

Research paper

Tai Chi training reduced coupling between respiration and postural control



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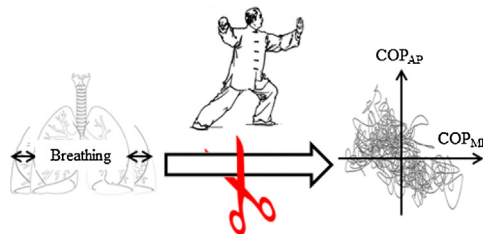
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HIGHLIGHTS

- Tai Chi training did not affect average sway speed & magnitude or respiratory rate.
- Yet tai Chi training reduced the impact of respiration on postural sway.
- The effects of Tai Chi on postural control could be optimized system interaction.

GRAPHICAL ABSTRACT



Tai Chi reduced the impact of respiration on postural control

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ABSTRACT

In order to maintain stable upright stance, the postural control system must account for the continuous perturbations to the body's center-of-mass including those caused by spontaneous respiration. Both aging and disease increase "posturo-respiratory synchronization;" which reflects the degree to which respiration affects postural sway fluctuations over time. Tai Chi training emphasizes the coordination of respiration and bodily movements and may therefore optimize the functional interaction between these two systems. The purpose of the project was to examine the effect of Tai Chi training on the interaction between respiration and postural control in older adults. We hypothesized that Tai Chi training would improve the ability of the postural control system to compensate for respiratory perturbations and thus, *reduce* posturo-respiratory synchronization. Participants were recruited from supportive housing facilities and randomized to a 12-week Tai Chi intervention ($n = 28$; 86 ± 5 yrs) or educational-control program ($n = 34$, 85 ± 6 yrs). Standing postural sway and respiration were simultaneously recorded with a force plate and respiratory belt under eyes-open and eyes-closed conditions. Posturo-respiratory synchronization was determined by quantifying the variation of the phase relationship between the dominant oscillatory mode of respiration and corresponding oscillations within postural sway. Groups were

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similar in age, gender distribution, height, body mass, and intervention compliance. Neither intervention altered average sway speed, sway magnitude or respiratory rate. As compared to the education-control group, however, Tai Chi training reduced posturo-respiratory synchronization when standing with eyes open or closed ($p < 0.001$). Tai Chi training did not affect traditional parameters of standing postural control or respiration, yet reduced the coupling between respiration and postural control. The beneficial effects of Tai Chi training may therefore stem in part from optimization of this multi-system interaction.

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1. Introduction

Human upright stance is inherently unstable and thus requires a complex control system in which sensory systems, motor circuitry, and cardio-respiratory activities function in concert to maintain stability of upright posture [1,5,6,13]. Spontaneous respiration continuously alters intrathoracic volume and thus influences the body's center-of-mass [2]. When healthy adults stand with eyes open, respiration-induced perturbations to the trunk are accompanied by phasic muscle activation patterns in the lower-extremities and related angular movements about the hips, knees and ankles [4]. The postural control system thus appears to account for respiration, ostensibly with the purpose of minimizing its effect on postural sway [4,20,21,23]. As such, understanding the dynamic interaction between the respiratory and postural control systems may provide new insights into the fundamental control mechanisms associated with bipedal stance.

The dynamics of various physiological processes are naturally complex [23]. Complexity refers to the presence of non-linear, non-stationary fluctuations across multiple time scales in the dynamics of physiological outputs [14]. The dynamics of both respiration and postural sway are complex [12] and as such, quantification of their interactions is non-trivial. The metric “posturo-respiratory synchronization” was recently introduced and provides one way to quantify the influence that respiration has on postural sway [15]. This metric was derived from adaptive signal processing techniques that do not assume linearity or stationarity of involved signals. Specifically, posturo-respiratory synchronization quantifies the degree to which respiration and postural sway, as measured by center of pressure excursions beneath the feet, are synchronized over time. A larger synchronization index indicates a greater influence of respiration on postural sway [15].

Virtually all elements of the postural control system decline in functional capacity as one ages from adulthood into senescence [12,14]. This decline manifests as a diminished ability to detect, respond and overcome perturbations to the body while standing [15]. Recently, Manor et al. [15] demonstrated that both aging and chronic brain damage secondary to stroke are associated with increased posturo-respiratory synchronization index; that is, a reduced capacity of the postural control system to counteract respiratory perturbations.

Tai chi, a traditional Chinese martial art form, has been used as an intervention strategy to effectively improve balance in numerous older adult populations [9,10,27,28]. This multi-component therapy incorporates a combination of slow purposeful movements, controlled diaphragmatic breathing and mind-body awareness [10]. As such, Tai Chi may be well-suited to improve the dynamic relationship between respiration and postural control. The purpose of this study was therefore to examine the effect of Tai Chi training on this multisystem interaction. We hypothesized that Tai Chi training would reduce the impact of respiration on postural control in older adults, as evidenced by a training-related decrease in posturo-respiratory synchronization. Due to the explicit goal of integrating respiration and bodily movement, we further hypothesized that this metric would be more sensitive to Tai Chi training

as compared to traditional metrics of average postural sway speed or area.

2. Methods

2.1. Protocol

A randomized controlled trial was completed to compare the effects of Tai Chi and educational control interventions on numerous outcomes associated with frailty in older adults living in supportive housing facilities (NCT01136723). Eligible participants were assessed at baseline and then randomly assigned to either the Tai Chi or control group. All assessments were conducted within seven days before and after the intervention by study personnel blinded to group assignment. The study was approved by the Hebrew SeniorLife Institutional Review Board and all participants provided written informed consent prior to enrollment.

2.2. Participants

Men and women >70 years of age were recruited from two supportive living facilities in the Boston area. Once facilities were identified, the study was advertised with flyers and a presentation was given by study personnel at a monthly resident's meeting. Interested individuals were initially screened for eligibility via phone interview. Potentially eligible individuals then completed an in-person evaluation. Exclusion criteria included (1) an inability to stand or ambulate unassisted, (2) the presence of any symptomatic cardiovascular or respiratory disease, (3) a history of myocardial infarction or stroke within 6 months, (4) self-reported painful arthritis, spinal stenosis, amputation, painful foot lesions, or neuropathy, (5) systolic BP above 160 or diastolic BP above 100 mmHg, (6) a known abnormal cardiac rhythm or presence of cardiac pacemaker, (7) diagnosis of Parkinson's disease, or (8) diagnosis of metastatic cancer or immunosuppressive therapy.

There were 68 eligible participants who enrolled for the study. Six participants withdrew from the study. Reasons for withdrawal included injury unrelated to the study ($n=1$) and diminished interest in study participation ($n=5$). A total of 62 participants completed all study procedures.

2.3. Interventions

The Tai Chi intervention was conducted within a common area in each housing facility. Two, instructor-led one-hour group training sessions were completed each week for 12 consecutive weeks. Group sessions contained a maximum of 12 participants. They were taught by one of three instructors, all with greater than 10 years of experience, including experience teaching older health-impaired adults in the context of clinical trials. Tai Chi training was broadly based upon a program initially developed for patients with heart disease and balance disorders and successfully implemented in several previous studies [3,11,16,22,31–33]. The program consisted of five essential Tai Chi movements and a complementary set of traditional Tai Chi warm-up exercises. The five chosen Tai Chi

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