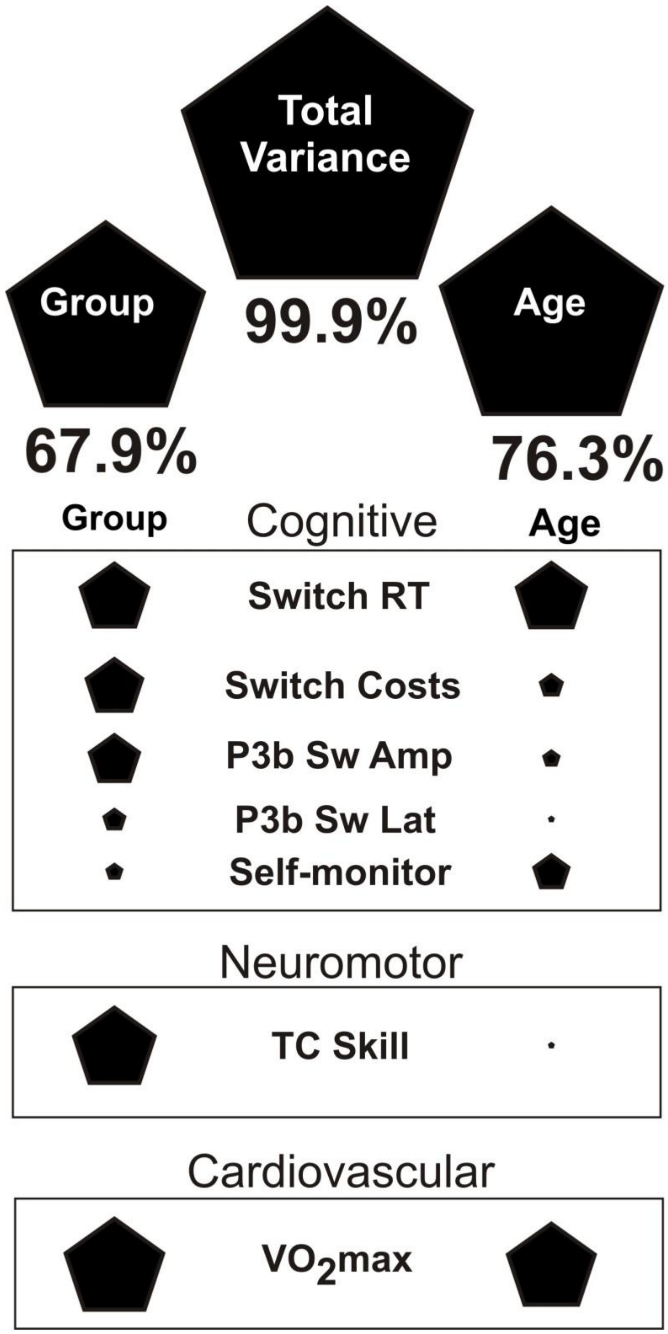


Figure IV.2. Relative weights of age and group on key outcome measures.

This suggests that while both age and lifestyle choices significantly impact executive function over the lifecycle, lifestyle choices that combine moderate aerobic exercise and executive function training may mitigate aging effects on complex executive attention capacity (see Figure IV.2).

Post-hoc results. As expected Tai chi (p = .025), meditation (p < .001), and aerobic fitness (p < .001) practitioners outperformed sedentary controls on estimated VO_2max. This difference suggests that exercise training effects may be mitigating the effect of normal aging on this important health variable for health regimen practitioners. This is consistent with current normative databases (Powers & Howley, 2004). Interestingly, aerobic fitness practitioners outperformed Tai chi practitioners (p = .043) on VO_2max (see Figure IV.3c). This is may be due to the wide range of METs required by different Tai Chi styles (i.e. Chen vs. Yang style, long- versus short-form) (Wolf, 1997, Li et al, 2001). However, our Tai Chi practitioners were a decade older on average than our aerobic practitioners (see Figure IV.3d). Thus, can we expect aging to explain some of this difference in their absolute estimated VO_2max scores (Powers & Howley, 2004; p. 335)? Additionally, we found estimated VO_2 max was significantly and negatively correlated with age ($r = -.539$, $p < .001$) in this data set, suggesting that younger individuals have greater aerobic capacity, consistent with normative evidence. This convergent evidence suggests aging effects are at work in the difference between Tai Chi and aerobic fitness practitioners on VO_2max.

Because each of our training groups outperformed sedentary controls on cardiovascular fitness, we can expect to see executive function training benefits as well (Colcombe et al, 2004). We saw some, but not all of the hypothesized effects.

Self-reported lifetime hours of aerobic fitness practice. As noted, all chronic training groups reported a statistically similar number of lifetime hours of aerobic fitness practice.

Self-reported lifetime hours of meditation practice. As expected, meditation practitioners reported significantly more hours of meditation practice than Tai Chi ($p = .002$), aerobic fitness ($p = .002$), or sedentary participants ($p = .004$).

Importantly, we saw no significant differences between groups on self-monitoring function. Indeed, the groups performed almost identically. Recall, we had expected our meditators to outperform other groups on this measure. This shows we did not

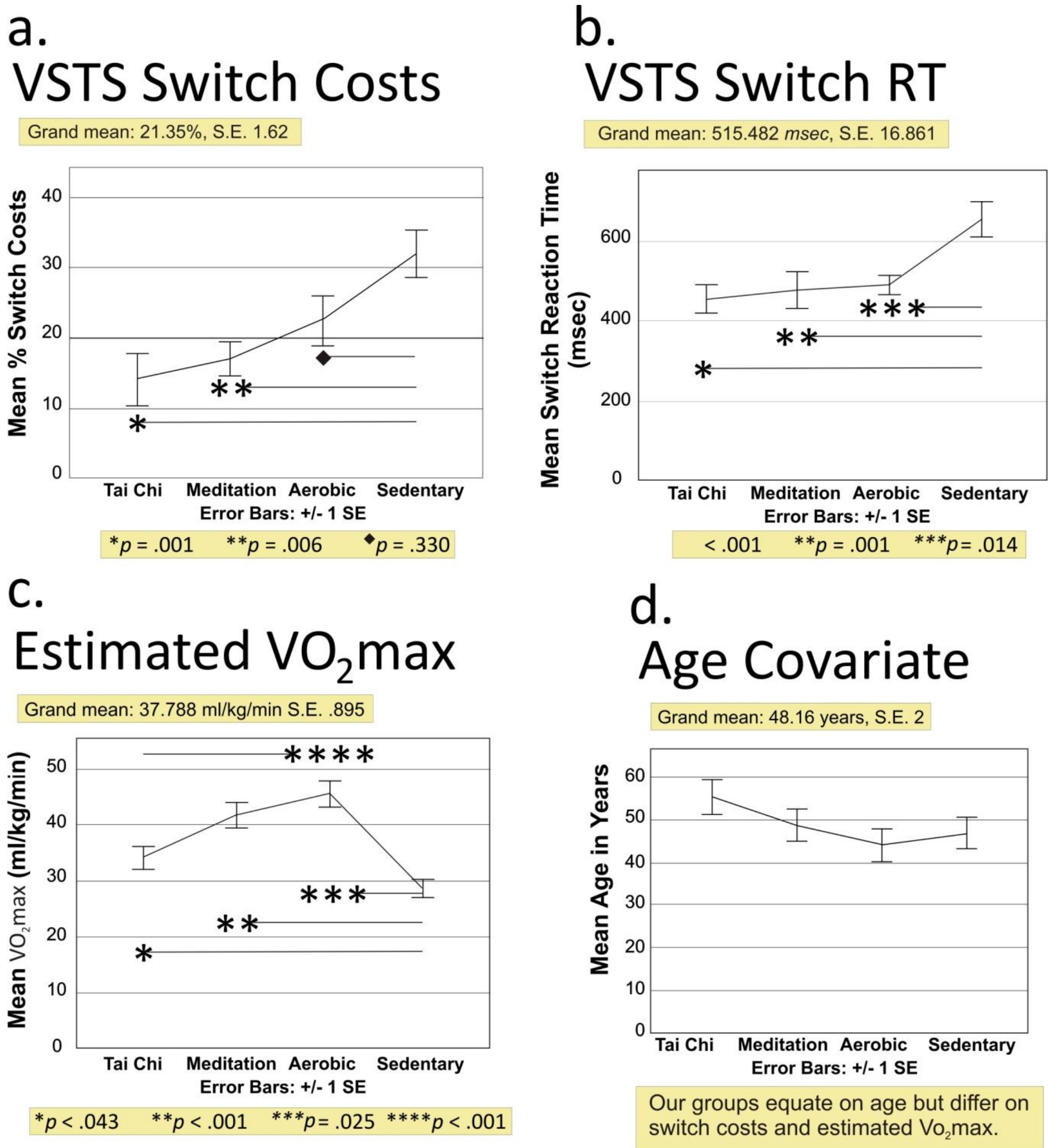


Figure IV.3. Key observations by group.

successfully identify an executive measure uniquely trained by meditation practice. Another possibility is this test may have been too easy. A more difficult version might isolate training effects between our groups (Bryan, 2000; Milham, 2003).

The training groups outperformed the sedentary controls on switch reaction time (Tai Chi ($p < .001$), meditation ($p = .001$), and aerobic fitness practioners ($p = .014$) (see

Figure IV.3b). This is in line with evidence showing aerobic fitness practice is associated with faster reaction times on executive function tests (Etnier & Chang, 2009; Ratey & Loehr, 2011). There were no significant differences between training groups on switch reaction time. However, only our Tai Chi and meditation practitioners outperformed sedentary controls on percent switch costs (Tai Chi: $p = .001$; meditation practitioners: $p = .006$). Aerobic fitness practitioners and sedentary controls did not differ significantly on this measure (see Figure IV.3a). Percent switch costs is a more stringent measure of switch capacity than raw reaction time. It is possible that there is an extra benefit accruing to these groups due to long-term practice of moderate exercise combined with executive function training. However, it is important to note there are no significant differences between training groups on percent switch costs. Is there a differential training effect? Group was significantly and positively correlated with both switch reaction time ($p = .003$, $r = .400$) and percent switch costs ($p < .001$; $r = .468$). This suggest that those in groups 3 and 4 (aerobic fitness, sedentary control) show longer reaction times and higher switch costs than those in group 1 and 2 (Tai Chi and meditation). Switch reaction time was negatively correlated with Tai Chi skill ($p = .004$, $r = -.395$), thus individuals with higher Tai Chi skill demonstrated shorter switch reaction times. Percent switch costs were negatively correlated with Tai Chi skill ($p = .003$, $r = -.401$). Thus, individuals with greater Tai Chi skill showed lower percent local switch costs (see Table IV.1).

This convergent evidence shows that although Tai Chi participants were older and demonstrated lower absolute estimated VO_2max, they outperformed younger aerobic practitioners on percent switch costs (see Figure IV.4), suggesting that age effects may be mitigated by this commonly available health regimen.

Table IV.1

Significant Correlations Between Key Measures

	Grp	Age	VO2	TCS	Self	SwRT	SCosts	SAmp	SLat
Grp		-.206	-.142	-.570**	-.130	.400*	.468*	-.409*	-.194
Age			-.539**	.099	-.344*	.433*	.181	-.156	.143
VO2				.129	.181	-.508**	-.289	.324	.077
TCS					.038	-.395*	-.401*	.254	.134
Self						-.136	-.131	.183	-.336
SwRT							.660**	-.517**	-.289
SCosts								-.370*	-.354*
SAmp									.214
Slat									

*$p < .0125$, **$p < .001$
Notes: Disc = Discipline, VO2 = VO_2max, TCS = Tai Chi Skill (% similarity), Self = Self-monitoring (% correct), SwRT = switch reaction time (msec), SCosts = switch costs (%), SAmp = P3b switch amplitude (mV), SLat = P3b switch latency *(msec)*.

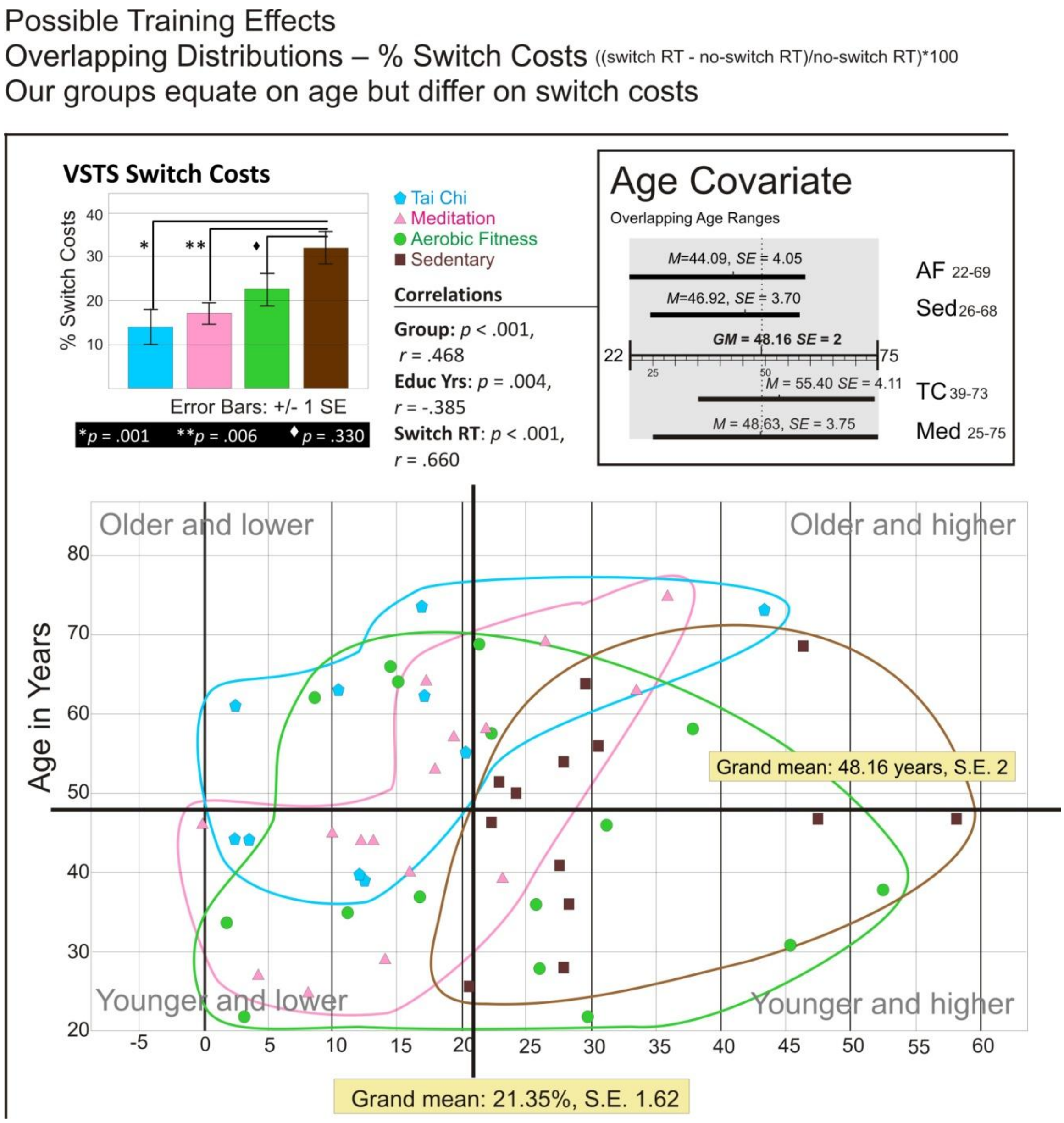


Figure IV.4. Possible training effects on % local switch costs.

<u>Discussion</u>

This study utilized a complex visuo-spatial task switch test (VSTS) (Mayr, 2001) to assess executive function of long-term Tai Chi, meditation plus exercise, or aerobic fitness practitioners compared to generally sedentary individuals. We first asked if our groups differed on aerobic capacity. We then asked if our groups differed on key executive attention measures. Our executive function measures were switch RT and switch capacity (% local switch costs). We predicted that long-term Tai Chi and meditation plus exercise training would produce the greatest benefits to our executive function measures, switch reaction time and capacity, followed by aerobic fitness training. We predicted all three training groups would significantly out-perform sedentary controls on our executive function measures. Further, we hypothesized that age effects on health regimen practitioners would be less than those for sedentary controls.

Our results show that each of our health training groups outperformed sedentary controls on our key cardiovascular fitness measure, estimated VO_2max. This was expected if they had indeed trained at least three days per week, 30 minutes per session for five or more years (Powers & Howley, 2004; Dishman et al, 2006). Any reaction time or switch cost benefits conferred by long-term moderate exercise should accrue to our training groups, but not our sedentary controls. That is what we saw. Even though our groups are equated on age, and age significantly affects all our outcome measures, these effects fell most detrimentally on our sedentary controls. Each group should be equally affected by aging effects on executive function measures (Hillman et al, 2002; Ratey & Loehr, 2011), yet our training groups outperformed sedentary controls. This suggests any executive attention performance differences we saw between our groups may be due to the effects of training. On the switch reaction time all our health training groups outperformed the sedentary controls. This is in line with the general body of literature that shows moderate exercise positively benefits reaction time on executive attention tasks (Ratey & Loehr, 2011). However on the crucial switch costs measure, only the Tai Chi and meditation training groups significantly outperformed the sedentary controls.

This was an interesting finding. Even though our groups did not differ significantly on age (*p*=.295), an inspection of the distribution of age scores by group shows the Tai Chi and meditation groups were older than the aerobic fitness or sedentary groups. Indeed, group rather than age had the strongest effect on percent switch costs. Six younger aerobic fitness practitioners demonstrated higher switch costs than older Tai Chi and meditation practitioners two or more decades older. Finally, group is positively correlated with switch costs ($p < .001$, $r = .468$). Remember that Tai Chi is coded 1, meditation 2, aerobic fitness 3, and sedentary controls , 4. We expected our groups to perform in that order. Our results show that higher group number is correlated with higher switch costs. This convergent evidence suggests that moderate aerobic exercise in combination with explicit mental training may produce greater benefits to complex executive operations requiring coordination of four of the main executive attention components: inhibition, updating, shifting, and working memory than aerobic fitness alone.

However, limitations in our data set may equally explain this outcome. Self-selection into these groups related to socio-economic status or upbringing, genetics (Gajewski et al, 2011), and different intensities of practice across participants are variables that could affect outcome measures. Additionally, we utilized an absolute VO_2max algorithm utilizing age, gender, and weight. However, evidence shows that a predicted VO_2max normalized to age and gender and height may yield more accurate estimates of VO_2max than absolute measures (Hansen & Wasserman, 1984). In addition, the literature suggests that VO_2max is differentially affected by exercise intensity (i.e. low to high exertion requirements) (Tanaka et al, 1997). Future analyses of these data should include age-normalized VO_2max. Future studies should be designed to examine the effects of age by decade and exercise type on aerobic capacity in normally aging adults.

In spite of these limitations, this evidence suggests these three commonly available health regimens may be equally effective in promoting executive attention health throughout the adult human lifecycle. This is good news for clinicians and individuals alike. Healthcare professionals need different types of evidence-based health practices to offer clients. If clients are able to select from these regimens based on personal inclinations and preferences, it is possible that participation in such regimens would become more habitual, insuring cognitive and physical benefits, lower healthcare costs, and a greater quality of life throughout their lifetimes.

Bridge

All health regimen training groups significantly outperformed sedentary, non-practicing controls on switch reaction time. This is consistent with established norms (Ratey & Loehr, 2011) and suggests long-term practice of Tai Chi, meditation plus exercise, and aerobic fitness compared to a generally inactive lifestyle benefits executive attention capacity. However, only the Tai Chi and meditation plus exercise groups outperformed sedentary controls on the more stringent percent local switch costs measure. Elecrtroencephalography (EEG) was used during the executive attention task to obtain average ERPs by switch trial during the VSTS. The P3a ERP is an index of attentional orienting network activation. The P3b is an index of working memory network activation (Polich, 2007). These two are seen in a ~250-800 *msec* window post-stimulus at midline electrode sites (Fz, Pz). Evidence suggests we should see larger P3 amplitudes and shorter latencies in our training compared to our sedentary groups. The behavioral measures showed mixed evidence for effects of training modality. Since the P3 is a bipolar neural component of attention circuitry (Knight, 1997; Polich, 2007), would it correlate with either raw switch score or percent local switch costs?

Chapter V describes the dense-array EEG component of the VSTS experiment that allowed us to address this question.

CHAPTER V

EFFECT OF LONG-TERM TAI CHI, MEDITATION AND AEROBIC PRACTICE VS SEDENTARY LIFESTYLE ON ADULT HUMAN P3B EVENT-RELATED POTENTIAL AMPLITUDE AND LATENCY. CORRELATION WITH NEUROPSYCHOLOGICAL MEASURES OF EXECUTIVE ATTENTION PERFORMANCE AND CARDIOVASCULAR FITNESS

Introduction

In our complex culture, cognitive capacity is a key concern throughout the adult lifecycle. Normal aging produces decrements in human cognitive capacity, including reaction time and accuracy on neuropsychological tests (Hillman, 2006; Pontifex et al, 2009; Gunning-Dixon & Raz, 2003). Health regimens that may contribute to successful cognitive aging are under active investigation. Such regimens include Tai Chi (Wolf, 1997; Li et al, 2001; Gatts, 2008), meditation (Chan & Woollacott, 2007), and moderate exercise (Ratey & Loehr, 2011). Moderate exercise leads to improvements in aerobic capacity as measured by estimated VO_2max. Aerobic capacity is correlated with improvements in cognitive capacity (Hillman, 2006). A core component of cognitive capacity is executive attention. Executive attention capacity may mediate successful cognitive aging (Salthouse, 2003). Four key executive components have been identified across many studies: inhibition, updating, shifting, and working memory) (Miyake, 2000; Gilbert, 2008). Post-lesion (i.e. concussion)(Halterman et al, 2006), transcranial magnetic stimulation (TMS)(Rushworth et al, 2002), functional magnetic resonance imaging (fMRI) Milham et al, 2003), and electroencephalography (EEG) (Polich, 2007) studies during neuropsychological tasks requiring inhibition, updating, and attentional shifting suggest the activity of prefrontal structures, particularly the dorsolateral, mediolateral, and anterior cingulate cortices contribute to executive attention output (Rushworth et al, 2007; 2005; 2004a; 2004b; 2002; Milham et al, 2003). There are a number of neuropsychological tests that have been used in combination with electroencephalography (EEG) to successfully evaluate human executive performance, including task-switching (Altmann, 2008; Poulsen et al, 2005). Event-related potential (ERP) amplitude and latency relative to events of interest during such tests have proven particularly useful for investigation of executive attention capacity (Colcombe, 2003; Hillman, 2006; Polich, 2007).

ERPs are derived from digitized EEG signals at the scalp during performance of specific cognitive tasks (Luck, 2005). These deflections are thought to index the total activity of specialized microcircuit activity within dedicated networks of cells during task execution (Grillner & Greybiel, 2007; Polich, 2007). Deflections within specified time windows at specified electrodes relative to events of interest (i.e. stimulus onset, trial type, button press response, etc.) are averaged across all trials of carefully defined cognitive tasks (i.e., go no-go, oddball, *n*-back, flanker, Stroop, and task switch). This averaging removes any part of the signal not correlated in time with the event of interest and leaves a waveform interpreted as representing brain activation required to output the specific task (Luck, 2005). While many signal processing and analysis issues remain, latency and amplitude of ERP waveforms have been reliably observed for many processes required for human executive attention operations. These ERPs can be used to compare cognitive performance across subjects and between groups. Indeed, tasks requiring stimulus identification, working memory, inhibition of inappropriate responses, shifting between response rules, and updating of response sequence routinely evoke the P300, a characteristic positive waveform complex in the time window ~ 250-800 *msec* post stimulus presentation (Duncan et al, 2006; Polich, 2007). Inhibition, updating, shifting, and working memory are all components of executive attention function (Miyake, 2000; Gilbert, 2008). This suggests the P300 may be one neural correlate of these components' co-activation. The P300 is seen at midline electrode sites (Fz, Cz, Pz)(Polich, 2007; Duncan et al, 2009; Pontifex et al, 2009). This waveform complex has been dissociated into two main components, the P3a and P3b. The P3a is seen at Fz . The P3b is seen at Pz. These comprise the two poles of the fronto-parietal attention network (Knight, 1990).

The P3a is thought to index orienting of attention to a relevant stimulus (Knight, 1996; Polich, 2007). Larger amplitudes are thought to index more robust allocation of attentional resources to the stimulus (Pontifex et al, 2009). Large P3a amplitudes are elicited by novel stimuli (Polich, 2007). The P3a shrinks with habituation (Segalowitz et al, 2001).

The P3b is thought to index working memory allocation to stimulus processing. Paradigm structure strongly affects the amplitude of the P3b. More complex tests result in smaller amplitudes and longer latencies. Shorter latencies are thought to index more efficient processing (Hillman et al, 2006). A growing literature is beginning to document exercise training effects on the P3b waveform (Ratey & Loehr, 2011). Larger P3b amplitudes are seen in elderly adults who regularly engage in moderate aerobic exercise as compared to sedentary elderly adults (Hatta et al, 2005). Younger and older subjects participating in regular physical activity showed larger P3b amplitudes and shorter latencies on a task switching paradigm than inactive subjects (Hillman et al, 2006). Importantly, Tai Chi has been shown to require moderate aerobic exertion (Li et al, 2001; Powers & Howley, 2004).

Only one study utilizing the attentional blink paradigm has examined meditation training effects on the P3b. The attentional blink test requires subjects to identify a target stimulus during rapid serial visual presentation of distracters (Banich, 1997). If target stimuli occur within a 250 *msec* time window of each other, error rates for target 2 detection are high. Meditators showed reduced P3b amplitudes to target 1 in this paradigm. This was correlated with a high accuracy rate for target 2 identification, suggesting more efficient allocation of attention resources, an executive attention process (Slagter, 2007). There are no studies examining the training effects of Tai Chi on P3b amplitude or latency. P3b characteristics are a potentially reliable normative database for comparing executive attention efficiency across subjects and groups (Etnier & Chang, 2009).

This cross-sectional study compared the effects of long-term training in Tai Chi, meditation plus moderate aerobic exercise, or aerobic exercise alone to sedentary lifestyle on complex executive attention function. We asked if our groups differed on aerobic capacity. Those groups demonstrating greater aerobic capacity were expected to show enhanced executive test scores. Aerobic capacity was assessed with the Rockport 1-mile walk (Kline et al, 1987; Colcombe, 2004). We utilized a demanding alternating runs, endogenously cued, short response to target interval, visuo-spatial task switch (VSTS)

(Mayr, 2000). This test required bilateral button press responses, inhibition, updating, shifting, and working memory (Monsell et al, 2000; Wylie & Allport, 2000; Milan et al, 2006). To optimize test difficulty, we used a novel, ecologically valid test structure. We did not control response to stimulus interval mathematically or temporally. Each response was followed immediately by the next stimulus. We asked if we would see a P300 at midline electrode sites (Woldorff, 1993). If so, we could examine any P3b differences between our groups. We expected to see larger amplitudes and shorter latencies in our training groups compared to our sedentary controls as a result of moderate exercise training effects (Hillman et al 2006; Latey & Loehr, 2011). Because Tai Chi and meditation health regimens also require mental concentration to perform (Lutz et al, 2007; Gatts, 2008; Voss et al, 2009; Pesce, 2011), we asked it this would interact with aerobic exercise training to produce greater benefits to P3b measures than aerobic fitness practice alone. We asked if P3b amplitude and latency would correlate with switch trial reaction time (Mayr, 2000), and percent local switch costs. Finally, we hypothesized that age effects on P3b measures would be less for health regimen practitioners than for sedentary controls.

Methods

Participants. Participants were recruited by word of mouth, local Craigslist and newspaper ads, and flyers posted throughout the communities of Eugene and Springfield, Oregon. Inclusion criteria were 1) no neurological or physical disorders, and 2) aged 20-75. Sedentary participants were required to have 1) a generally inactive lifestyle for five or more years, and 2) no prior experience with meditation or Tai Chi. Health regimen practitioners were required to 1) have practiced at least five years or more, three times per week, 30 minutes per session. All participants had self-selected into their preferred level and type of exercise activity. Fifty-nine participants responding to a health regimen recruitment campaign agreed to four hours of testing scheduled at their convenience. Because acute exercise has been shown to positively affect cognitive performance (Pesce, 2011; Davranche, 2004) we scheduled the cognitive and exercise testing separately. If the participants preferred to do the testing in one day, the cognitive testing was done first followed by the exercise testing. Two Tai Chi participants who could not use a computer effectively were excluded since our key executive attention tests were administered via PC computer. Two subjects did not complete the testing. One subject who presented with bipolar disorder and presently off medication was excluded due to that psychological abnormality. Thus, 54 subjects completed all tests and were included in this analysis (female = 27). Final group composition was 1) 10 Tai Chi (female = 3), 2) 16 meditation plus exercise (female = 6), 3) 16 aerobic fitness (female = 8), and 4) 12 generally sedentary (female = 10) participants. Body mass index (BMI) was calculated for each participant (U.S. Department of Health & Human Services, 2012) (see Table II.1). Subject recruitment and experimental protocol were approved by the University of Oregon Institutional Review Board. Subjects gave Informed Consent and were compensated for their participation.

Multivariate Cross-sectional Design. In multivariate designs multiple dependent variables are measured on subjects who are assigned membership in carefully defined groups (Stevens, 2002). For our overall study, we had three training groups: 1) Tai Chi, 2) meditation, and 3) aerobic fitness. Our fourth group was composed of generally sedentary participants who had never engaged in Tai Chi or meditation training. During data collection our meditation participants all self-reported sufficient aerobic activity to qualify for the aerobic fitness group as well. Thus, each training group was equated on moderate aerobic exertion. The difference between these groups was the attentional focus required to perform their respective health regimens (Pesce & Audiffren, 2011; Voss et al, 2009) (see Figure II.1).

Testing

Lifetime Aerobic Activities Self-report. Participants self-reported average daily and weekly aerobic fitness practice, and total number of years of that intensity of practice.

Aerobic Capacity --Rockport 1-mile Walk. (Kline et al, 1987; American College of Sports Medicine, 2009). Subjects were fitted with an Athletic Connection Polar E600 heart rate monitor (Polar Electro-USA). A chest strap with heart sensor sent information on heart rate and walk time to a wrist recorder. Per American College of Sports Medicine guidelines, subjects walked 1 mile as fast as they were able. Estimated VO_2Max (aerobic capacity in ml/kg/min O2 utilized during exercise) (Powers & Howley, 2004) was calculated by entering subject's age, weight, gender, walk time, and ending heart rate in a java applet located at http://www.exrx.net/Calculators/Rockport.html.

Executive Attention Test. Visuo-spatial task switch (VSTS) (Mayr Laboratory, University of Oregon, 2009) with dense array EEG 256-hydrocel, NetAmps 300 system, Electrical Geodesics, Inc., Eugene, Oregon(Electrical Geodesics, Inc. 2006a).

Visuo-spatial Task Switch Test Overview. We utilized a randomized alternating runs, non-cued visuo-spatial task switch test developed at the Mayr Laboratories, University of Oregon (Altmann, 2008). A red dot stimulus was displayed in a horizontally-oriented fixation rectangle on a computer monitor located ~ 24 inches in front of the participant. Participants were trained to respond as quickly and accurately as possible to stimulus appearance using a two-button mouse. In this ecologically valid paradigm, the next stimulus appeared immediately subsequent to each response. Button press response rules are detailed below. All tests were administered from the same instruction script on the same PC computer.

Button Press Response Rules. Participants were trained in two primary response rules (Rule 1 and 2) to indicate the spatial location of a randomly appearing dot within the fixation rectangle (see Figure II.5). For Rule 1, the button press response was compatible with the dot's location in space. For Rule 2 the button press was incompatible with the dot's location in space. For the Switch test (Rule 3) participants switched between Rule 1 and 2 on every other trial. For Rule 3 participants were provided with visual feedback in the case of erroneous responses. They corrected their error and continued the trial block. Trials in which a switch of response rule was required were designated switch trials. Trials when the response rule remained the same as the previous trial were designated no-switch trials. Participants practiced each Rule until they achieved at least 85% accuracy. Rules 1 and 2 consisted of 48 trials in two blocks. Rule 3 (the actual task switch) consisted of twelve blocks of 48 trials each. The test was coded in E-Prime (Psychology Software Tools) for use with dense array EEG (see below)(Electrical Geodesics, Eugene, Oregon). Coded events in the EEG datastream and the VSTS raw data output were: 1) stimulus type (Congruent Right, Congruent Left; Incongruent Right, Incongruent Left); 2) Trial type (Congruent switch, congruent no-switch, Incongruent switch, incongruent no-switch); and response (correct or incorrect). Trial and stimulus type coding allowed us to precisely identify reaction time associated with each type of trial and stimulus. For this analysis, switch and no-switch trials were analyzed. Switch costs were calculated in the following way, to control for any possible speed-accuracy trade-off effects: Switch RT – No-switch RT/No-switch RT. P300 ERPs were extracted (see below).

EEG Data Collection. Dense-array EEG data was collected with an Electrical Geodesics EEG System 300 and digitized with a 24 bit A/D converter (EGI, Eugene, OR). Subjects were fitted with a 256-electrode hydrocel net by an investigator trained in EGI net application (Electrical Geodesics, Inc., 2006a). Data were collected at 250 Hz. Channels were referenced to VREF. Scalp electrode impedances were at or below 5 KΩ. Data were collected in a sound attenuated, EM-shielded booth (cell phone signals, CB, TV, AM, FM signals, radiofrequency radiation and microwaves, and other signals up to 18 GHz). Subjects were provided with a Table Clamp chin rest (Richmond Products, Inc., Albuquerque, NM).

Data Analysis.

EEG Data Analysis. Netstation EEG data processing workflow for ERP extraction was performed. Data were processed with 1) 2hz first-order high-pass, and 2) 30 Hz low-pass filters. Data were segmented to create a time window in which the P300 would be observed: (300 *msec* before event to 500 msec after event). Artifact detection (bad channels, eye blinks, and eye movements) was performed. All segments contaminated by bad channels, eye blinks or movements were eliminated. All data were then hand inspected to identify any remaining bad segments. Bad channel replacement through interpolation from surrounding channels was performed. Segments were averaged by channel, this average was re-referenced to a computed average reference, then baseline corrected from 300 *msec* pre-stimulus to 500 *msec* post stimulus (Electrical Geodesics, 2006b). P3b waveforms were plotted at Pz. Magnitude of amplitude and latency to peak were extracted and plotted from baseline corrected files in the time window 300 *msec* pre- to 500 *msec* post-stimulus.

Overall Data Analysis. A multivariate analysis of variance (MANOVA) and Levene's test for homogeneity of variance was performed. Sidak correction (a variant of the Bonferroni correction) was used for post hoc analyses. *Alpha* was set at .05 for the main MANOVA. A bivariate correlation was run on all variables. To control for *a* slippage for multiple analyses (PCA and cluster analyses reported elsewhere), a Bonferroni correction was applied and *a* was set at .0125. Our independent variable was group. Because normal aging is associated with degradation of cognitive and physiological function, age was included as a covariate. Dependent variables were estimated VO_2max, switch RT, switch costs, P3b switch amplitude, P3b switch latency. Participant VSTS switch and no-switch reaction times were collapsed onto means. P3b ERP graphs and statistics were extracted using Netstation Waveform Tools (Electrical Geodesics, Inc., 2006). Because we were evaluating whole system efficiency, error trials were included in all means. Accuracy and post-error reaction times were not significantly different between our groups. Groups were numerically coded thus: Tai Chi, 1; Meditation plus exercise, 2; Aerobic fitness, 3; and sedentary control, 4. All analyses were run with PSAW Statistics 19 (IBM, Chicago, Illinois). EEG Data analysis is described in detail below.

Results

P300. We saw a P300 complex at midline electrode sites in the time window 300 *msec* pre- to 500 *msec* post-stimulus. We saw the P3b robustly across subjects and groups at Pz (see Figure V.1). P3b amplitude and latency were included as executive attention measures along with switch reaction time and percent local switch costs.

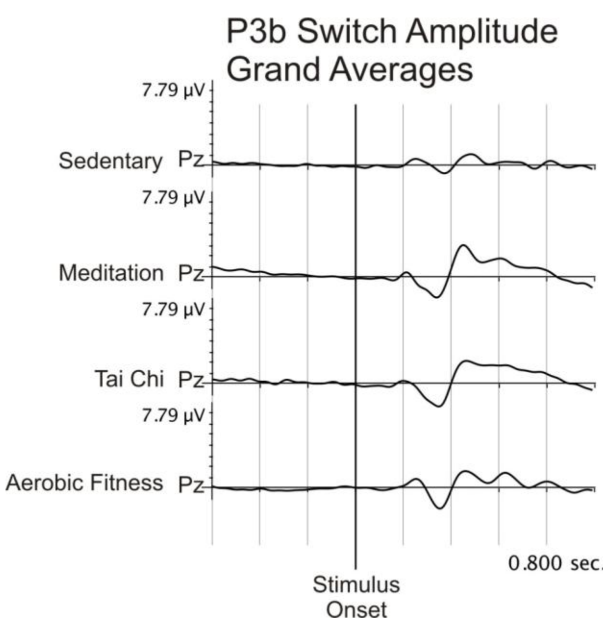


Figure V.1. P3b switch amplitude grand averages. 800 *msec* time window.

Manova. Levene's statistic indicates our data is suitable for the MANOVA procedure (see Appendix G). Our MANOVA was significant (Wilk's lambda (Λ) (F(24, 26) = 1417.561, $p < .001$, *partial eta square* = .999). This indicates we have explained 99% of the variance in our outcome measures. This may be due to the fact that we included aerobic capacity (estimated VO_2max) and age as a covariate in our design. Both age and cardiovascular fitness have been shown to impact cognitive function (Hillman, 2006; Pontifex, 2009). Indeed, age (Wilk's lambda (Λ) (F(24, 26) = 3.488, $p = .001$, *partial eta square* = .763) and group membership (Wilk's lambda (Λ) (F(72, 78.562) = 2.321, $p < .001$, *partial eta square* = .679) significantly affected our outcome measures. Age explained ~76% and group membership explained ~68% of our explained variance. This confirms these key factors explained unique and shared variance.

Effect of Age and Group on Key Dependent Measures. Means, standard deviations, and variance explained by group and age for our key variables are presented in Figure IV.1.

Age. As expected, age had a significant effect on 1) VO_2max (F(1, 49) = 31.789, $p < .001$, *partial eta square* = .393.) This suggests age accounts for almost 40% of the variance we have explained in VO_2max scores (Stevens, 2000). 2) Age also significantly impacted switch reaction time (F(1, 49) = 22.249, $p < .001$, *partial eta square* = .312). Thus, 31% of the variance we explained in switch reaction time is accounted for by normal aging. 3) Interestingly, though age significantly impacted percent switch costs (F(1, 49) = 5.025, $p = .030$, *partial eta square* = .093), the effects of aging on percent switch costs was small (9%). 4) Age did not significantly impact P3b switch amplitude

(*F*(3, 49) = 5.459, *p* = .075, *partial eta square* = .063), and contributed only 6% of the variance explained.

Group. Not surprisingly, group had a significant effect on 1) VO_2max (*F*(3, 49) = 16.103, *p* < .001, *partial eta square* = .496). This suggests almost 50% of the variance in VO_2max score was due to the effects of group membership. Thus, group membership and aging contribute similarly to this executive function measure, suggesting health regimen compliance may counterbalance the effects of normal aging. 2) Switch reaction time was also significantly affected by group (*F*(3, 49) = 8.528, *p* < .001, *partial eta square* = .343), with 34% of the variance in switch reaction time being due to group membership. Again, this is similar to the variance explained by normal aging, suggesting health regimen compliance can hold aging effects in check. 3) Percent switch costs was significantly affected by group (*F*(3, 49) = 6.399, *p* = .001, *partial eta square* = .282), with 28% of the variance in percent switch costs being due to group membership. Recall the age covariate explains only 9% of the variance on this measure while group explains 28%. This suggests compliance with health regimens can overcome the effects of normal aging on complex executive function. 4) Importantly, P3b switch amplitude (*F*(3, 49) = 5.459, *p* = .003, *partial eta square* =.250) was impacted by group. Group membership explained 25% of the variance in P3b switch amplitude while the age covariate did not significantly affect this executive function outcome. This suggests that at the neural level, health regimen compliance counteracts the effects of normal aging on complex executive function.

Neither age nor group significantly affected P3b switch latency.

Post-hoc Comparisons.

Self-reported lifetime hours of aerobic practice. Aerobic fitness practitioners reported significantly more hours of aerobic practice than sedentary controls (p = .021). Meditators reported a similar number of lifetime hours of aerobic practice. Thus, we expected all our training groups to show the effects of chronic moderate exercise. That is what we found.

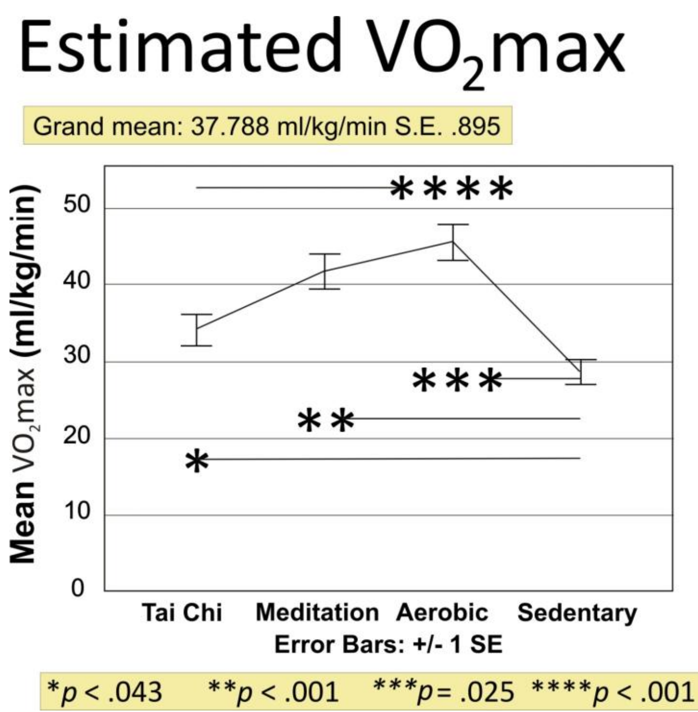


Figure V.2. Comparison of estimated VO_2max by group.

VO2max. Not surprisingly aerobic fitness practitioners outperformed Tai chi practitioners (p = .043) and sedentary controls (p < .001) on aerobic capacity. Meditators (p < .001) and Tai chi practitioners (p = .025) also outperformed sedentary controls (see Figure V.2). This is to be expected, since Tai Chi requires moderate aerobic exertion and our meditators self-reported aerobic activity, which qualified them for our aerobic group. Because Tai Chi practitioners were on average a decade older than our aerobic fitness group, this may contribute to the differences in aerobic capacity we observed between these two groups.

Switch Reaction Time. Tai Chi ($p < .001$), meditation ($p = .001$), and aerobic fitness practitioners ($p = .014$) showed significantly shorter switch reaction times than sedentary controls. There were no significant differences between training groups on switch reaction time.

Percent local switch costs. As expected, Tai Chi ($p = .001$) and meditation practitioners ($p = .006$) showed significantly lower local percent switch costs than sedentary controls. Importantly, aerobic fitness practitioners and sedentary controls did not differ significantly on percent local switch costs, yet there were no significant differences between training groups on this measure (see Figure V.3a).

P3b Switch Amplitude. Here we see a similar pattern to local switch costs. Tai Chi ($p = .031$) and meditation practitioners ($p = .003$) had significantly larger P3b switch amplitudes than sedentary controls. Again, aerobic fitness practitioners and sedentary controls did not differ significantly on this key executive function measure (see figure V.3b). Again, though there were no significant differences between training groups on P3b switch amplitude, examination of the distribution of scores suggest training regimens combining mental and aerobic exertion may confer superior benefits to cognitive capacity (see Figure V.4). Additionally, this suggests percent local switch costs may be a reliable neuropsychological index of executive attention network capacity. Further study is warranted (Etnier & Chang, 2009).

P3b switch latency. There were no significant differences between our groups, though P3b switch latency was significantly and negatively correlated with percent local switch costs (p = .009, r = -.354), showing that lower switch costs are associated with longer P3b switch latencies.

P3a amplitudes and latencies were similar across our groups. This suggests attentional orienting function is similar across all groups.

Correlations. Correlations supply evidence that significant patterns of association are present in a data set. Only correlations significant at the $p < .0125$ level are reported in Table IV.1.

Group membership was significantly and positively correlated with switch reaction time (p = .003, r = .400); 2) positively correlated with switch costs ($p < .001$, r = .468); and 3) negatively correlated with P3b switch amplitude (p = .002, r = -.409). Tai Chi was coded 1, meditation 2; aerobic fitness 3, and sedentary 4, in line with our hypothesis that participants combining concentration and aerobic fitness would outperform participants practicing aerobic fitness alone or those engaged in a primarily sedentary lifestyle. Thus, we see that participants in groups 3 and 4 demonstrate longer switch reaction times, larger switch costs, and smaller P3b switch amplitudes than those in Groups 1 or 2.

Age was significantly correlated with 1) switch reaction time (p = .001, r = .433). This convergent evidence suggests age significantly impacts complex executive attention capacity. Older individuals can be expected to react more slowly than younger individuals. Yet, we see that Tai Chi and meditation practitioners were similar to or outperformed younger aerobic fitness and sedentary controls.

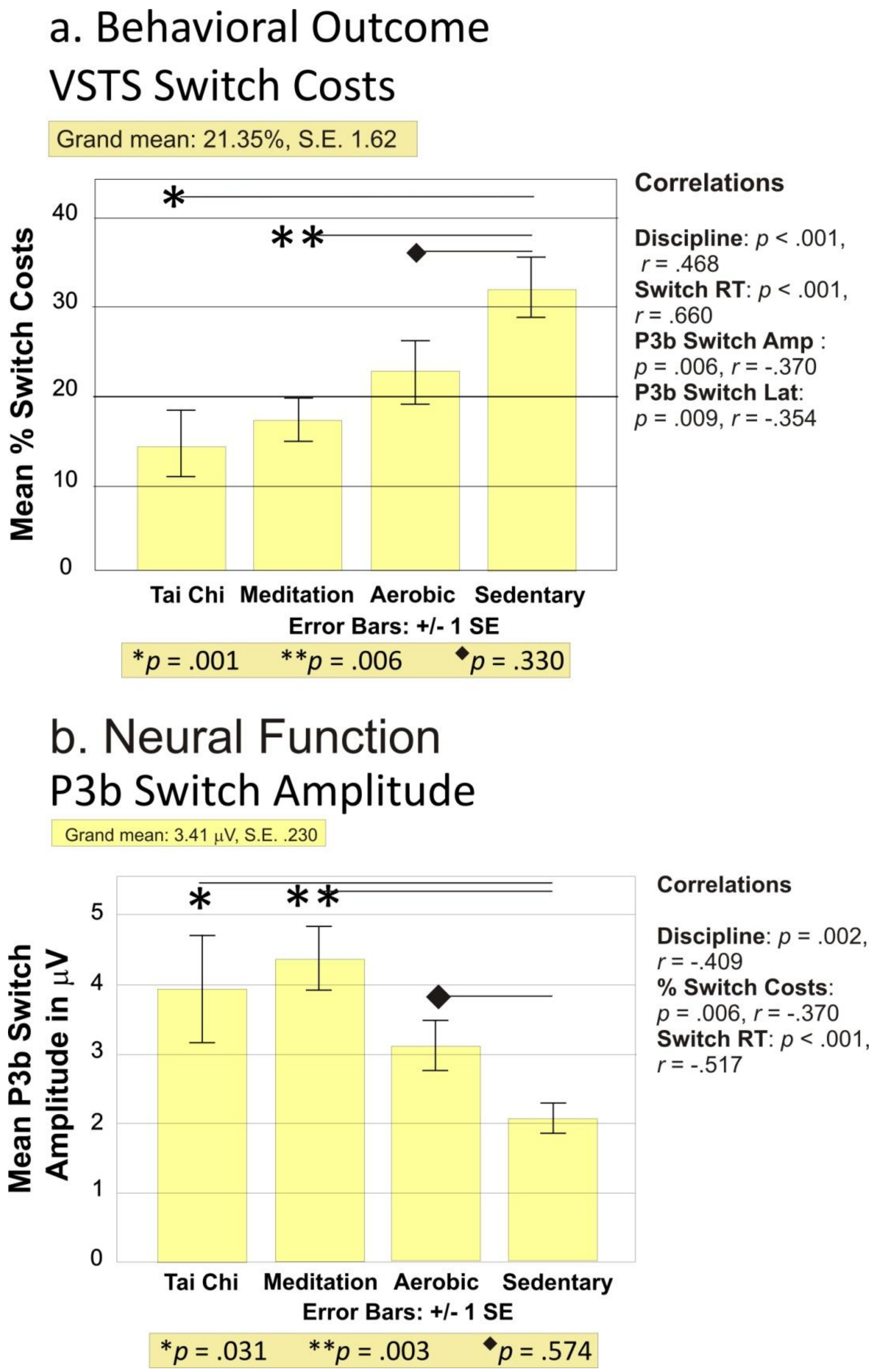


Figure V. 3. Comparison of group performance on key executive measures.

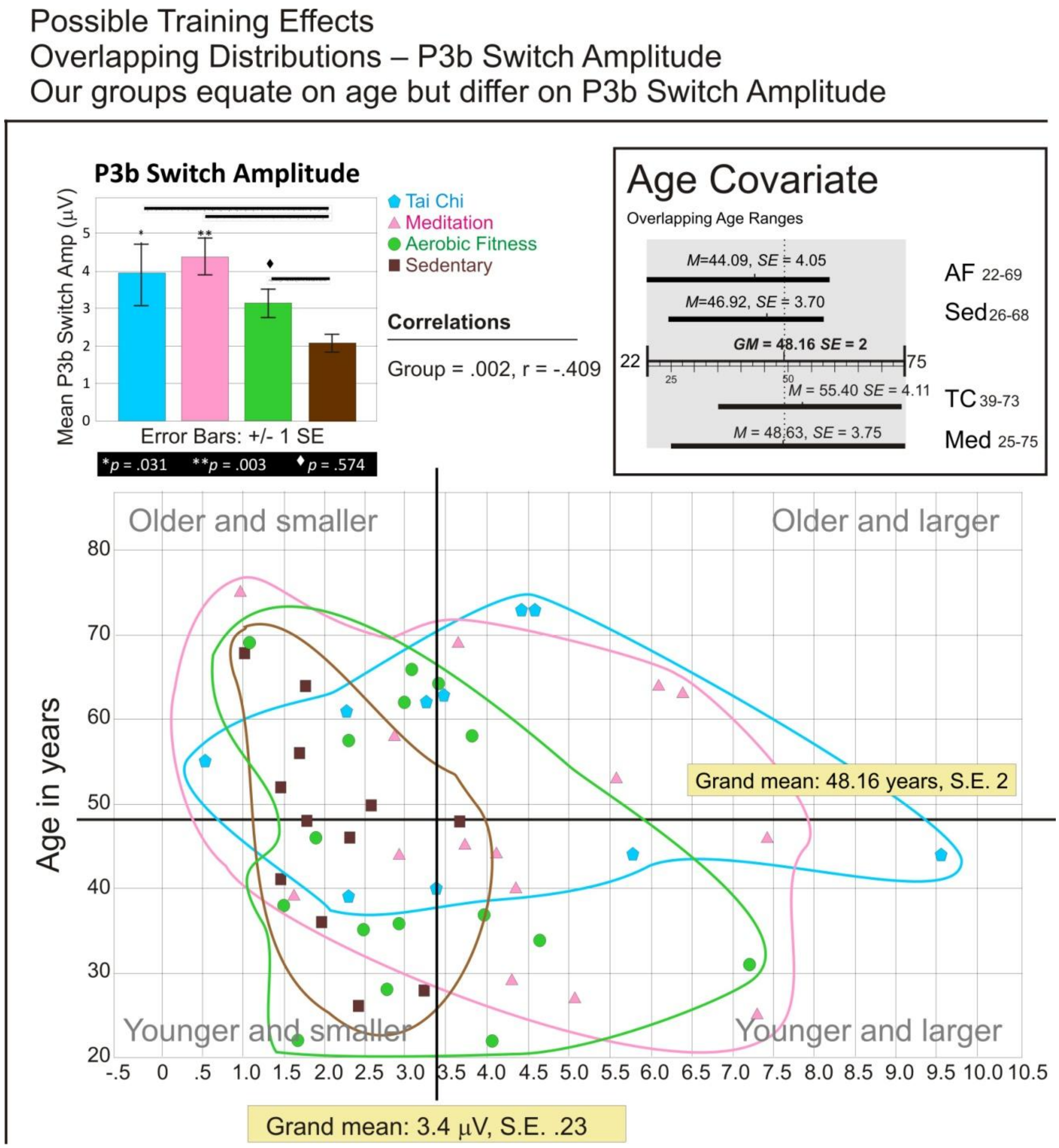


Figure V.4. Possible training effects on P3b switch amplitude.

Switch reaction time was significantly and positively correlated with 1) age ($p = .001$, $r = .433$) (greater age is correlated with longer switch reaction times); and 2) switch costs ($p < .001$, $r = .660$) (lower switch costs are correlated with shorter switch reaction times). Switch reaction time was significantly and negatively correlated with 1) VO_2max ($p <$

.001, $r = -.508$) (greater aerobic capacity was correlated with shorter switch reaction times; and 2 P3b switch amplitude ($p < .001$, $r = -.517$) (shorter reaction times were correlated with larger P3b switch amplitudes).

Percent local switch costs were significantly and positively correlated with 1) group ($p < .001$, $r = .468$) (Tai Chi and meditation practice was associated with lower percent local switch costs); and 2) switch reaction time ($p < .001$, $r = .660$) (higher switch costs were correlated with longer switch reaction times). Percent local switch costs were significantly and negatively correlated with P3b switch amplitude ($p = .006$, $r = -.370$) (lower switch costs were correlated with larger P3b switch amplitudes).

Discussion

This cross-sectional study compared the effects of long-term training in Tai Chi, meditation plus moderate aerobic exercise, or aerobic exercise alone to sedentary lifestyle on executive attention function. We first asked if our groups differed on aerobic capacity. Long-term practitioners of Tai Chi, meditation plus exercise, and aerobic fitness practitioners outperformed sedentary controls on estimated VO_2max . Since each of the training groups self-reported chronic moderate aerobic exertion, this is what we expected and this is what we found. Interestingly, aerobic fitness practitioners outperformed Tai Chi practitioners. This may be due to the fact that there is a mean age difference of a decade between these two groups. It is estimated that VO_2max declines by 1% per year after the age of twenty (Powers & Howley, 2004, p. 335). Our Manova results showed that age effects contributed almost 40% of the variance explained for estimated VO_2max.

Group explained almost 50% of the variance on estimated VO_2max, suggesting moderate aerobic exercise is positively benefitting our training groups' aerobic capacity. Indeed, age was correlated significantly and negatively with VO_2max ($p < .001$, $r = -.539$). That means younger participants demonstrated higher VO_2max, as expected, suggesting age may be the main reason for the significant difference in VO_2max performance by aerobic and Tai Chi practitioners. However, it is also possible that the intensity of exercise in Tai Chi is less than that in aerobic fitness activities, and that interaction with age produces the difference we observed.

We then asked if our groups differed on key executive attention measures. We expected to see larger amplitudes and shorter latencies in our training groups compared to our sedentary controls as a result of moderate exercise training effects (Hillman et al 2006; Latey & Loehr, 2011). Because Tai Chi and meditation health regimens also require mental concentration to perform (Lutz et al, 2007; Gatts, 2008; Voss et al, 2009; Pesce, 2011), we asked it this would interact with aerobic exercise training to produce greater benefits to P3b measures than aerobic fitness practice alone. Further, we hypothesized that age effects on health regimen practitioners would be less than those for sedentary controls.

Our whole model was significant ($p < .001$, *partial eta squared* = .999). Age and group did significantly affect our outcome, with each demonstrating a large effect size ($p = .001$, *partial eta squared* = .763, and $p < .001$, *partial eta squared* = .679, respectively). Clearly these two categories must explain unique variance, but also interact, because their effect sizes add up to over the 99.9% we have explained. We did see the P300 complex in the time window ~250 - 800 *msec* post-stimulus at midline electrode sites. This allowed us to include P3b amplitude and latency in our analysis.

Our visuo-spatial task switch behavioral measures were reported in Chapter IV. Briefly, as expected, our three training groups significantly outperformed sedentary controls on switch reaction time. However, they did not on percent local switch costs. Only our Tai Chi and meditation groups outperformed sedentary controls on this key variable. Yet our training groups did not differ significantly from each other. This is an interesting result that calls for an examination of convergent evidence to tease apart any possible differences between our groups on this measure (Niewenhuis et al, 2011). An examination of the age covariate shows that even though our groups do not differ significantly on age (p = .295), Tai chi practitioners are on average a decade older than aerobic practitioners, yet they outperformed sedentary controls while the aerobic fitness group did not. This suggests Tai Chi practice may confer superior benefits to executive function than moderate exercise alone. Meditators also outperformed sedentary controls while aerobic fitness practitioners did not. However, the mean age difference between these groups was only ~5 years. This suggests the mental concentration required to perform meditation in combination with chronic moderate aerobic activities may confer superior benefits to executive function than moderate exercise alone. Taken together this convergent evidence suggests the benefits of Tai Chi and meditation practice may overcome normal aging effects more efficiently than aerobic exercise alone. Finally, group but not age was significantly and positively correlated with percent switch costs ($p < .001$, $r = .468$). Since Tai Chi is coded 1, meditation 2, aerobic fitness 3, and sedentary controls 4, this indicates individuals in the Tai Chi or meditation groups demonstrated lower switch costs than aerobic fitness practitioners or sedentary controls.

Did our P3b measures follow this pattern? Only our Tai Chi and meditation training groups differed significantly from sedentary controls on the P3b ERP measure of executive function. Again our aerobic fitness group is not significantly different from the sedentary group. This may be interpreted in a way similar to that for percent local switch costs. The aerobic fitness and sedentary controls are younger by almost a decade than the Tai Chi group, yet age did not significantly affect P3b switch amplitude, but group did (p = .003, *partial eta square* = .250). Additionally, group membership was significantly and negatively correlated with P3b switch amplitude (p = .002, r = -.409). This indicates members of the Tai Chi and meditation groups demonstrated larger P3b switch amplitudes, suggesting more efficient executive function. Indeed, our percent switch costs and P3b switch amplitude measures are significantly and negatively correlated (p = .006, r = -.370). This indicates lower switch costs are correlated with larger P3b switch amplitudes. Recall the P3b is thought to index working memory allocation during neuropsychological tasks (Polich, 2007). This convergent evidence suggests that mental training in combination with moderate aerobic exercise may confer superior updating and working memory network benefits across the normal adult lifespan.

P3b switch latency did not differ significantly between our groups, though it was significantly and negatively correlated with switch costs (p = .009, r = -354). Thus as P3b switch latency increased, switch costs were lower. In general, shorter P3b latencies have been identified as indexing more efficient executive function (Hillman, 2006; Etnier & Chang, 2009; Ratey & Loehr, 2011). However, this was observed in paradigms in which stimuli and responses were isolated in time or jittered such that mathematical techniques could be used to extract the ERP of interest (Woldorff, 1993). In this physiologically-relevant paradigm we see the opposite. Lower, more efficient switch costs were associated with longer P3b switch latencies. Perhaps in physiologically-relevant paradigms where source generators are always on, this finding reflects the effects of executive function resource allocation to meet the demands of speed-accuracy trade-off. Further investigation of this finding is warranted. P3a amplitudes and latencies were similar across our groups. This suggests attentional orienting network capacity is similar across all groups.

Limitations of this study include its cross-sectional design. Individuals self-selected into their health regimen. This self-selection may be due to genetic or environmental factors which we did not assess in this study. Since health regimen compliance is a key concern in the clinical setting (Nigg et al, 2011), is it possible self-selection may be an ally in the struggle to insure long-term engagement with health regimens? All three of our regimens provided benefits to raw executive function (switch reaction time), suggesting that each may provide clients with different health regimen options. Since these three training programs are routinely available in educational, Parks & Recreation, and wellness center settings, they may be an economical addition to health care protocols designed to maximize cognitive and cardiovascular capacity in normally aging adults. Our training groups all outperformed sedentary controls on estimated VO_2max, suggesting they exhibited expected exercise-related benefits. We used an absolute measure of VO_2max which accounted for age, gender and weight. Evidence suggests a predictive measure of VO_2max may provide more accurate estimates of aerobic capacity

(Hansen & Wasserman, 1984). Such a measure should be added to future studies. Even so, our results suggest that individuals who engaged in chronic aerobic exercise in combination with mental concentration (Tai Chi and meditation) may have received greater complex executive function benefits than individuals engaging in aerobic fitness practice alone. This finding should be investigated further.

Finally, evidence suggests that amount of sleep per night can affect P3b amplitude. Individuals who sleep < 6 hours per night showed reduced P3b amplitudes during an oddball stimulus identification task than individuals getting 7-8 hours (Gumenyuk et al, 2011). Normally aging individuals over the age of 65 have been indeed been documented to get less sleep than individuals < 36 years of age: 7.5 vs 9 hours per night (Klerman & Dijk, 2008). We did not take field notes on average hours of sleep per night for this study. However, our subjects fall within an age range that could be expected to get at least 7.5 hours per night, which suggests they may fall within the normal sleep range (Gumenyuk et al, 2011). Future studies should include sleep questionnaires to address this possible confound.

<u>Bridge</u>

As predicted, all training groups outperformed sedentary controls on switch reaction time. However, contrary to our hypothesis, only Tai Chi and meditation plus exercise demonstrated lower percent local switch costs and larger P3b ERP switch amplitudes than sedentary controls. Aerobic fitness practitioners did not significantly differ from any of our other groups on these two measures. An examination of the distribution of percent local switch costs and P3b switch amplitude plotted against age suggests training regimens combining mental and aerobic exertion may provide superior protection against normal executive function aging. Chapter VI discusses this in light of clinical considerations and future studies.

CHAPTER VI

GENERAL DISCUSSION

In our cognition-based society, cognitive control is a capacity that is of considerable social importance. Public health interventions that benefit cognitive capacity throughout the lifespan are under investigation. Two widely available health regimens, moderate exercise (Kramer, 2007) and meditation (Chan & Woollacott, 2007; Tang et al, 2007), have been shown to benefit executive function across the lifecycle. Tai Chi is another promising, widely available health regimen that may benefit cognitive capacity.

This multivariate cross-sectional study asked if Tai Chi would be as effective as meditation or aerobic fitness for protecting executive attention capacity after controlling for normal aging effects. As expected we saw aging effects on the cardiovascular system (estimated VO_2max). However, cardiovascular function was as strongly impacted by group as by age, adding to the evidence that long-term aerobic exertion helps offset aging effects. Interestingly, the effect of group on complex executive capacity (% local switch costs), the working memory network (P3b switch amplitude and latency) was far greater than the effect of age. This suggests chronic practice of these three training regimens has counteracted the effects of normal aging on adult human executive capacity.

However, practitioners of Tai Chi and meditation plus moderate aerobic exercise, but not aerobic fitness, demonstrated significantly more efficient percent local switch costs than sedentary controls (p = .001 and p = .006 respectively). This pattern held for the P3b switch amplitude. Tai Chi and meditation plus moderate aerobic exercise, but not aerobic exercisers demonstrated significantly larger P3b switch amplitudes than sedentary controls ($p = .031$ and $p = .003$ respectively). It is important to note Tai Chi and meditation practitioners were not significantly different than aerobic practitioners ($p = .691$ and $p = .589$ respectively) on these executive attention measures. These complex results suggest there may be differential training effects of training regimens combining mental plus aerobic exertion versus aerobic exertion alone, but further study is needed to confirm this interpretation.

Regardless of ranking these three health training regimens in terms of benefits to successful executive attention capacity over the lifespan, they do suggest that Tai Chi and meditation can take a place in the clinical setting as exercise-based health regimens useful for maintaining executive attention capacity in normally aging adults.

Limitations of the Study

Limitations of this study include the small sample size, the lack of a sensitive measure of meditation skill, the need to further field test the Tai Chi Skill Assessment, lack of genetic testing, and the lack of range in self-reported lifetime hours of practice within health regimen groups. This makes correlating skill level with executive capacity impossible. However, though we cannot estimate a dose-response curve, the data support the hypothesis that long-term practice of Tai Chi and meditation plus exercise benefitted executive attention function in our study sample. We also did not collect data on individual sleep patterns. Healthy sleep is correlated with a more robust P3b response. Any participants chronically sleeping < 6 hours a night could be expected to show smaller P3bs, which constitutes a confound in these data. Finally, this study used an absolute estimated VO_2max measure. Predicted estimated VO_2max, may be a more accurate assessment of participant aerobic capacity, and should be added to future studies.

Clinical Implications

Client health regimen compliance is a key concern of health and wellness professionals. Our subjects all self-selected into their particular health regimens. Field observations show that most participants spoke with great enthusiasm about their particular regimen, and were eager to share details about its finer points. This suggests self-selection based on personal interests may be an ally in health-regimen compliance. Tai Chi, meditation plus exercise, and general aerobic fitness offer three very different styles of exercise and mental exertion. This increases the size of the list of health training modalities that may optimize cognitive performance across the lifespan. Field tests are needed to examine applications in the clinical, wellness, and rehabilitation settings.

Future Studies

1. To isolate the effects of self-selection on executive attention, a two-armed longitudinal training study should be undertaken. In arm 1, subjects would self-select into six weeks of training in Tai Chi, meditation plus exercise, or aerobic fitness. In arm 2, subjects would be randomly assigned to one of these training modalities. Pre- post-training scores on VO_2max and executive scores pre- post-

training would be collected. If self-selected participants outperformed randomly assigned participants, this would suggest self-selection into health regimens may benefit long-term compliance.

2. Aging effects on VO2max, Tai Chi Skill, simple self-monitoring, switch capacity (% local switch costs), and P3b switch trial amplitude (μV) and latency (*msec*). This study's data serve as pilot data. Binning of all scores by decade can show the progression of decline with age by system. This sample size is too small to draw any firm conclusions about the decline in function over the decades 30-50. Further study using these measures on a larger sample size of practitioners and non-practicing sedentary controls is proposed.
3. Source localization (GeoSource, Electrical Geodesics, Inc., Eugene, Oregion) analysis of this data set should be performed. Correlations of source localizations with VSTS and P3b ERP measures should be undertaken.
4. Path Length Analysis of Tai Chi Skill Assessment kinematic data (KinTools, Motion Analysis Corporation, Santa Barbara, CA). Derive 1) head, 2) torso, 3) CoM, and 4) hip, 5) knee, and 6) ankle joint center path lengths from our Tai Chi leg kick participants (n=57). Compare across groups on total path length. Hypothesis: participants with no consistent physical training will show longer path lengths than either Tai chi, meditation plus exercise, or aerobic fitness practitioners due to effects of motor learning. Hypothesis: short path length will correlate high Tai Chi Skill Assessment scores.

APPENDIX A

INFORMED CONSENT

A Study of Executive Function in Tai Chi, Aerobic Walking

And Sitting Meditation Experts and Sedentary Controls

University of Oregon

You are invited to participate in a research study being conducted by Teresa Hawkes under the direction of Dr. Marjorie Woollacott in the Department of Human Physiology of the University of Oregon. As a result of the study we hope to learn more about how aerobic exercise and attention training affects executive attention function. The results from this study will contribute to a better understanding of Tai Chi, moderate aerobic exercise, and concentrative attention training on executive attention function. This knowledge can provide insight into the development of appropriate training protocols to maximize student benefit from attention training regimens.

If you decide to participate, you will be scheduled to visit the Motor Control Laboratory for 2-4 visits to participate in the following tests:

1. Motion Analysis: An analysis of balance control ability will be done. You will be asked to wear a tank top and shorts. Thirty-one reflective markers will be placed on your body. You will be asked to stand on two force plates and execute a simple movement from Tai Chi.

2. Go, No-Go Test. You will be seated at a computer. You will respond to stimuli displayed on a computer monitor by means of keystrokes on a special keypad. This will evaluate your ability to relax while concentrating on a simple task.

3. Visuo-spatial Task Switch Test. You will be seated at a computer. You will respond to stimuli displayed on a computer monitor by means of keystrokes on a special keypad. The Mayr Task Switch test will evaluate your ability to remain relaxed while swiftly and accurately switching between rule sets. During this test your brainwave activity will be monitored through surface EEG (electroencephalography). You will be fitted with a sensor net that rests

comfortably on top of your head. This device does not emit anything; it passively records the electrical activity of your brain like a tape recorder (see Risks and Benefits below).

4. 1 Mile Timed Walk. Your heart rate will be recorded. You will walk briskly for 1 mile. Your heart rate will be recorded again, as well as your walk time.

5. You will be asked to report which hand you use for different tasks, your age, gender, education level, lifestyle activities, and comfort with the sensor net during the EEG test.

If you are an expert, these tests allow us to assess the effect of your training on executive attention function. If you are sedentary, we will be able to assess the possible effects of expert training in sitting meditation, aerobic walking, or Tai Chi on executive function.

Confidentiality

All data collected during the test session will be coded with letters and numerals. The names of participant's names will be kept on a separate sheet matched to their respective codes. This sheet will be kept in the investigator's file. Any information obtained in connection with this study that can be identified with you will remain confidential and will be disclosed only with your permission.

Voluntary Participation

Since your participation is voluntary, your decision as to whether or not to participate will not affect your relationship with the Motor Control Lab. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

Risks and Benefits

During the EEG-Task Switch testing session you will be fitted with a Geodesics Sensor Net that monitors brain activity. You may see this net before deciding whether to participate or not. People's brains send out tiny amounts of electricity at all times, and the sensor net picks up changes in these electrical signals. These changes can reflect differences in thinking and feeling. The sensor net consists of a series of plastic tubes held in place with elastic strings, placed comfortably over the head. The tubes contain sponges which hold saline solution, and these sponges make light contact with your scalp and hair. The sponges pick up weak electrical signals and are referred to as electrodes. There is no rubbing or abrasion of skin and no hair removal involved. The saline solution contains a small amount of baby shampoo, and this breaks up oil on the scalp. You will be asked if you have allergies to shampoo. It takes about 10-15 minutes to fit the net so that all the sponge-electrodes are operational. You should note that the sensor net is 100% safe, and there is no possibility of electricity or any other substance (except mild dampness) passing from the net to you. Occasionally, individuals report a slight itching sensation from the saline solution as it dries on their skin during the recording process. This condition resolves immediately upon removal of the Geodesics Sensor Net. Some participants may also experience localized redness of the scalp due to the hypoallergenic adhesive collars used on the electrodes. This response, similar to the redness experienced after removal of a Band-aid, subsides within an hour. Your participation in this experiment is entirely voluntary. You are free to leave the experiment at any time if you do not want to continue for any reason. The experimenter can quickly remove the sensor net at any point.

Benefits

Benefits from participation in this project are free results of your balance, locomotion, and cognitive tests.

Appointments

All appointments are arranged with the person who recruited you to this study. Please call the researcher at the number provided 24 hours in advance of your scheduled research session if it is necessary for you to reschedule or cancel. Please expect a reminder phone call the day before your scheduled sessions.

If you have any questions, please feel free to contact Dr. Marjorie Woollacott at (541) 346-414, or by mail at the Department of Human Physiology, 122 Esslinger Hall, University of Oregon, Eugene, Oregon, 97403. If you have a complaint about the research procedure or about the personnel administering the procedure, contact Dr. Marjorie Woollacott. If you are not satisfied with Dr. Woollacott’s response, you may bring your grievance to the attention of the department head, Dr. Christopher Minson. If you have questions regarding your rights as a research subject, contact the Human Subjects Compliance Office, University of Oregon, Eugene, OR 97403, (541) 346-2510. You will be offered a copy of this form to keep.

Your signature below indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you will receive a copy of this form, and that you are not waiving any legal claim, rights or remedies.

Signature ________________________________ Date _________________________

Print Name ____________________________________

APPENDIX B

QUESTIONNAIRES

Expertise Questionnaire

There are 3 sections in this questionnaire: Aerobic Training, Sitting Meditation, and Tai Chi.

Frequency of Aerobic Exercise

In the last week how many DAYS did you participate in Aerobic activities? (please estimate)

0-----1-----2----3----4----5----6----7

In the last week how many minutes did you participate in Aerobic activities during a typical workout?

0------10-----20-----30-----40-----50-----60-----70-----80-----90----100----110----120+

How many YEARS have you participated in Aerobic activities? (please estimate)

0---1----2----5-----10----15----20----25----30----35----40----45----50+

<u>MEDITATION PRACTICE</u>

Frequency of Meditation

In the last week how many DAYS did you Meditate? (please estimate)

0-----1-----2----3----4----5----6----7

In the last week how many minutes did you Meditate in a typical session?

0------10-----20-----30-----40-----50-----60-----70-----80-----90----100----110----120+

How many YEARS have you Meditated? (please estimate)

0---1----2----5-----10----15----20----25----30----35----40----45----50+

What type of meditation do you practice? ________________________________

TAI CHI PRACTICE

Frequency of Tai Chi practice

In the last week how many DAYS did you practice Tai Chi? (please estimate)

0-----1-----2----3----4----5----6----7

In the last week how many minutes did you practice Tai Chi during a typical workout?

0------10-----20-----30-----40-----50-----60-----70-----80-----90----100----110----120+

How many YEARS have you practiced Tai Chi? (please estimate)

0---1----2----5-----10----15----20----25----30----35----40----45----50+

What type of tai chi do you practice? ________________________________

Adult Temperament Questionnaire (Derryberry & Rothbart, 1987)

Please provide the following information by checking the appropriate response or filling in the blank.

Sex: ______ Male ______ Female

Is English your first language? ______ Yes ______ No

Age: ______

Country of Origin: ______________________________

ADULT TEMPERAMENT QUESTIONNAIRE (VERSION 1.3)

Directions

On the following pages you will find a series of statements that individuals can use to describe themselves. There are no correct or incorrect responses. All people are unique and different, and it is these differences which we are trying to learn about. Please read each statement carefully and give your best estimate of how well it describes you. Circle the appropriate number below to indicate how well a given statement describes you.

circle #:	if the statement is:
1	extremely untrue of you
2	quite untrue of you
3	slightly untrue of you
4	neither true nor false of you
5	slightly true of you
6	quite true of you
7	extremely true of you

If one of the statements does not apply to you (for example, if it involves driving a car and you don't drive), then circle "X" (not applicable). Check to make sure that you have answered <u>every</u> item.

1. I become easily frightened.

   1 2 3 4 5 6 7 X

2. I am often late for appointments.

   1 2 3 4 5 6 7 X

3. Sometimes minor events cause me to feel intense happiness.

   1 2 3 4 5 6 7 X

4. I find loud noises to be very irritating.

   1 2 3 4 5 6 7 X

5. It's often hard for me to alternate between two different tasks.

   1 2 3 4 5 6 7 X

6. I rarely become annoyed when I have to wait in a slow moving line.

   1 2 3 4 5 6 7 X

7. I would not enjoy the sensation of listening to loud music with a laser light show.

   1 2 3 4 5 6 7 X

8. I often make plans that I do not follow through with.

   1 2 3 4 5 6 7 X

9. I rarely feel sad after saying goodbye to friends or relatives.

   1 2 3 4 5 6 7 X

10. Barely noticeable visual details rarely catch my attention.

    1 2 3 4 5 6 7 X

11. Even when I feel energized, I can usually sit still without much trouble if it's necessary.

    1 2 3 4 5 6 7 X

12. Looking down at the ground from an extremely high place would make me feel uneasy.

1 2 3 4 5 6 7 X

13. When I am listening to music, I am usually aware of subtle emotional tones.

1 2 3 4 5 6 7 X

14. I would not enjoy a job that involves socializing with the public.

1 2 3 4 5 6 7 X

15. I can keep performing a task even when I would rather not do it.

1 2 3 4 5 6 7 X

16. I sometimes seem to be unable to feel pleasure from events and activities that I should enjoy.

1 2 3 4 5 6 7 X

17. I find it very annoying when a store does not stock an item that I wish to buy.

1 2 3 4 5 6 7 X

18. I tend to notice emotional aspects of paintings and pictures.

1 2 3 4 5 6 7 X

19. I usually like to talk a lot.

1 2 3 4 5 6 7 X

20. I seldom become sad when I watch a sad movie.

1 2 3 4 5 6 7 X

21. I'm often aware of the sounds of birds in my vicinity.

1 2 3 4 5 6 7 X

22. When I am enclosed in small places such as an elevator, I feel uneasy.

1 2 3 4 5 6 7 X

23. When listening to music, I usually like turn up the volume more than other people.

1 2 3 4 5 6 7 X

24. I sometimes seem to understand things intuitively.

1 2 3 4 5 6 7 X

25. Sometimes minor events cause me to feel intense sadness.

1 2 3 4 5 6 7 X

26. It is easy for me to hold back my laughter in a situation when laughter wouldn't be appropriate.

1 2 3 4 5 6 7 X

27. I can make myself work on a difficult task even when I don't feel like trying.

1 2 3 4 5 6 7 X

28. I rarely ever have days where I don't at least experience brief moments of intense happiness.

1 2 3 4 5 6 7 X

29. When I am trying to focus my attention, I am easily distracted.

1 2 3 4 5 6 7 X

30. I would probably enjoy playing a challenging and fast paced video-game that makes lots of noise and has lots of flashing, bright lights.

1 2 3 4 5 6 7 X

31. Whenever I have to sit and wait for something (e.g., a waiting room), I become agitated.

1 2 3 4 5 6 7 X

32. I'm often bothered by light that is too bright.

1 2 3 4 5 6 7 X

33. I rarely notice the color of people's eyes.

1 2 3 4 5 6 7 X

34. I seldom become sad when I hear of an unhappy event.

1 2 3 4 5 6 7 X

35. When interrupted or distracted, I usually can easily shift my attention back to whatever I was doing before.

1 2 3 4 5 6 7 X

36. I find certain scratchy sounds very irritating.

1 2 3 4 5 6 7 X

37. I like conversations that include several people.

1 2 3 4 5 6 7 X

38. I am usually a patient person.

1 2 3 4 5 6 7 X

39. When I am resting with my eyes closed, I sometimes see visual images.

1 2 3 4 5 6 7 X

40. It is very hard for me to focus my attention when I am distressed.

1 2 3 4 5 6 7 X

41. Sometimes my mind is full of a diverse array of loosely connected thoughts and images.

1 2 3 4 5 6 7 X

42. Very bright colors sometimes bother me.

1 2 3 4 5 6 7 X

43. I can easily resist talking out of turn, even when I’m excited and want to express an idea.

1 2 3 4 5 6 7 X

44. I would probably not enjoy a fast, wild carnival ride.

1 2 3 4 5 6 7 X

45. I sometimes feel sad for longer than an hour.

1 2 3 4 5 6 7 X

46. I rarely enjoy socializing with large groups of people.

1 2 3 4 5 6 7 X

47. If I think of something that needs to be done, I usually get right to work on it.

1 2 3 4 5 6 7 X

48. It doesn't take very much to make feel frustrated or irritated.

1 2 3 4 5 6 7 X

49. It doesn’t take much to evoke a happy response in me.

1 2 3 4 5 6 7 X

50. When I am happy and excited about an upcoming event, I have a hard time focusing my attention on tasks that require concentration.

1 2 3 4 5 6 7 X

51. Sometimes, I feel a sense of panic or terror for no apparent reason.

1 2 3 4 5 6 7 X

52. I often notice mild odors and fragrances.

1 2 3 4 5 6 7 X

53. I often have trouble resisting my cravings for food drink, etc.

1 2 3 4 5 6 7 X

54. Colorful flashing lights bother me.

1 2 3 4 5 6 7 X

55. I usually finish doing things before they are actually due (for example, paying bills, finishing homework, etc.).

1 2 3 4 5 6 7 X

56. I often feel sad.

1 2 3 4 5 6 7 X

57. I am often aware how the color and lighting of a room affects my mood.

1 2 3 4 5 6 7 X

58. I usually remain calm without getting frustrated when things are not going smoothly for me.

1 2 3 4 5 6 7 X

59. Loud music is unpleasant to me.

1 2 3 4 5 6 7 X

60. When I'm excited about something, it's usually hard for me to resist jumping right into it before I've considered the possible consequences.

1 2 3 4 5 6 7 X

61. Loud noises sometimes scare me.

1 2 3 4 5 6 7 X

62. I sometimes dream of vivid, detailed settings that are unlike anything that I have experienced when awake.

1 2 3 4 5 6 7 X

63. When I see an attractive item in a store, it's usually very hard for me to resist buying it.

1 2 3 4 5 6 7 X

64. I would enjoy watching a laser show with lots of bright, colorful flashing lights.

1 2 3 4 5 6 7 X

65. When I hear of an unhappy event, I immediately feel sad.

1 2 3 4 5 6 7 X

66. When I watch a movie, I usually don't notice how the setting is used to convey the mood of the characters.

1 2 3 4 5 6 7 X

67. I usually like to spend my free time with people.

1 2 3 4 5 6 7 X

68. It does not frighten me if I think that I am alone and suddenly discover someone close by.

1 2 3 4 5 6 7 X

69. I am often consciously aware of how the weather seems to affect my mood.

1 2 3 4 5 6 7 X

70. It takes a lot to make me feel truly happy.

1 2 3 4 5 6 7 X

71. I am rarely aware of the texture of things that I hold.

1 2 3 4 5 6 7 X

72. When I am afraid of how a situation might turn out, I usually avoid dealing with it.

1 2 3 4 5 6 7 X

73. I especially enjoy conversations where I am able to say things without thinking first.

1 2 3 4 5 6 7 X

74. Without applying effort, creative ideas sometimes present themselves to me.

1 2 3 4 5 6 7 X

75. When I try something new, I am rarely concerned about the possibility of failing.

1 2 3 4 5 6 7 X

76. It is easy for me to inhibit fun behavior that would be inappropriate.

1 2 3 4 5 6 7 X

77. I would not enjoy the feeling that comes from yelling as loud as I can.

1 2 3 4 5 6 7 X

APPENDIX C

DATA COLLECTION WORKFLOW

Questionnaires & IRB Form Checklist

_______ Consent Form
_______ Expertise Questionnaire
_______ Adult Temperament Questionnaire
_______ IRB Forms (2)
_______ Demographics
_______ Gender
_______ Age
_______ Race
_______ Job/Profession
_______ Handedness (L/R/A: L=left; R=right; A=ambidextrous)
_______ Educational Level
1 = Some high school
2= High School diploma
3=Some college/associate degree
4= Baccalaureate degree
5=Some graduate work
6=Master degree or other post-baccalaureate degree such as Nurse or Physical Therapist
7=Ph.D. degree
____________________Head Circumference (cm)

Moving the EEG

Disassembly

______ Switch all power sources off

______ Disconnect amp cables

______ Pull amp cables free

______ Amp power Booster

______ Amp to clock box

______ Remove single clock response cable from single clock control box

______ Remove single clock timing box from E-Prime computer

______ Remove network cable from PC and Mac

______ Remove firewire cable from the Mac and T junction

______ Remove Mac power cable

______ Remove PC power cable

______ Remove T junction cord from Cyberpower

______ Disconnect Cyberpower strip from Medical grade Transformer

______ Disconnect Medical Grade Adapter cord

______ Disconnect Medical Grad Power Cord

______ Disocnnect Software dongles (E-Prime & NetStation)

______ Remove arm from black 2x4

______ Place arm hardware in a box

Assembly

_____ Ensure all power sources are off (UPS, Cyberpower, etc)

_____ Place PC on the left and the Mac on the right

_____ Plug subject monitor into PC

_____ Plug subject mouse into PC

_____ Replace dongles

_____ Connect single clock response box to amp

_____ Connect amp to T junction

_____ Attach single clock to PC

_____ Attach amp timing bus to single clock response box

_____ Network the two computers

_____ Attach T junction (green) to Mac firewire cable

_____ Connect amp to T junction

_____ Attach Medical Grade Power cord to UPS (surge protection & battery backup)

_____ Attach Cyberpower to Medical Grade Transformer

_____ Plug power cords to both computers into the Cyberpower

_____ Turn on UPS

_____ Turn on Medical Grade Transformer

_____ Switch on Cyberpower

_____ Attach arm

_____ Turn on subject monitor

Subject Prep -- EEG

_____ Place experiment in progress sign on door

_____ Prepare electrolyte solution, transport to EEG room

_____ Check disinfectant solution. Make more if necessary

_____ Have measuring tape, timer, and china marker in EEG room

_____ Place towel and washcloth beside solution

_____ Measure subject's head_________________________size

_____ Place appropriate size net beside electrolyte solution______________________size

EEG Protocol

MAC OS X

Password: [redacted]

Net application:

_______ Start Netstation

_______ Acquisition Setup: Open Mayr SwitchSession Acquisition setup

_______ Turn on workbench

_______ Calibrate amplifier

_______ Turn on High pass filter

_______ After subject is trained, apply net. Follow instructions on net application card.

_______ After net application, connect subject net to arm, connect arm to amplifier.

_______ Run gains

_______ Check impedances

_______ Save and close impedance check

_______ Instruct subject to begin

Neurocognitive Testing Operator Instructions

_____ Input session information into NetStation

_____ Rename the session with the subject's number

_____ Record subject session number: ___________________________________

_____ Record name of subject smallwood .dat file:

____

_____After administration of Smallwood, check for .dat file

_____ Record any unusual occurrences:

Smallwood Experiment Information Sheet

Subject State: ____

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Any unusual events during the experiment that may have affected subject performance:

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EEG Experiment Information Sheet

Subject State: ____

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Impedance Issues (electrode #s):

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Any unusual events during the experiment that may affect the subject:

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Subject Prep – Motion Analysis

______ Place experiment in progress sign on door

______ Place unitard ready.

______ Place markers ready.

Motion Analysis Checklist
Equipment Preparation & Data Collection

_____Anything reflective must be covered

_____Camera set-up

_____Ladder, friction cloth for ladder legs.
_____Camera aiming if required.
_____Blue-taped cameras aimed at central volume
_____Turn on camera activation switch on main camera box
_____Make sure there are four dots around the number 1 camera. (master camera) Sends clock signal to sync analog data.

_____System Calibration

_____Turn on cameras.
_____Start Cortex computer.
_____Log into Motor Control
_____Start Cortex
_____Connect to cameras – radio button, bottom left
_____All on. Radio button bottom left of screen.
_____Place markers around force plates
_____Click Run in Cortex, middle lower right
_____Observe what the cameras are seeing in the 2D view
_____Load project file.
_____Calibrating Volume
_____Remove all markers from volume
_____Click "Run"
_____Mask extraneous markers from Camera interference
_____Right click inside of 2D marker view.
_____Select Auto Mask
_____Make sure all the 2D views see 0 markers.
_____Bring out the L-frame
_____Make sure cameras see 4 dots in 3-D
_____Click the camera aiming button
_____Unclick the camera aiming button
_____Click Collect and Calibrate with L-Frame.
_____Put away L-Frame (conceal under black cloth)
_____Bring out the wand
_____Have operator count -> Ready, Set Go
_____Click Collect and Calibrate, duration of 180 seconds, length of 500

_____Calibrator uses wand in collection volume
_____Have the calibrator give equal time to each camera
_____Once collected, allow to go through the wand processing status
_____Ideal statistics are an Average 3 Residual of < 0.5, Wand length ~ 500.00 mm +/- .03 mm
_____Click Accept Calibration, or Run again.
_____Select the Calibration Tab from the bar on the upper portion of the screen
_____Select tools from the menu bar, select settings
_____Select the Lenses/Orientation tab from the lower tab list
_____Make sure the Positioning for all cameras is correct
_____Record the Focal Lengths of the Cameras
_____Go back to the camera settings as above, and make sure the focal lengths are correct.

_____Forceplates
_____Verify project file includes forceplates – Analog tab
_____Turn on forceplates
_____Zero Forceplates

_____Before subject arrives make sure markers are ready for placement.

_____Final Check Before Data Collection
_____Make sure all 31 markers are visible (lower left below main motion analysis window)

_____Data Collection
_____ Be SURE to click on trc and trb boxes!!!!

_______Create a folder for each subject for each recording session.
_______Subject Number is name of main folder.
_______Name files as they are created during motion capture thus:
_______Subject number_static (5 seconds)
_______Subject number_horsestance_static (60 seconds)
_______Subject number_horsestance_moving (60 seconds)
_______Subject number_Wolf Form 9_1 (2, 3, 4, 5….12)

_______Record trials (static, static horse, moving horse, 12 trials of Wolf form 9)

_____After Collection
_____Shut Down Cortex
_____Make sure all your files are saved

_____Stop the cameras…click disconnect
_____Close Cortex
_____Turn off Cameras
_____Turn off forceplates

Motion Analysis Experiment Information Sheet

Subject State: ____

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Any unusual events during the experiment that may have affected subject performance:

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Rockport 1-Mile Walk Experiment Information Sheet

Subject State: ____

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Any unusual events during the experiment that may have affected subject performance:

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APPENDIX D

SUBJECT INSTRUCTIONS

I. IRB forms and Questionnaires.

Good (morning, afternoon, evening). Thank you for your participation in this experiment.

First, we'd like you to carefully read and sign the Informed Consent and Information Confidentiality Agreement forms.

Subject does so or if subject declines to do so, thank them for their time and allow them to depart.

II. EEG net measurement.

We'd like to measure your head to ascertain proper EEG net size. May we do so at this time?

If yes, measure head and record size.

If no, thank the subject for their time and allow them to depart.**

Confirm that the subject has no product in their hair or on their face or neck.

Do you have any hair product such as mousse or hairspray in your hair or make-up or lotion on your face or neck?

**If yes, skip to the questionnaires and motion analysis and Rockport sections of the testing. **

We will need to reschedule your EEG testing. Please remember that for the EEG part of this experiment your hair and face must be clean and free of any kind of chemical. Chemicals can interfere with the data collection.

If no, proceed with the measurement and the testing.

III. Demographic Information

We'd like to record demographic information at this time.

What is your:

1. Gender
2. Age
3. Race
4. Job/Profession
5. Handedness (L/R/A: L=left; R=right; A=ambidextrous). Do you have any left-handers in your family?
6. What is your educational Level:
   1 = Some high school
   2= High School diploma
   3=Some college/associate degree
   4= Baccalaureate degree
   5=Some graduate work
   6=Master degree or other post-baccalaureate degree such as Nurse or Physical Therapist
   7=Ph.D. degree

Subject may decline to provide any or all of this information.

After the subject has been questioned, proceed to the Questionnaires.

IV. Questionnaires

Thank you for your demographic information. Now we'd like you to fill out two questionnaires. The first asks for information on your experience with aerobic fitness, sitting meditation, and Tai Chi. The second is a basic temperament questionnaire.

Please read the instructions on each test. You may ask questions about the instructions before filling out the form if necessary.

When the subject is done, thank them and proceed with the testing.

V. Testing

SART Go No-go Test

It is time to begin the cognitive testing.

Take the subject into the EEG booth and seat them comfortably at the computer table. Adjust the chair height until the subject feels comfortable.

Show the subject the mouse and how it functions. Let them practice with the mouse.

<u>Instructions</u>: *This first test has two sections.*

In section one, you will see a fixation cross appear in the center of the computer screen. This is the location where all stimuli will appear. Keep your eyes focused here.

*When the test begins, you will see the number (**0**) or the letter **X** appear in the center of the screen.*

*If you see the number (**0**), press either mouse button. Respond as quickly as possible. 0's are non-targets.*

*If you see the letter **X**, do not press either mouse button. X's are targets.*

The reason Xs are targets is because we want to see if you can withhold a response to these stimuli.

In section two, you will be asked to evaluate your performance relative to the targets. Were you able to withhold a button press response for the X's during the preceding trial block? You will have these choices:

1. *On Task. Fully attentive to performing the task.*
   a. *Sure you made no mistakes.*
   b. *Sure you made a mistake.*

2. *Off Task.*
    a. *Tuned out. Off-task and suspect you may have made a mistake.*
    b. *Zoned out. Off-task and unsure if you made a mistake.*

These two sections go together. You do section one first, then section two follows. We repeat this sequence 24 times. You will be able to practice before the actual experiment begins. You will be able to rest between trial blocks.

Direct the subjects to look at the computer screen and begin the practice.

Visuo-spatial task switch (VSTS).

Place the chin rest in front of the subject. Adjust it to a comfortable height.

This chin rest will be used during the experiment, so we'd like you to become accustomed to it before the actual experiment begins. Please place your chin in the chin rest throughout your training. Also, during the EEG test, you will need to keep your head, eyes, tongue, facial muscles, and upper body as still as possible. You may practice this during your training as well.

Show subject VSTS Instruction Card as you describe the test.

There are three response rules for this test. You will be trained on all three rules before the actual experiment begins. The actual experiment with the EEG net will test you on all 3 Rules in random order. For example, you might be instructed to use response rule 3. The instructions for that Rule will be displayed. You will be able to do a short practice to refresh your memory, then you will perform the Rule 3 test. Then you might be instructed to perform Rule 1. Again, you will do a short practice, then proceed to the actual test. Rule 2 will then follow. You practice Rule 2, and then the actual test commences.

Here are the Rules:

For Rule 1, please press the mouse button that is on the same side as the stimulus.

For Rule 2, please press the mouse button opposite to the stimulus location.

For Rule 3, please alternate between Rules 1 & 2 in the following manner:

Do two repetitions of Rule 1. Switch. Do two repetitions of Rule 2. Switch.

Do two repetitions of Rule 1. Switch. Do two repetitions of Rule 2. Switch.

Etc.

Please respond as fast and accurately as possible throughout this test: that is, respond as fast as you can while minimizing your errors as much as possible. There are practice blocks in which you will learn each Rule thoroughly before being trained in 4 blocks of 48 trials each.

After you complete training, the EEG net will be applied. You will then perform Rules 1 through 3 in random order. Please read the instructions on your computer screen carefully before beginning each section of the test.

Direct the subject to look at the screen.

Test instructions will be displayed on the screen. Please follow these instructions carefully.

It is time to begin training.

Ascertain that the subject is comfortable, then close the door. The training will begin.

The subject is trained.

When the training is complete, open the door and escort the subject to the chair where the EEG net will be applied. Apply the net. Direct the subject back to the EEG booth. Make sure they are seated comfortably. Run impedances.

It is time for the experiment to begin.

The experiment will be subdivided into 2 parts:

1) A base-line rest period of 2 minutes with your eyes open. Just gaze softly at this screen.

2) *When the first stimulus appears at the end of the 2 minute baseline period, you will be instructed to begin the test.*

Read all instructions on the screen carefully before beginning each portion of this test.

Please respond as fast and accurately as possible throughout this test

3) You may choose to rest between each block, and press either mouse key when you are ready to continue.

During the test we will need you to remain as still as possible and to minimize all movements. This includes tensing your jaw or neck and moving your lips or tongue. We will also ask you to not move your eyes around while you are taking the test. Please let your eyes remain focused on the screen before you. The reason why it is important that you keep your body and eyes still is that body movements or eye movements can interfere with the currents we record from your scalp.

Motor Control Skill Assessment

Ask the subject to change into clothing they have brought or the unitard we supply. Measure subject's height and weight. Place 31 markers (modified Helen Hayes marker set).

Position subject correctly across force plates for static marker trial.

Please stand facing this wall (clock wall) with your feet shoulder width apart and arms lifted to the side parallel to the floor.

In order to insure that the Motor Control test is safe, we are going to give you two exercises to warm up your legs, back, and arms.

**Show the subject horsestance **

This is horsestance. You will need to work from this position throughout this test. We'd like you to become accustomed to this position.

Position subjects for static horsestance. (on cross-hairs across plates).

Please assume horsestance. Gaze softly at the floor ten feet in front of you. Please hold this position for 1 minute, or until you feel any uncomfortable strain in your thighs, knees, ankles, or low back. This will accustom you to this position, and it will warm up your muscles.

Subject holds horsestance for 1 minute or stops whenever they begin to feel strain.

You may stretch your legs or move about until you feel you are ready to continue.

Now we'd like you to become accustomed to moving in horsestance. We'd like you to be in horsestance again. This time we'd like you to shift your weight all the way from your right foot to your left foot and back again continuously for one minute. Do not move either foot. Simply shift your weight smoothly and continuously. You may stop at any time if you feel discomfort. You may practice this movement.

The operater asks the subject to do 1 minute of weight shifts or stop whenever they feel uncomfortable strain.

Thanks. Now please shake out your legs or walk around if you need to.

**Show the subject the Tai Chi Leg Kick video.

Ask subject to practice the Tai Chi Leg Kick until they feel ready to be tested.

Subject is positioned on the forceplates in horse stance.**

We would like you to do twelve repetitions of this movement. Each repetition will be a single trial. You will not need to perform all twelve trials consecutively. We only ask you to do this form to the left side, that is, you will lift the left leg only.

**Subject performs 12 repetitions of the Tai Chi Leg Kick. During the collection remind the subject they may shake out their legs and stretch whenever they feel the need.

Thank subject and remove markers. **

Estimated VO_2Max

Place heart rate monitor on subject. Take subject to indoor track if raining or outdoor track if weather permits.

Please walk as fast as you can for 1 mile. Walk fast enough that you feel about to break into a run.

(indoor track: 10 laps; outdoor track: 4 laps).

Subject walks for one mile as fast as they can. Record final heart rate and walk time in minutes and seconds.

Remove heart rate monitor. Thank subject. Have subject sign reimbursement form. Give subject the reimbursement envelope.

APPENDIX E

POST-HOC RESULTS, OTHER MEASURES

Education Years. Aerobic fitness (p = .030) and meditation practitioners (p = .004) showed significantly more years of education than sedentary controls. Tai Chi practitioners and sedentary controls did not differ significantly on years of education.

Body Mass Index (BMI). Meditation practitioners showed significantly lower BMI than Tai Chi practitioners (p = .004) or sedentary controls (p = .036). Aerobic fitness practitioners showed significantly lower BMI than Tai Chi practitioners (p = .009).

No-switch Reaction time. Tai Chi (p = .008) and meditation practioners (p = .021) showed significantly shorter no-switch reaction times than sedentary controls. Aerobic fitness practitioners and sedentary controls did not differ significantly on no-switch reaction time. There were no significant differences between training groups on no-switch reaction time.

P3a switch amplitude. There were no significant differences between our groups.

P3a no-switch amplitude. There were no significant differences between our groups.

P3a switch latency. There were no significant differences between our groups.

P3a no-switch latency. There were no significant differences between our groups.

Adult Temperament Questionnaire (ATQ). There were no significant differences between our groups on any ATQ measure.

Other Correlations

Correlations. Correlations significant at the $p < .0125$ level are reported.

Group was significantly correlated with P3b No-switch amplitude ($p = .003$, $r = -.391$).

VO_2max was significantly correlated with 1) BMI ($p = .004$, $r = -.386$), and 2) no-switch reaction time ($p < .001$, $r = -.500$).

SART self-monitoring was significantly correlated with SART Inhibition ($p < .001$, $r = -.509$).

Switch reaction time was significantly correlated with 1) no-switch reaction time ($p < .001$, $r =.938$), and 2) P3b no-switch amplitude ($p < .001$, $r = -.490$).

Switch costs were significantly correlated with 1) education years ($p = .004$, $r = -.385$), and 2) no-switch reaction time ($p = .005$, $r = .375$).

P3b switch amplitude was significantly correlated with 1) no-switch reaction time ($p < .001$, $r = -.495$) and 2) P3b No-switch amplitude ($p < .001$, $r = .963$).

P3b no-switch amplitude was significantly correlated with 1) group ($p = .003$, $r = -.391$), 2) switch reaction time ($p < .001$, $r = -.490$), 2) no-switch reaction time ($p < .001$, $r = -.505$), and 3) P3b switch amplitude ($p < .001$, $r = .963$).

P3a no-switch amplitude was significantly correlated with 1) P3a switch amplitude ($p < .001$, $r = .915$) and 2) P3a switch latency ($p < .001$, $r = .591$).

P3b no-switch latency was significantly correlated with P3b switch latency (p = .003, r = .401).

P3a no-switch latency was significantly correlated with 1) P3a switch latency (p < .001, r = .570), and 2) P3a no-switch amplitude (p < .001, r = .481).

APPENDIX F

LEVENE'S STATISTIC RESULTS

Levene's Test of Equality of Error Variance

	F	df1	df2	Sig.
EducationYears	.594	3	50	.622
BMI	6.452	3	50	.001
AerobicHours	4.003	3	50	.012
MeditationHours	9.602	3	50	.000
TaiChiHours	6.668	3	50	.001
METs	.718	3	50	.546
VO2Max	1.140	3	50	.342
TCSkill	.563	3	50	.642
SARTMonitoring	.254	3	50	.858
SARTInhibition	1.414	3	50	.250
SwitchRT	.135	3	50	.939
NoSwitchRT	.415	3	50	.743
SwitchCosts	3.350	3	50	.026
PostError	2.691	3	50	.056
Accuracy	2.695	3	50	.056

	F	df1	df2	Sig.
VSTSFractalD	.745	3	50	.530
P3bSwitchAmp	3.271	3	50	.029
P3aSwAmp	1.017	3	50	.393
P3bSwLat	2.853	3	50	.046
P3aSwLat	3.843	3	50	.015
P3bNSAmp	1.898	3	50	.142
P3aNSAmp	.844	3	50	.476
P3bNSLat	.924	3	50	.436
P3aNSLat	.945	3	50	.426

BMI: Composite number composed of height and weight. Number of hours of lifetime practice is a discriminant variable and should show a different variance between groups. Switch costs is a composite number.

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