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ORIGINAL RESEARCH

Effects of Tai Chi on a Functional Arm Reaching Task in Older Adults: A Cross-Sectional Study

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This study quantified the effect of aging and the long-term practice of Tai Chi on upper limb movement control, indicated by performance outcome (temporal) and performance production (amplitude) measures, on a multiplanar stand-reaching (i.e., functional) task. Twelve Tai Chi practitioners (TCPs), 11 age-matched older nonpractitioners (ONPs), and 12 young subjects performed cued, flexion-reaching, and abduction-reaching tasks using a custom set-up. Surface EMG and acceleration data sampled from wireless sensors rendered performance outcome (reaction time, burst duration, time to peak, and movement time) and performance production (normalized EMG amplitude and peak acceleration) measures. Young subjects and TCPs demonstrated better performance outcome and performance production than ONPs. Relative-effect computations (i.e., the effect of Tai Chi expressed as a percentage of the effect of aging) showed that TCPs exhibited approximately 20–60% (flexion) and 20–100% (abduction) improvement in reaching task performance compared with ONPs. Tai Chi practitioners displayed better arm movement control than ONPs on a relatively challenging and functional stand-reaching task.

Keywords: aging, mind-body exercise, motor control, electromyography & acceleration, functional reaching

Deterioration in movement control and balance due to aging is not a new concept; age-linked decline ranges from cellular levels—reduced cross-sectional area of muscle and loss in the number of neurons (Vandervoort, 2002)—to functional levels—slower reaction times (Pew & Van Hemel, 2004; Ranganathan, Siemionow, Sahgal, & Yue, 2001), reduced muscle strength (Metter, Conwit, Tobin, & Fozard, 1997), poor eye-hand coordination (Fozard, Vercruyssen, Reynolds, Hancock, & Quilter, 1994; Verhaeghen & Cerella, 2002), worsened performance of goal-directed arm movements (Bellgrove, Phillips, Bradshaw, & Gallucci, 1998), and decreased movement speed (Ketcham, Seidler, Van Gemmert, & Stelmach, 2002). Likewise, aging also causes significant functional deterioration in both static and dynamic balance control (Balogun, Akindele, Nihinlola, & Marzouk, 1994). An increase in age has been negatively correlated to an individual's ability to control sway while standing (Wingert, Welder, & Foo, 2014), a decrease in total single-leg stance time (Jonsson, Seiger, & Hirschfeld, 2004), and a delay in anticipatory postural responses resulting from a self-induced perturbation. Self-induced perturbations are evoked by performing rapid arm movements, and necessitate generation of anticipatory feed-forward mechanisms (Aruin & Latash, 1995) to maintain a stable posture. Inglin and Woollacott (1988) employed a similar paradigm (with the additional measurement of voluntary arm movement control) and reported a disproportional delay in reaction time of arm prime movers compared with postural muscles (Inglin & Woollacott, 1988).

The benefits of exercise to mitigate age-related symptoms have been confirmed repeatedly (Rogers & Evans, 1993; Vincent et al., 2002). One such exercise is Tai Chi. Tai Chi is a popular form of mind–body exercise that involves controlled weight shifting between single- and double-leg stances, coordinated arm movements, and synchronized head and trunk movements complemented by notable gaze fixation (Wolf, Coogler, & Xu, 1997). Practiced by millions of people all over the world, Tai Chi has been particularly identified for its low intensity compared with strength training (Tsao, 1995) and its ready implementation as a group exercise among older adults (Gillespie et al., 2003).

Several studies have reported the benefits of Tai Chi to static and dynamic balance control (Liu & Frank, 2010; Tsang & Hui-Chan, 2003; Tsang & Hui-Chan, 2004; Tse & Bailey, 1992). More recently, the effect of Tai Chi practice on upper extremity control has been reported as well (Kwok, Hui-Chan, & Tsang, 2010; Pei et al., 2008; Tsang, Kwok, & Hui-Chan, 2013; Yan, 1999). Three out of these four studies examined the effect of the long-term practice of Tai Chi on a seated, finger-pointing task, specifically focusing on variables such as reaction time (simple and choice), movement time, and end-point accuracy. The results suggested that Tai Chi practitioners (TCPs) exhibited significantly better reaction and movement times for more complex tasks, such as those with a choice paradigm or multiple targets, but not on simple, seated reaction time tasks. The TCPs displayed lesser force variability, better accuracy, and fewer submovements, however no difference was observed in peak velocity.

These results must be viewed in the light of certain features of the task design. First, reaching was performed from a seated starting position. Although seated reaching is important in workspace activities, reaching with the arm while standing is very common in daily living and is more challenging owing to the inherent instability that standing entails (i.e., a relatively smaller base of support and preparatory demands on postural muscles). As a further consideration, only sagittal plane forward reaching was studied, which, despite its abundance in day-to-day activities, does not adequately represent the diversity of routine arm movements. For instance, there are many lateral reaching activities in the real world that justify an investigation into arm abduction, and yet this has rarely been examined in the past. Finally, variables were limited to performance outcome measures (reaction time, movement time, and accuracy) rather than performance production measures (kinetic and kinematic measures such as acceleration and muscle activations), except for one study in which peak velocity was reported (Magill & Anderson, 2010; Pei et al., 2008). It has been previously suggested that performance production measures might provide meaningful information about

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movement behavior *during* the performance of a motor task as well as its underlying neural control (Magill & Anderson, 2010). Therefore, the movement behavior, including production-based measures, of a multidirectional stand-reaching task remains to be examined in aging and Tai Chi populations.

Furthermore, Tai Chi practice fundamentally requires the movement of arms in the functional planes (i.e., requiring both sagittal and lateral plane movements, within the demands of standing balance), yet there has been little investigation into its effects on a stand-reaching task. The purpose of this study, thus, was to observe and quantify the effect of aging and the long-term practice of Tai Chi on motor performance, indicated by both outcome-based as well as production-based measures, on a multiplanar stand-reaching task. In this cross-sectional study, we hypothesized that, on both flexion- and abduction-reaching tasks (1) older adults would show greater decline in movement control, marked by more significant deterioration in neuromechanical variables, as compared with younger subjects and (2) older TCPs would perform significantly better than older nonpractitioners (ONPs).

Methods

Participants

Thirty-eight healthy adults (14 TCPs, 12 ONPs, and 12 younger adults) participated in this study. All subjects were from the Chicagoland area and were recruited via flyers. Practitioners were recruited from Tai Chi centers and young participants were recruited from the university student pool. To be included, subjects: (1) answered a general health questionnaire; (2) scored < 8 on the Short Orientation Memory Concentration Test (SOMCT), thereby demonstrating 'normal' cognitive performance; (3) answered the Physical Activity Scale for the Elderly (PASE); and (4) demonstrated comfortable and full range of motion in the shoulder. Besides this, TCPs needed to fulfill a practice condition of at least 100 hr of practice in the last year. Subjects were excluded upon reporting recent surgeries (< 2 months), active signs or symptoms of any discomfort in the shoulder, or if they did not meet the SOMCT criterion. In addition to ruling out any cognitive deficits (commonly encountered in older adults), the SOMCT score also allowed for the comparison of cognitive performances of the two older adult groups. All participants signed an informed consent form approved by the institutional review board of the University of Illinois at Chicago.

Test Procedures

The design, apparatus, and protocol for the stand-reaching task used in this study have been comprehensively detailed previously along with reliability analyses of response variables (Varghese, Hui-Chan, Wang, & Bhatt, 2014). Figure 1 shows a schematic representation of the reaching set-up used for the study.

For flexion reaching, subjects stood facing the target with a shoulder-width base of support on a paper foot mat with their arms at their sides. Feet were marked on the paper mat to maintain a constant base of support throughout the trials. The target was set at 90% of the subject's maximum arm length (defined as the distance from acromion to the tip of the middle finger). This set-up was

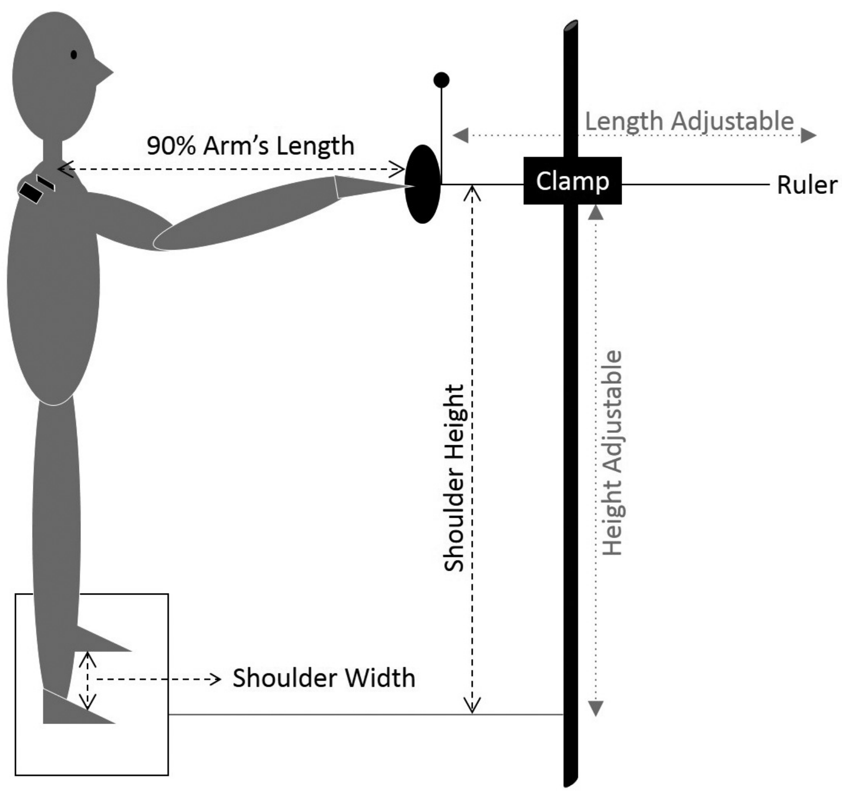

Figure 1 — Schematic representation of the experimental set-up showing the custom-made apparatus, including a ruler and eye-fixator marker held by a clamp complex and attached to a stationary pole and adjusted based on height and arm length. The subject stands with shoulder-width distance between feet and back supported against the wall, reaching out to the target set at 90% of arm length. Electromyography sensors are affixed to the anterior and middle deltoid muscles of the dominant arm.

repeated for abduction reaching, but with subjects standing with their dominant side facing the target.

Subjects received two preset, computer-generated auditory cues. The preparatory cue —*"Get Ready"*— was given at 2 s from the start of the trial (marked by when the subject indicated that he/she was ready and in position), at which time subjects visually focused their attention on the eye fixator, a passive marker held at a fixed distance (3.5 in.) above the target point. The final cue —*"Go"* — was given at 4 s, at which time the subjects visually located the target, reached out, touched it "as quickly and as accurately" as possible, and returned to the starting position.

In this study, 14 blocked trials of each target-reaching task (flexion and abduction), with goal attainment, were recorded for every subject. Three familiarization trials for each direction were provided in the beginning and subjects were given short breaks after every five trials. Instructions to be "quick and accurate" were given from time to time to ensure continued adherence to the protocol.

Data Recording and Analysis

Trigno wireless surface electromyography (EMG) sensors (Delsys, Natick, MA) were used to record EMG activity in the anterior deltoid muscle (prime mover for shoulder flexion) and middle deltoid muscle (prime mover for shoulder abduction). The sensors were affixed to the skin surface in line with the muscle over its belly, as recommended by Cram, Kasman, and Holtz (1998). EMG signals were sampled at 2,000 Hz and hardware band-pass filtered over a bandwidth of 20–450 Hz. Triaxial accelerometers embedded in these sensors rendered signals sampled at 148.1 Hz over a bandwidth of 50 Hz and amplitude range of ± 1.5*g*.

To smooth the EMG data, signals were digitally high-pass filtered using a fourth-order zero-lag Butterworth filter (MATLAB, MathWorks, Inc., Natick, MA) with a cutoff of 20 Hz, full-wave rectified, and then low-pass filtered with a cutoff of 50 Hz. The acceleration signals were smoothed using a fourth-order low-pass Butterworth filter with a cutoff of 80 Hz.

EMG signals from a total 28 trials per subject were analyzed solely from the involved prime mover (i.e., the anterior deltoid for the 14 flexion-reaching trials and the middle deltoid for the 14 abduction-reaching trials) to extract the variables of interest using a customized MATLAB code. Figure 2 shows raw and processed EMG signal and filtered acceleration trace from the anterior deltoid muscle during a single flexion-reaching trial depicting the following variables of performance outcome measures and performance production measures.

Performance Outcome Measures. Reaction time (RT) was defined as the time elapsed between the final cue, "Go" (at 4 s), and the onset of the EMG signal (calculated as ± 1 *SD* from the baseline). Burst duration was defined as the time elapsed between

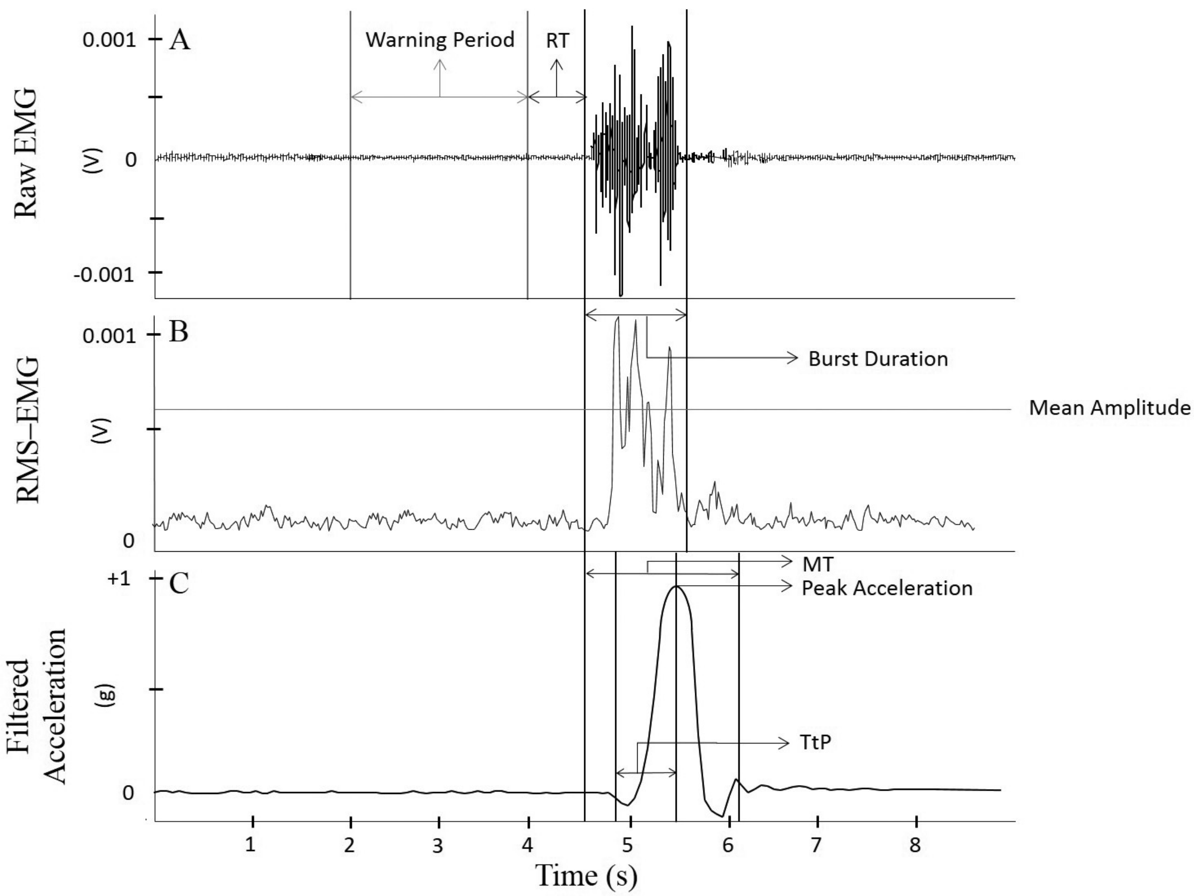

Figure 2 — (A) Raw and (B) processed (filtered and rectified) electromyography (EMG), and (C) acceleration traces depicting variables of interest. Reaction time (RT) is the time between the final cue and EMG onset. Burst duration is the time between the start and end of the EMG signal. Normalized EMG is given as the root-mean-squared (RMS) EMG divided by mean amplitude. Peak acceleration is the maximum amplitude of the signal along the X-axis. Time to peak (TtP) is the period between acceleration onset and the time at which its peak occurs. Movement time (MT) is the time elapsed between EMG RT and the end of acceleration.

the start and end of the EMG signal (return to baseline). Time to peak (TtP) was defined as the time taken to reach maximum acceleration; it was calculated as the period between acceleration onset (calculated as ± 2 *SD* from baseline) and the time point at which maximum acceleration occurred. Movement time (MT) was defined as the total time elapsed from the start to the end of the movement, measured as the time period between EMG RT and the end of the acceleration signal, which was the time point at which the signal returned to the baseline.

Performance Production Measures. Regarding normalized EMG amplitude, by convention, the root-mean-squared (RMS) value of the EMG signal is the best representation of signal power. For the normalization of EMG data, we calculated the RMS amplitudes of each of the 14 trials and used trial-wise mean amplitudes as the normalization value, thus represented as an ensemble average for each trial. We used this mean amplitude normalization approach instead of maximum voluntary isometric contraction (MVIC) to reduce intersubject variability (Yang & Winter, 1984). Peak acceleration was defined as the maximum amplitude of the acceleration signal along the X-axis of the sensor's coordinate system. We used the X-axis because the sensor was placed relatively closer to the joint rather than the endpoint of the shaft, hence movements occurred along the sagittal axis of the sensor.

Statistical Analyses

From the 38 subjects (14 TCPs, 12 ONPs, and 12 younger adults) who volunteered to participate in this study, two TCPs and one healthy ONP were excluded from the analyses because of technical problems during data collection. Out of the remaining data (490 trials, each of flexion and abduction), 26 trials (12 trials of TCPs: 6 flexion and 6 abduction; 14 trials of ONPs: 7 flexion and 7 abduction) were excluded from the analyses due to signal contamination (noise), probably resulting from loose sensor contact.

A one-way ANOVA test was used to compare the means of ages, heights, arm lengths, and each of the six response variables for flexion and abduction reaching among the three groups, and sex was compared using a Chi-square test. Independent *t* tests were performed to compare SOMCT and PASE scores between the two older adult groups. Primary planned comparisons between the ONPs and the younger subjects (effect of aging), and the TCPs and ONPs (effect of Tai Chi) were done using the Bonferroni adjustment. Secondary post hoc analysis for comparisons between younger controls and TCPs were done using Tukey's honest significance difference (HSD). A significance level (α) of .05 was chosen for statistical comparisons. All analyses were performed using SPSS v.21 (IBM, Chicago, IL) for Windows. Effect sizes (ω^2) were computed to estimate the strength of the observed differences among the groups.

We also computed the relative effect of Tai Chi on aging, using mean values for each variable in the equation:

$$\frac{ONP - TCP}{ONP - YNP} \times 100,$$

where YNP = young nonpractitioners.

Relative effect is the effect of Tai Chi expressed as a percentage of the effect of aging for a given variable, and it was calculated for all variables.

Results

There were no significant differences in the arm lengths, heights, and the number of males to females among the three groups, as well as between the ages ($p = .737$) and the SOMCT and PASE scores of the TCP and ONP groups (Table 1).

There were significant differences in both performance outcome variables and performance production variables among the three groups. For the flexion-reaching task, there was a significant difference among the three groups for the performance outcome measures: RT ($F_{2,474} = 23.012$, $p < .001$), burst durations ($F_{2,474} = 46.556$, $p < .001$), TtP ($F_{2,474} = 35.947$, $p < .001$), and MT ($F_{2,474} = 39.567$, $p < .001$). There was a significant group effect for both the performance production measures as well: normalized EMG amplitude ($F_{2,474} = 46.690$, $p < .001$) and peak accelerations ($F_{2,474} = 62.317$, $p < .001$). A similar difference was observed for all abduction-reaching variables, including: RT ($F_{2,474} = 10.931$, $p < .001$), burst durations ($F_{2,474} = 34.210$, $p < .001$), TtP ($F_{2,474} = 8.686$, $p < .001$), MT ($F_{2,474} = 6.864$, $p < .01$), normalized EMG amplitudes ($F_{2,474} = 73.080$, $p < .001$), and peak accelerations ($F_{2,474} = 58.618$, $p < .001$). Effect sizes for the differences observed among groups are also reported (Table 2).

Planned between-group comparisons revealed that younger subjects and TCPs had significantly better performance outcome measures (faster RT, smaller burst durations, shorter TtP acceleration, and overall quicker MT) and performance production measures (larger EMG amplitudes and peak accelerations) than ONPs for flexion and abduction reaching tasks (younger: $p < .001$, except abduction MT, where $p = .002$; Tai Chi: $p < .05$). Secondary comparisons revealed that there was no significant difference in performance outcome measures of abduction

Table 1 Demographics, Cognitive Ability, and Physical Activity Scores for Older Tai Chi Practitioners, Older Nonpractitioners, and Healthy Young Adults

	Tai Chi Practitioners (*n* = 12)	Older Control Subjects (*n* = 11)	Young Control Subjects (*n* = 12)	*P*-value
Age (years)	67.75 ± 7.57	65.82 ± 6.34	23.58 ± 4.19†**	< .001
Height (cm)	168.06 ± 8.65	172.72 ± 10.10	165.52 ± 7.72	.160
Arm length (in.)	28.29 ± 2.12	29.50 ± 1.09	28.02 ± 1.61	.098
Sex (F/M)	8/4	6/5	9/3	.585
SOMCT	1.58 ± 0.99	1.09 ± 1.38	—	.334
PASE	173.82 ± 70.64	143.79 ± 73.78	—	.330

Abbreviations: SOMCT = Short Orientation Memory Concentration Test; PASE = Physical Activity Scale for the Elderly.

Note. Values are mean ± 1 *SD*.

†** Denotes significant difference at $P < .001$ between young controls and both older adult groups using complex contrast comparison.

Table 2 Performance Outcome and Performance Production Measures for Flexion and Abduction Stand-Reaching Tasks in Older Tai Chi Practitioners, Older Nonpractitioners, and Healthy Young Adults

Measures	Tai Chi Practitioners (*n* = 12)	Older Control Subjects (*n* = 11)	Young Control Subjects (*n* = 12)	Effect Size (ω^2)
FLEXION				
Performance outcome				
RT (ms)	495.43 ± 55.69	518.22 ± 90.97†*	465.88 ± 57.71‡**	0.084
Burst duration (ms)	880.83 ± 172.75	983.68 ± 208.21†**	810.34 ± 79.74‡**	0.161
TtP (ms)	756.93 ± 251.49	851.96 ± 270.71†*	603.78 ± 269.71‡**	0.128
MT (ms)	1,299.70 ± 235.64	1,432.63 ± 220.91†**	1,214.25 ± 198.71‡**	0.139
Performance production				
Normalized EMG amplitude (units)	1.34 ± 0.15	1.28 ± 0.10†*	1.44 ± 0.17‡**	0.136
Peak acceleration (*g*)	0.837 ± 0.097	0.812 ± 0.068†*	0.907 ± 0.070‡**	0.205
ABDUCTION				
Performance outcome				
RT (ms)	506.03 ± 84.90	547.28 ± 126.04†*	497.67 ± 85.14‡**	0.040
Burst duration (ms)	771.98 ± 164.49	898.82 ± 189.66†**	777.66 ± 86.17‡**	0.122
TtP (ms)	662.92 ± 305.67	740.45 ± 363.07†*	593.62 ± 300.08‡**	0.031
MT (ms)	1,282.11 ± 243.38	1,354.71 ± 205.95†*	1,268.66 ± 203.13‡*	0.024
Performance production				
Normalized EMG amplitude (units)	1.30 ± 0.12	1.25 ± 0.10†*	1.44 ± 0.20‡**	0.232
Peak acceleration (*g*)	0.874 ± 0.121	0.820 ± 0.087†**	0.932 ± 0.075‡**	0.182

Abbreviations: RT = reaction time; TtP = time to peak; MT = movement time; EMG = electromyography.

Note. Values are mean ± 1 *SD*. Effect sizes: small effect = 0.01–0.059; medium effect = 0.06–0.139; large effect = ≥ 0.14.

†* Denotes that difference between Tai Chi practitioners and older controls is significant at $P < .05$.

†** Denotes that difference between Tai Chi practitioners and older controls is significant at $P < .001$.

‡* Denotes that difference between younger and older nonpracticing controls is significant at $P < .05$.

‡** Denotes that difference between younger and older nonpracticing controls is significant at $P < .001$.

reaching between TCPs and younger controls (p-values: RT = .724, burst durations = .937, TtP = .330, and MT = .841); however, younger controls performed significantly better on all other variables ($p \leq .001$).

Relative effect was greatest for abduction reaching; values ranged from 26.31% for normalized EMG amplitude to 104.69% for burst duration. Values ranged from 26.31% (peak acceleration) to 60.87% (MT) for the flexion-reaching task. For both tasks, relative effect was greater for performance outcome measures than performance production measures. Specific p-values from primary comparisons between TCPs and ONPs, as well as relative effect computations, are displayed in Figure 3.

Discussion

The results from this study suggest that younger nonpracticing subjects and TCPs exhibited greater movement control than ONPs, demonstrated by significantly better performance outcome measures and performance production measures. More importantly, taking the methodology of this study into consideration, these group differences were particularly noted on a relatively challenging, multiplanar stand-reaching task.

The reaching task used in this study is unique in that it evokes the various processes involved in sagittal and lateral plane stand-reaching in a more functional and challenging yet sufficiently controlled manner. It is known that fast reaching movements of the arm and postural stability tend to be complexly related to each other. Movements of the trunk that occur during reaching cause disturbances in hand trajectories, which are minimized by feed-forward control (Bortolami, Pigeon, DiZio, & Lackner, 2008; Pigeon, Bortolami, DiZio, & Lackner, 2003) that executes a synergy to coordinate trunk and arm segments (Ma & Feldman, 1995). Conversely, arm reaching movement in itself causes postural perturbations due to reaction joint torques and changes in body configuration, which are corrected for by anticipatory postural adjustments before the execution of movement (Massion, 1992). This complexity arising from the added postural component of a stand-reaching task forms a major consideration for development of a motor plan when executing a reach.

Effect of Aging

ONPs had a significantly greater degree of deterioration in all outcome variables compared with younger controls. These findings are in accordance with previous studies (e.g., Inglin & Woollacott, 1988) regarding delayed RT of prime movers during fast, forward arm reaching. Moreover, this delay in RT also holds true for lateral or abduction reaching; this is an original finding in our study. This delay may be attributed to the several age-related changes in voluntary movement control as well as anticipatory adjustments. In addition, we observed that burst duration and total MT increased significantly with respect to young adults for both reaching tasks.

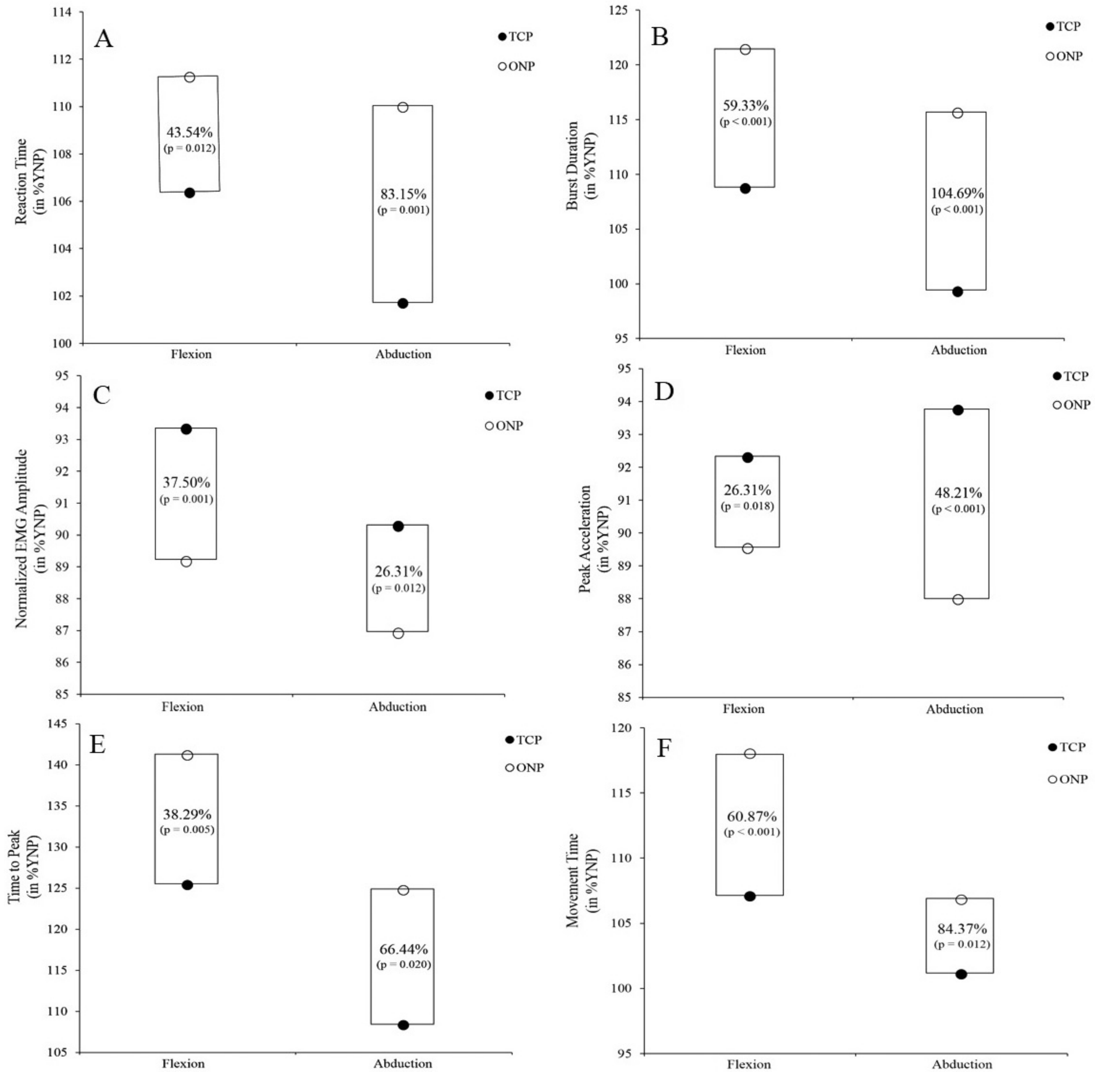

Figure 3 — Relative effects of Tai Chi on aging for (A) reaction time; (B) burst duration; (C) normalized electromyography (EMG) amplitude; (D) peak acceleration; (E) time to peak; and (F) movement time for each reaching task. Relative effect was computed using the formula: *(ONP – TCP) / (ONP – YNP)* × 100, displayed as a box between open and closed markers representing older nonpractitioners (ONP) and Tai Chi practitioners (TCP), respectively. The Y-axis represents values for a given variable expressed as a percentage of young nonpracticing (YNP) controls.

Longer burst durations may be attributed to fatigue caused by eccentric contraction of prime movers that can delay the motor component of RT (consisting of the burst duration period) (Miles, Ives, & Vincent, 1997) or the reduced ability of older adults to produce optimal levels of neuromuscular activation.

Within this premise, Freund and Büdingen (1978) described an inverse relationship between amplitude and duration of activation. In addition to longer burst durations, older adults also exhibited smaller EMG amplitudes, further justifying this supposition. There was also a significant decrease in peak acceleration and an increase in the TtP in ONPs compared with young subjects, similar to past reports (Goggin & Meeuwsen, 1992; Ketcham et al., 2002). Whereas it might be intuitive that the inadequate activation of prime movers can bear consequences on the kinematics of the motor task, the findings from this study provide more evidence of this link between performance production measures and kinematic measures.

Effect of Tai Chi

TCPs performed significantly better than their ONP counterparts on both flexion- and abduction-reaching tasks. Our findings of significantly faster RT and quicker overall MT contrasts those reported by previous Tai Chi studies (Kwok et al., 2010; Yan, 1998) that employed a simple RT paradigm on a seated reaching task; however, they conform to the findings from other studies that employed either multiple targets or a choice paradigm (Pei et al., 2008; Tsang et al., 2013). One plausible explanation for such disparity might be the effect of task complexity. Multiple target-reaching, choice-reaction paradigms and stand-reaching tasks are comparatively more challenging than the simple seated reaction-time task in terms of attentional resources required and/or postural demands, both of which deteriorate with aging (Brown, Shumway-Cook, & Woollacott, 1999).

Tai Chi practice involves whole-body movements, including multiplanar movements of the arms within the balance constraints arising from standing. This may, over the course of long-term training, lead to the gradual priming of the motor system in these individuals. It also has a distinct 'mind' component, which has been stipulated to influence cognitive processes (Lu, Siu, Fu, Hui-Chan, & Tsang, 2013; Wolf et al., 2003) leading to better allocation of attentional resources. Therefore, while the effects of Tai Chi could not be differentiated on a seated, reaction-time task (Kwok et al., 2010) due to relative simplicity, the stand-reaching paradigm could have employed complex processes of the motor system. As stated previously, stand-reaching requires intricately well-timed motor programming to resolve interferences between control of posture and control of voluntary arm movements, as well as optimal utilization of neuromuscular reserves. It might therefore be possible that Tai Chi practice could promote the optimal utilization of shared reserves (between postural muscle and prime mover activation) during such a complex task performance. Hence, Tai Chi not only enables practitioners to maintain standing balance and postural control, but, at the same time, display efficient control of arm movements with relative ease compared with ONPs.

TCPs also displayed larger EMG amplitudes and shorter burst durations. This could be attributed to underlying improvements in arm muscle conditioning (strength and endurance). Tai Chi practice involves sustained and coordinated use of an antigravity posture, especially involving arm movement in the diagonal plane with an occasional rotatory component (Wolf et al., 1997). This pattern of movement necessitates activation of shoulder musculature, including the anterior and middle deltoid, leading to gradual improvements in the strength and endurance of these muscles. This benefit has been previously recognized in the case of lower limb musculature where Tai Chi practice was shown to improve knee muscle strength and endurance (Lan, Lai, Chen, & Wong, 2000). Thus Tai Chi may not only lead to better balance, posture, and muscle conditioning of the lower extremities, but to that of the upper extremities as well, translating into better overall reaching function.

Clinical Implications

The results of this study provide proof of concept for the use of Tai Chi as an intervention for arm reaching during standing and can have many clinical implications pertaining to its use in older adults. Relative-effect computations and effect sizes provide estimates of the practical use of Tai Chi as a rehabilitation tool in this study. Relative effects, expressed as the standardized percent change between aging individuals and TCPs, also help in redirecting the focus from primary group comparisons to specific trends observed in each reaching direction and the two classes of variables (performance outcome and performance production). Considerable amounts of improvement in both flexion (~20–60%) and abduction (~20–100%) reaching are seen in TCPs compared with nonpracticing counterparts. Overall, greater relative change was observed in the performance outcome measures (ranging from 38.29–104.69%) than in the performance production measures (ranging from 26.31–48.21%), suggesting that these effects tended to concentrate on the timing of movement rather than amplitude. This finding is particularly noteworthy because the temporal characteristics of the response, in this case of the prime mover, results only *after* the proper execution of the motor plan preceding it as opposed to *during* the execution of the movement itself, and thus is indicative of the action preparation phase of the movement. This further reinforces the notion that Tai Chi practitioners might be able to optimize the use of neuromuscular reserves shared during the preparatory stage of movement leading to quicker activation latency of the prime mover.

It is postulated that Tai Chi practice could significantly increase neuromuscular reserves for complex tasks, which is indicated also by the close approximation of performances between older TCPs and young adults, especially on the abduction-reaching task. Exercise-induced improvements in neuromuscular activation and strength have been addressed repeatedly in the literature (Andersen et al., 2006), but what gives prominence to the use of Tai Chi instead of general strength training is its low intensity, making it especially appealing to older adults. In addition, Tai Chi has been identified as the most effective group-based exercise (Gillespie et al., 2003), further endorsing its use. Finally, it should be noted that the outcomes reported in this study are indirect markers of motor control; that Tai Chi can be used to improve voluntary limb movement control encourages its application in the aging population and beyond.

Conclusion

Both performance outcome measures as well as performance production measures showed considerable deterioration with age. Tai Chi practitioners displayed better arm movement control than older nonpractitioners on a relatively challenging and functional stand-reaching task for both forward and lateral reaching.

Future studies should systematically examine the benefits of Tai Chi intervention on posturally-demanding functional tasks.

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