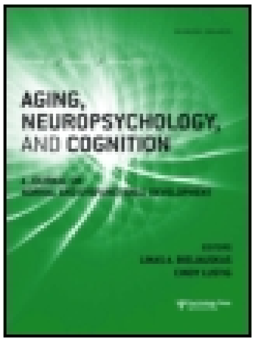

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No panacea? Tai Chi enhances motoric but not executive functioning in a normal aging population

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ABSTRACT

Tai Chi Chuan (TCC) is a promising intervention against age-related decline. Though previous studies have shown benefits in motoric and cognitive domains, it is unclear how these effects are functionally related. Therefore, a randomized controlled trial was conducted in an aging population (53–85). Two measures of motor functioning – motor speed and functional balance – and three cognitive control measures – shifting, updating and inhibition – were included. The TCC condition consisted of an online 10 week 20 lessons video program of increasing level and control condition of educational videos of similar length and frequency. All analyses were done with Bayesian statistics. Counter to expectation no differences were found in cognition between TCC and control pre-to-posttest. However, there was extreme evidence for TCC benefits on functional balance and moderate evidence for increased motoric speed. After weighing the evidence and limitations of the intervention we conclude that TCC does not enhance cognitive control.

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Aging; cognitive control; mobility; motor functioning; physical exercise

Aging is affecting societies worldwide. The average life expectancy at birth has increased by 6.2 years from 1990 to 2013 (Murray et al., 2015): in the following decades it is expected that the world population of people aged 65 and over will have more than doubled (He et al., 2016). One of the phenomena related to aging is individual functional decline, both in a physical and a cognitive sense, which has negative consequences both for the individual and society as a whole. Pathological aging conditions such as Alzheimer's disease are a large individual and societal burden. But even normal age-related cognitive decline and loss of mobility have far reaching consequences, such as on quality of life, which has received increasing attention (Hoang et al., 2020). In the current study, it is tested whether older adults performing a series of 20 Tai Chi Chuan exercise sessions improve their control of motor and cognition function relative to a control condition.

1.1. Aging, cognition & motor function

For some cognitive functions, decline already starts around the age of thirty (Salthouse, 2009), such as for cognitive control or executive functions (EF). EF is a broad construct that

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covers various cognitive functions to monitor and regulate thought, emotion and (automatic) behavior. It is generally divided into three functional components (Miyake & Friedman, 2012; Miyake et al., 2000). *Shifting* refers to the switching between mental sets or task rules, *updating* refers to the monitoring and refreshing of working memory representations according to contextual demands, and *inhibition* refers to inhibitory control of irrelevant information or unwanted actions (response inhibition).

Various accounts explain age-related decline by general resource limitations, such as decreased processing speed Salthouse (1996, 2000)), decreased perfusion and blood flow (Spiro & Brady, 2011), and recruitment of other brain areas (Li et al., 2001; Cabeza, 2001; Davis et al., 2008). These factors affect not only cognitive, but also motor functions. As a result, shared resource accounts predict interdependence between cognitive and motoric performance. Reduced mobility is a common issue in aging populations (Tang & Woollacott, 1996) and with it comes an associated risk of injuring falls (Ambrose et al., 2013). An important risk factor for loss of mobility and falling is dysfunctional balance and gait (Deandrea et al., 2010).

An important finding is that motoric and cognitive decline indeed have a bi-directional relationship (Montero-Odasso et al., 2017; Montero-Odasso et al., 2014). EF and attention play a critical role in the production of gait (Amboni et al., 2013; Holtzer et al., 2006; Yogev-Seligmann et al., 2008) and vice versa (Hausdorff & Buchman, 2013). This mutual dependence fits with shared resource accounts. In a review by Seidler et al. (2010) it is consistently shown that older people recruit EF more during motor tasks (e.g., walking tasks) than do young people. The entanglement of EF and motor functioning in aging leads to an interesting conjecture: enhancing cognition might have the added benefit of improving mobility and thus reduce falls. But perhaps cognition itself might also be improved indirectly by training functional balance (Montero-Odasso et al., 2014). Any physical exercise intervention aiming at increased vitality would therefore be well advised to include functional balance.

1.2. Enhancement: buffering age-related decline

As it turns out, prospects for aging are indeed not all bleak: many lifestyle interventions provide a buffer against decline or even improve physical and cognitive functioning (see for a review Ballesteros et al., 2015). Tai chi chuan (TCC), a traditional Chinese contemplative practice, is such a promising practice (Larkey et al., 2009). It combines exercises in balance, slow, complex movement sequences, with breathing, concentration and relaxation techniques. TCC has low physical demands and is a low to mild intensity aerobic exercise (Taylor-Piliae & Froelicher, 2004). As TCC is usually accompanied by and highly similar to qi gong exercises, these terms are used interchangeably in the scientific literature, and we know of no studies showing differential effects, we will refer to them both under the common denominator of TCC (Larkey et al., 2009). As TCC has both a meditative aspect and a physical exercise component, it can be counted among the mind-body exercises. Both physical exercise and meditation have shown to enhance EF and ameliorate age-related cognitive decline.

Many studies provide evidence that physical exercise of different kinds – aerobic, endurance and motor coordination training – strongly enhances cognitive control and that effects of aging on brain and cognition can be reduced or slowed down by aerobic exercise (Berryman et al., 2014; Colcombe & Kramer, 2003; Kramer et al., 2006; Smith et al., 2011; Tse et al., 2015; Voss et al., 2013). Coordination training has shown similar effects on cognition in aging, across the three components, as has aerobic exercise (Tsai et al., 2017; Voelcker-Rehage et al., 2011; Voelcker-Rehage & Niemann, 2013). It might also be the case that different forms of exercise have specific effects on specific components, for example, aerobic fitness is related to inhibitory control (Boucard et al., 2012). In a comparison between training regimens, Tsai et al. (2017) showed that shifting benefited more from coordination exercise, and updating more from endurance exercise. TCC combines all three types of exercise: aerobic, endurance and coordination. Consistent enhancement of EF across components fits with common factor accounts of aging such as the vascular hypothesis (Spiro & Brady, 2011). Indeed, exercise intervention studies have shown that exercise leads to increases in growth factor responsible for angiogenesis, neurogenesis and synaptic growth (Cotman et al., 2007; Vonderwalde & Kovacs-Litman, 2018).

Meditation, another feature of TCC, has been shown to act as a buffer against EF and working memory decline (Gard et al., 2013; Zeidan et al., 2010). Furthermore, meditation might even slow the frontal cortex atrophy in aging (Lazar et al., 2005) and increase gray matter density in other brain areas, notably the hippocampus, after meditation interventions (Chiesa & Serretti, 2010; Hölzel et al., 2011). A recent review indicated that all three EF components are enhanced by mindfulness meditation but that inhibition benefited most consistently (Gallant, 2016). According to a recent model – the respiratory vagal nerve stimulation model (rVNS) – a way these practices are able to produce these effects is through system relaxation and stress relief (Gerritsen & Band, 2018), tentatively driven by breathing regulation. TCC, especially qi gong exercises therein, prescribes highly similar breathing exercises both in motion and in meditative stance, as discussed by these authors.

In conclusion: TCC practices, especially those including multiple forms of physical exercise (e.g., aerobic and endurance training), together with meditation and breathing techniques, are expected to lead to enhanced cognition and to combat age-relate decline. The types of exercise combined in TCC also seem ideally suited for enhancement; as it is a combination of open coordination exercises, strength and endurance training with a low to mild aerobic aspect. Furthermore, there are indications that multi-modal interventions are better suited to protect or enhance EF than any single intervention, showing additive effects (Burgener et al., 2009). Indeed, prior studies on TCC seem to confirm its potential as a cognitive enhancer. However, a Cochrane review of studies in aging populations with dementia (Forbes et al., 2015), could not find evidence for enhancement of cognitive functioning by various exercise programs including TCC, though activities of daily living did show improvement. In normal (aging) populations TCC enhances EF and working memory or acts as a buffer against EF and working memory decline (Chang et al., 2014; Laird et al., 2018; Wu et al., 2013; Zheng et al., 2015) and this is reflected in their neural substrates (Hawkes et al., 2014). TCC even seems to have a larger effect on cognition than just physical exercise, as expected from its multi-modal design (Wayne et al., 2014). It is less clear whether EF components are equally affected, as a controlled study including all three factors is absent.

Perhaps less surprising: functional mobility is also enhanced by TCC practice. Several studies and reviews demonstrate the value of TCC in increasing functional mobility (Rogers et al., 2009; Sun et al., 2015; Voukelatos et al., 2007; Yeh et al., 2006). According to a meta-review by the Cochrane Collaboration, TCC reduces the risk of falling (Gillespie et al., 2012). Specifically, TCC has been shown to lead to greater muscle strength (Chen et al., 2012; Lu, Hui-Chan et al., 2013; Li et al., 2009) and dynamic balance (Wong et al., 2011, 2001). Long term practitioners have better postural control than matched controls (Lu, Siu, et al., 2013). There are also indications that TCC practitioners have a generally higher motor speed (Tsang et al., 2013). These results might not be surprising given the physical exercise component in TCC and the specific exercises aimed at balance and strengthening the lower body. However, it is still unclear whether EF and mobility enhancement by TCC are functionally related, as we would expect from shared resource accounts and findings of their bi-directional influence.

1.3. Current study

A systematic comparison between EF components and motor functioning was performed within a randomized controlled design in an aging population. The aim was to 1) replicate findings on motor and cognitive enhancement by TCC 2) study whether potential positive effects on physical and cognitive functioning are related 3) fit these patterns with common factor or shared resource accounts of aging. This leads us to the following questions: does TCC practice enhance any of the EF subtypes: shifting, updating and inhibition, in aging populations? Does shifting, updating or (response) inhibition, as measured by the task-switching task (switch costs), 2-back (sensitivity) or stop-signal task (stop-signal reaction time), respectively, improve more from pretest to posttest in a TCC than in a control condition? Does TCC enhance functional mobility, as measured by the Timed Up and Go test (TUG), or motor speed, as measured by the finger-tapping task (FTT)? If so, is EF a modulator of this effect, or vice versa?

Our expectation is that functional balance will be improved for the TCC group, as seen in a greater improvement in TUG-time. We also expect general motor speed will be enhanced, as seen in a greater increase in finger taps. Based on both common factor and shared resource accounts we expect all three EF components to be enhanced. Furthermore, we expect EF enhancement to be a moderator of improvement in TUG scores: individuals showing EF enhancement will improve more in motoric functions, as predicted from a compensatory perspective. In contrast we expect EF to be modulated by FTT scores, as motor speed indirectly measures processing speed, and thus the Salthouse common factor. Note that as long as the motoric effects are present these predictions also fit with a brain growth perspective of exercise efficacy. In the absence of any motoric effects – and thus perhaps physical challenge – our predictions for EF remain the same from the rVNS model, by way of stress relief through respiratory control. However, we do not control directly for any of these (additive) effects.

We will use a randomized controlled trial design to try and answer these questions. The active TCC intervention constitutes a 10 week 20 session online video program. The control condition is an online program of watching videos on health and contemplative practices of the same length, duration and frequency as the active condition. After each session participants fill in self-reports on compliance, difficulty, both physical and mental, and specific understanding of the specific practice. Pre- and post-measures are taken in the lab.

2. Materials and methods

2.1. Participants

Participants were recruited by flyers posted at locations frequented by the target population, such as community centers and libraries; through advertisements in local and regional media; and by e-mail to local organizations focused on elderly interests. Participants were required to be 50 and over, have normal or corrected-to-normal vision and no history of severe psychiatric or neurological disorders. The screening was done by e-mail, phone or face-to-face meeting. In total, 55 applicants were recruited and randomly assigned to either the intervention group (TCC) or the active control group (health education). Five participants dropped-out due to personal reasons, two because of an unrelated injury and one due to an unreported disability (in visual acuity). Three participants dropped out while reporting the intervention as cause: two in the TCC group, one of which was unable to follow the instructions and the other got agitated by the tone of instruction; the drop-out in the control condition reported a disbelief in its efficacy. The program was completed by 20 participants in the TCC group and 24 participants in the control group. Preliminary analysis led to the exclusion of one participant from the control group because of a low score (22 out of 30) on the MMSE, leaving 23 participants in the control group. See Table 1 for descriptive statistics on both groups. This study has been approved by the ethics committee of the Leiden University institute of psychology. All participants gave informed consent prior to participation and were debriefed afterward. Before enrollment they also signed a medical declaration confirming their general, neurological and cardiopulmonary health; and intact functional mobility. Participants were intrinsically motivated to participate and received no compensation for their participation. Similar expectations on health and cognitive benefits were induced in both groups by similar phrasing.

2.2. Procedure

2.2.1. Testing

After screening, participants were enrolled in the randomized controlled trial. Pre- and posttests were performed in psychology labs. The interventions were followed at home

Table 1. Descriptive means ± SD of both intervention groups (TCC/Control). Bayesian factor (BF_{10}) is shown for independent t-tests. M = Male; F = Female; MMSE = Mini-Mental State Examination; STAI-T = State-Trait Anxiety Test – Trait; IPAQ = International Physical Activity Questionnaire; MET-min = Metabolic Equivalents of Task minutes per week; ContAct = Contemplative Activities.

	Group		
Measures	TCC	Control	BF_{10}
Sample Size	20	23	
Sex (M/F)	11/9	12/11	
Age range	56–81	53–85	
Age	63.95 ± 7.25	63.17 ± 7.73	0.32
Education level	4.55 ± 1.47	4.74 ± 1.05	0.33
MMSE	29.45 ± 0.89	29.17 ± 1.15	0.41
STAI-T	35.90 ± 7.09	36.96 ± 8.08	0.32
IPAQ (MET-min)	3581.1 ± 3038.1	4481.2 ± 4197.7	0.39
ContAct level	0.65 ± 1.39	0.65 ± 1.15	0.30

and online. At pretest participants were informed of the procedure and asked to sign the informed consent form and the medical declaration. Next, participants had to fill out a questionnaire inquiring about demographics, and current and previous experience with contemplative practice and frequency of practice (e.g., meditation, yoga). Furthermore, the International Physical Activity Questionnaire (IPAQ, Craig et al., 2003), the Mini-Mental State Examination (MMSE, Folstein et al., 1975) and the State-Trait Anxiety Inventory (STAI, Laux et al., 1981) were presented. The MMSE was taken verbally and the rest of the questionnaires on the computer (Qualtrics). Next, a One Legged Standing Test with open eyes (OLST, Ekdahl et al., 1989) and a Time-to-get-Up-and-Go test (TUG, Mathias et al., 1986) were conducted to test functional balance. Lastly, the FTT and three cognitive tasks and were performed on the computer: the task-switching task, N-back, and stop-signal task. All cognitive tasks were presented on a computer screen, which was at 70 cm distance from the participant, in a quiet lab-space without distractions. At posttest appointment STAI-T, OLST, TUG and the cognitive tasks were performed again. However, by error of omission of one of the experimenters only half the sample retook the STAI-T and the OLST at both measurement points, resulting in insufficient statistical power for repeated measures comparison. After the posttest participants were debriefed: they were informed to which group they were assigned, and the complete goal of the study and expected results were explained. The pretest lasted approximately 2.5 hours and the posttest approximately 1.75 hours.

2.2.2. Intervention

Both TCC and control group followed a home-based online video program over the course of 10 weeks, that consisted of 20 sessions of about 45 minutes each – so 2 sessions or 90 minutes per week. The TCC intervention was designed and guided on screen by a licensed instructor of the Dutch Academy for Taijiquan and Qigong, who employed more than 30 years of experience in TCC to this project. Videos were recorded at a martial arts training center in Oegstgeest, the Netherlands. The lessons consisted of beginner level TCC principles and techniques in adapted Yang style (Zheng Man Qing form) and Dao Yin Qi Gong techniques (Ma Wang Dui form), which acted as a recurring warm-up. Every session built on previous lessons and scaled in difficulty. At the end of the course practitioners were expected to know and be able to move independently through half of the Zheng Man Qing short form, which has 37 movements in total. The Qi Gong warm-up consists of exercises combining endurance training with stretching, muscle relaxation and breathing techniques – inhaling and exhaling synced with movement – all these aspects recurred in the TCC instructions as well. The edited videos were made available as Youtube videos with restricted access. The control group watched health educational videos on public online broadcast for the same amount of time in total per week (~1:30 hours). These were obtained from the open access Dutch public broadcast network on www.npo.nl. Per session there could be 1–2 different programs ranging from 30–60 minutes per session. The subjects of educational video's matched themes and aims of the TCC interventions, for example: interviews with health professionals on life-style and healthy aging or a documentary on the mental benefits of meditation. There was no particular order of programming and thus in scaling of sessions, but this was held constant for each participant in the control group.

Once per week, participants individually received an e-mail reminding them of their participation and asked to either follow the next two lessons (TCC) or watch two educational programs (control). They were instructed to follow these lessons a few days apart and were urged to watch and participate with their full attention, to the best of their abilities, without forcing anything. Participants in the TCC condition were expected to stand in front of their computer, in a quiet room and follow the instructions, imitating the movements of the trainer.

2.2.3. Session questionnaires

At the end of each session participants were required to fill out online questionnaires. These questionnaires inquired about self-assessed performance and the main aim was to check for compliance and to assess the difficulty curve. Two questionnaires were designed: for TCC and for control. The questionnaires were identical after each session. For the TCC group this included questions about difficulty, attention and alertness, breathing, mindfulness/meditation, physical strain, balance and TCC principles. The questionnaire for the control group was designed to test general understanding and investment to a similar degree, albeit not oriented toward the specific television episode. These queried on the interest in the topic, its difficulty, attention and alertness, physical arousal and whether they learned something or were going to apply anything from the video into their own lives. Adherence to the video session was assumed when the questionnaire was filled in.

2.3. Measurements

2.3.1. Questionnaires

2.3.1.1. Demographics. An online Qualtrics questionnaire was designed to assess the demographics: sex, age and level of education. Education level was remapped to a scale from 1–6.

2.3.1.2. MMSE. The MMSE (Folstein et al., 1975) is a questionnaire designed to measure clinical cognitive functioning. The MMSE was taken on paper; the continuous value (max. 30) was obtained and compared to the cutoff point to indicate mild cognitive impairment (<27, O'Caoimh et al., 2016) or dementia (<23, Kochhann et al., 2010). It was also used to compare pre-intervention differences in cognitive functioning between groups.

2.3.1.3. STAI-T. STAI-T (Spielberger et al., 1983) was administered to map baseline levels in trait anxiety and used to check differences between the intervention groups at pretest. The STAI-T consists of 20 statements each of which can be likened to how participants generally feel on a 4-point Likert scale. These add up to a to a single trait anxiety score ranging from 4 to 80.

2.3.1.4. IPAQ. Current physical activity was assessed by the IPAQ questionnaire (Craig et al., 2003). The IPAQ short form contains questions about walking, moderate and vigorous activities, as well as questions addressing time spent sitting down. It allows for calculating a continuous score of metabolic equivalents of task minutes per week (MET-min), whereby participants can be divided into three main levels of physical activity: low, moderate, and high. To obtain MET-min, answers are weighed according to the intensity and duration of the activity: low intensity = 3.3 x minutes x days per week; average intensity = 4.0 x minutes x days per week; and vigorous intensity = 8.0 x minutes x days per week. The METs per week are added up and can be compared to cutoff points for three different categories of activity: low, average and high.

2.3.1.5. Contemplative activities. Current contemplative activity was assessed by an online questionnaire at the end of the demographic questionnaire (Qualtrics). Two categories were distinguished in the questionnaire: *meditation & mindfulness* and *mind-body exercises* (yoga, qi gong, TCC). Participants answered whether they currently practiced and if so they reported frequency of practice: *every day, 2–6 times a week, once a week, 1–2 times a month, 5–10 times a year, 1–4 times a year*. Since all provided answers were either: *never, 1–2 times a month, once a week* or *2–6 times a week*, the values 0–3 were attached to these answers in corresponding order. The sum of the two scores represents the current level of contemplative activity and ranges from 0–6. If participant reported that they were not currently practicing in either category, a question inquired about their previous practice using the same frequency scale as above. As none of the participants reported previous practice these were left out of analysis.

2.3.1.6. Session self-report. After each session a self-report questionnaire was presented in both groups. This online questionnaire, administered through Qualtrics, had a number of statements, 26 for TCC and 18 for control, about the previous session, with responses on a 5-point Likert-scale ("not at all" – "very much so"). These self-report scores provide insight into the degree of difficulty participants experienced while following the TCC or the control group program. The TCC group self-report questionnaire consisted of 26 questions that address topics that pertain to the previous session, like comprehension of instructions, relaxation, attention, breathing, physical capability, and pain. The control group self-report questionnaire consisted of 14 questions addressing topics like comprehension of the video, attention while watching, breathing and interest in the subject of the session. The two questionnaires contained questions specific to the condition and questions that were constant in both questionnaires, such as on relaxation and attention. Though the self-reports were mainly created to check and nudge compliance, these could also be used to extract scores on factors such as effort, attention and motivation; and to follow progression through the sessions. After unexpected null-results in the cognitive domain on all predicted EF components this was done in the TCC group as a manipulation check on the level of challenge and physical exertion. Five scores ranging from 1 to 5 were obtained. For challenge: ease and effort; for physical exertion: aerobic quality, heart rate and muscle ache. See appendix for questions and scoring.

2.3.2. Motor function tasks

2.3.2.1. One-legged standing test. OLST was performed by participants in order to assess standing balance (Ekdahl et al., 1989). However, erroneously only half the sample performed the OLST pretest and posttest, where the other half did neither. Therefore, the OLST was left out of all analyses.

2.3.2.2 Timed up and go task. The TUG (Mathias et al., 1986) was used to assess gait speed and functional balance. A chair is placed facing a wall at a distance of three meters. The participant is seated in the chair and asked to walk to the wall without touching it, walk back to the chair and return to a seated position. The experimenter counts down from 3, at which point the participant should start. Time is measured by stopwatch. Two practice rounds and three test rounds were performed. In between rounds there is no instruction toward increased speed. The final score on the TUG is the mean score of the three test rounds.

2.3.2.3 Finger tapping task. FTT (Reitan & Wolfson, 1985) was implemented in Inquisit and used to assess motor speed. Participants were asked to tap the spacebar on the keyboard with either their right or left index finger as fast as they could and as many times as they could within trials of 10s. The rest of the hand should remain immobile. Each participant received between 5 and 10 trials for the participant's dominant hand and 5 to 10 trials for the non-dominant hand. After the first five trials, if the scores of these rounds were not within 5 taps of each other, another trial was added until there were 5 trials with scores within this range. There was an upper limit of 10 trials in total. The mean of these 5 trials was the final score. In between trials there were breaks of 10s or 60s after every 3 trials. During a practice trial the experimenter monitored correct procedure.

2.3.3. Cognitive measures

2.3.3.1. Task-switching task. The shifting component (Miyake et al., 2000) was assessed by a task-switching task and implemented with Inquisit software. It measures an individual's ability to efficiently switch from one set of task rules to another, as quantified in the switch cost (Rogers & Monsell, 1995). Participants had to respond to a dyad comprised of a letter, number or symbol combination within a 2 × 2 white grid made of evenly divided squares, against a black background. The dyads were presented clockwise in one of the 4 squares. The participant was required to respond to only one stimulus of the dyad. The two stimuli of the dyad could either be a digit, letter or a symbol, but never two symbols (e.g., A7, #b, 2!). The task consisted of 3 different conditions: the letter, number and mixed condition; and set into four blocks of 120 trials each – 2 pure blocks (letter and digit) and 2 switch blocks. The order of block types was counter-balanced across subjects. In the pure blocks no switch had to be made between task rules: participants had to always respond to only one of the two stimuli, either the letter or the digit. In the digit condition, they were either required to respond by pressing "Z" with the left index finger on the keyboard if the presented digit was smaller than 5, and to respond by pressing "M" with the right index finger when the digit was greater than 5. In the letter condition, participants had to respond by pressing "Z" when the presented stimulus was a lowercase letter, and to respond with "M" when the stimulus was a capital letter, using either the left or right index finger respectively. This was not counterbalanced for the purpose of online distribution. In the two switch blocks the participants had to switch between these rules (and thus the target stimulus), when the dyads alternated down or up. They were required to respond to the digit when stimuli were presented in the top two squares, and to the letter when presented in the bottom two squares. Trials could be either congruent (both the target and distractor stimulus signaling the same response), incongruent (both stimuli signaling different responses) or neutral (the distractor being a symbol that cues no response).

Switch costs in accuracy and reaction time can be either global (between pure and switch blocks) or local (between repeat and switch trials within the switch blocks). Practice rounds were included for all blocks. Participants were asked to respond as accurately and fast as possible at the start of the task, after practice rounds and in between each block.

2.3.3.2. N-back. To assess working memory performance and the updating component of cognitive control (Miyake et al., 2000) an n-back paradigm (Gevins & Cutillo, 1993) was employed (in Inquisit). In a single trial, a series of stimuli was presented on a computer screen and the participant was asked to press the spacebar on the keyboard when the stimulus shown on the screen at a given time was the same stimulus as the one 2 stimuli back (n = 2). Each trial started with a 250 ms delay, after which the stimulus was presented for 500 ms with a fixed response window of 2500 ms starting at stimulus onset, thereafter the trial finished with another 250 ms delay before the next stimulus (i.e. inter-stimulus interval = 3000 ms). There were 8 blocks of 40 trials, so a total of 320 test trials. Half of the blocks, 4 blocks of 40 trials each, consisted of a letter task, where the identity of the stimulus was to be remembered (A, E, G, M, U, X, Y,Z). The other half of the blocks concerned a location task, where the location of a blue square (6.8 cm x 6.8 cm) was to be remembered. Order of the tasks was randomized for each participant, but always stringed together (e.g., 4 position blocks followed by 4 letter blocks). In the letter task letters (4.2 cm height by 3.1 cm max. width on screen) were presented in sequence in the middle of the screen in a gray-lined square (7.5 cm x 7.5 cm). In the location task squares were shown in a 3 × 3 gray-lined matrix (each field 7.5 cm x 7.5 cm) where the middle field was used for a fixation cross only. All stimuli were presented in white against a black background. Blocks were stringed together according to task, the order of which was counterbalanced. For both forms of stimuli there were several practice rounds, where n = 1 and n = 2, with and without feedback on accuracy. Participants were asked to respond accurately, but also as fast as possible, and were given these instructions between blocks and after practice rounds. Feedback on accuracy and reaction time was provided between the test blocks, but not during. There was an opportunity for a short break in between test blocks. As an indicator of updating the sensitivity index of accuracy, d′ was obtained by subtracting the false alarm rate from the hit rate. Though the task was originally designed to function as a dual n-back with higher levels of n and both tasks concurrently, this single 2-back was chosen because an early pilot showed that higher levels were too taxing and this 2-back was challenging enough for this age bracket.

2.3.3.3. Stop-signal task. Response inhibition, which according to the horse-race model is the inhibitory force in a race between a stop and a go process (Band et al., 2003; Logan et al., 1984), was taken as a representation of the inhibition component of cognitive control. For this end, a stop-signal paradigm (Lappin & Eriksen, 1966) was implemented in E-prime to assess stop-signal reaction time (SSRT), a quantitative value of response inhibition performance. SSRT here represents an estimate of the time needed to suppress a go response (Verbruggen & Logan, 2008). Participants performed a choice RT task in 3 blocks of 35 trials each, where participants responded to a go stimulus, either an “X” or an “O”, presented in black over a white background on the computer screen, by pressing the corresponding button, either “C” or “N”, on the keyboard (counterbalanced across subjects). In 25% of the trials the target stimulus was followed by a stop signal, an auditory tone presented through headphones, which indicated that participants had to withhold their response. The time between the go stimulus ("X" or "O") and the stop signal is defined as the stop signal delay (SSD). A staircase tracking procedure was used, which altered SSD dynamically after each trial according to whether the participant was able to inhibit the response (Verbruggen & Logan, 2008). As preliminary analyses showed that a majority of the participants had a commission rate of under 35% and thus likely waited with their responses (reaction time was relatively high on go trials as well) the nth method of obtaining SSRT was used (Ridderinkhof et al., 1999). Also the recommendations of Verbruggen et al. (2019) were used: SSRT was only calculated if commission error rates were between.25 and .75. There was one practice round, which could be repeated as many times as the participant needed to in order to understand the task. In actual testing this was never repeated more than three times.

2.4. Statistical analysis

Statistical analyses were done in JASP 0.10.2.0 for all (Bayesian) statistics (Wagenmakers et al., 2018).

Bayesian Statistics. All statistical analysis were performed with their Bayesian counterparts. The main reason being that with Bayesian statistics inferences can be made on the actual evidence load (its strength) and it does not have the weaknesses or issues associated with classical p-testing, such as multiple comparisons (Gelman & Tuerlinckx, 2000) and insufficient power (as long as the Bayesian factor is low or high enough, there is enough power). Two types of comparisons were made: every possible single model (excluding null) versus the null-model and a comparison of every possible model (excluding null) with a particular effect to every possible model without that effect taken together. Bayesian odds BF_{10} (the relative likelihood of the H_1 being true over H_0) or BF_{incl} (the relative likelihood of all the inclusive models being true over all the exclusive models) are reported respectively. The last type of comparison was only added when there were more than two factors, which results in an exponential increase in comparisons, and always targets the expected interaction effects of *time**group*. We follow Jeffreys (1961) Bayesian factor cutoff points for strength of evidence, notably: a factor of 3 or above or 1/3 or below for moderate evidence for or against H_1 (as adapted by Andraszewicz et al., 2015). When the strength of evidence falls in other categories this will be noted. R scale priors are set to 0.5 (equal prior likelihood of both hypotheses being true)

T-tests. Bayesian independent sample t-tests were used to test for group differences in age, education level, MMSE, STAI-T, IPAQ MET and contemplative practice.

Repeated-measures ANOVA. Bayesian general linear model repeated-measures ANOVA was conducted for all tasks to compare pre-intervention performance to post-intervention performance between the TCC group and the control group. Intervention *group* (TCC/control) was taken as a between-subjects factor and *time* (pretest/posttest) as a within-subjects factor in every analysis. In comparisons with more than two factors, BF_{10} is only reported for the top model and the strongest with *time*group*. The BF_{incl} of the *time**group* interactions is then also reported (the Bayesian factor comparing all models including that effect with all models without that specific interaction effect).

3. Results

3.1. Questionnaires

3.1.1. Demographics & descriptives

Table 1 shows the demographic means of the sample. Bayesian independent samples t-tests were performed to test for average group differences between TCC and control for: *age* [BF_{10} = 0.32, error % = 0.02]; *education level* [BF_{10} = 0.33, error % = 0.02]; *MMSE score* [BF_{10} = 0.41, error % = 0.02]; *STAI-T score* [BF_{10} = 0.33, error % = 0.02]; *IPAQ MET-min* [BF_{10} = 0.39, error % = 0.02]; and *contemplative activity level* [BF_{10} = 0.30, error % = 0.02]. There was no evidence for difference between any of the means. However, strength of evidence varied: whereas *age, education level, STAI-T score* and *contemplative activity level* all indicated moderate evidence against a difference in means, *MMSE score* and *IPAQ MET-min* showed only anecdotal evidence against a difference in means.

3.1.2. Session self-report

In terms of the level of *Challenge* in the TCC group, the reported *Ease* of exercises and instructions over all sessions was M: 3.51 (SD: 0.25). Reported overall put-in *Effort* was M: 3.79 (SD: 0.11). The *Physical Exertion* level was assessed by *Aerobic* aspect M: 1.64 (SD: 0.15), higher *Heart Rate* M: 1.64 (SD: 0.15) and expectation of *Muscle Ache* M: 1.14 (SD: 0.08). As far as *Adherence* is concerned: all questionnaires were filled out for each participant and each session.

3.2 Motor function

3.2.1 TUG

Figure 1 shows the TUG scores pre- to posttest for TCC and control conditions. Bayesian repeated-measures ANOVA [*time*(2)**group*(2)] resulted in a BF_{10}(*time*) = 264.8, error % = 1.3; BF_{10}(*group*) = 0.6, error % = 0.6; BF10(*time+group*) = 153.3, error % = 1.7; and BF_{10}(*time+group+time*group*) = 713.5, error % = 1.5. In other words: the complete model including the *time*group* interaction effect is the strongest model and 714 times more likely to be true, than null model. Any factor above 100 is in the highest category: extreme evidence for H_1 (Jeffreys, 1961). In sum: both groups decreased their TUG scores over time, where TCC scores decreased more than that of control, from pretest to posttest [*TCC*: 5.64 ± 0.91s to 4.98 ± 0.78s vs. *control*: 5.64 ± 0.97s to 5.45 ± 1.16s].

3.2.2 FTT

Figure 2 shows the FTT count averaged across hands pre- to posttest for TCC and control conditions. Bayesian repeated-measures ANOVA [*time*(2)**group*(2)] resulted in a BF_{10} (*time*) = 1.7, error % = 1.2; BF_{10}(*group*) = 0.7, error % = 8.9; BF_{10}(*time+group*) = 1.1, error % = 2.7; and BF_{10}(*time+group+time*group*) = 3.1, error % = 3.7. The complete model including interaction *time*group* is the strongest model, but is barely in the moderate evidence category. Tentatively concluding: FTT count increased more in TCC than in control, pretest to posttest, from a higher baseline level [*TCC*: 61.52 ± 8.95 to 63.78 ± 9.27 vs. *control*: 59.83 ± 9.4 7 to 59.88 ± 8.94].

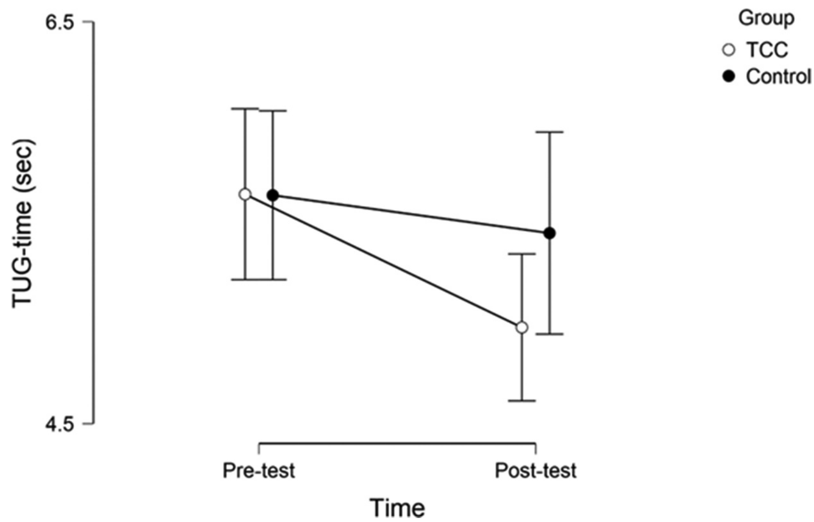

Figure 1. TUG scores for TCC and control conditions between pretest and posttest (in seconds).

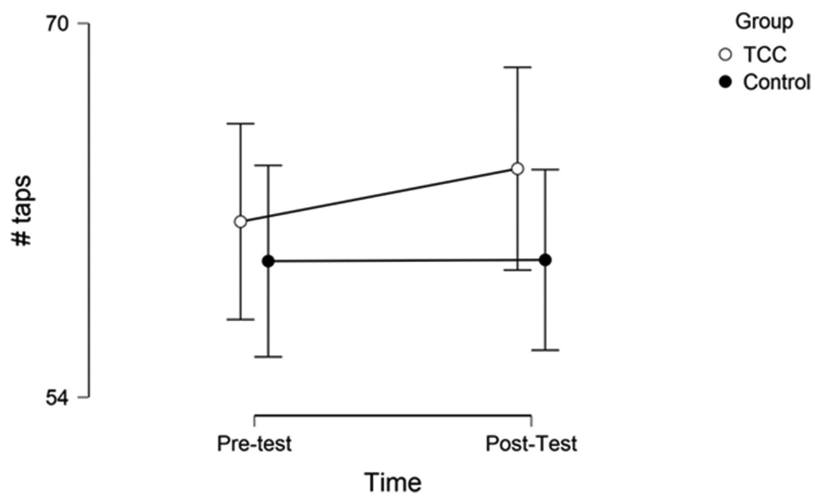

Figure 2. FTT number of taps averaged over both hands for TCC and control conditions between pretest and posttest.

3.3. Cognitive measures

3.3.1. Task-switching task

3.3.1.1. Global switching costs.

Accuracy. Bayesian repeated-measures ANOVA [*time*(2) **block*(2)**group*(2)] on accuracy means revealed the top model to be *time+block* [BF_{10} = 16.5, error % = 3.7]: there is strong evidence for both these main effects over null. In comparison, the strongest model (7[th]) with the expected interaction was *time+block +group+time*group* [BF_{10} = 1.3, error % = 2.1], this together with a BF_{incl}(*time*group*) of 0.14, indicates that there is moderate evidence against any model with the interaction, as opposed to without the interaction effect, this is very strong for the three-way [BF_{incl}

(*time*block*group*) = 0.02]. In sum: accuracy overall increased from pretest to posttest [93.9% ± 9.3 to 96.2% ± 6.3], accuracy was higher in the repeat block than in the switch block [96.2% ± 6.9 vs. 93.9% ± 8.8] and there were no interaction effects of *time*group*.

Reaction time. Bayesian repeated-measures ANOVA [*time*(2)**block*(2)**group*(2)] on reaction time means revealed a similar result: the top model was again *time+block* [BF_{10} = 1.15*e^{21}, error % = 5.0]: there is extreme evidence for both these over null. The strongest model (8th) with interaction was again *time+block+group+time*group* [BF_{10} = 1.07*e^{20}, error % = 4.6] and BF_{incl}(*time*group*) = 0.14 indicates that there is moderate evidence against models with this interaction over those without. This is very strong for the three-way interaction [BF_{incl}(*time*block*group*) = 0.03]. In sum: reaction time overall decreased from pretest to posttest [942 ms ± 258 to 893 ms ± 221], responses were much faster in the repeat block than in the switch block [787 ms ± 165 vs. 1049 ms ± 234] and there were no *time*group* effects.

3.3.1.2. Local switching costs. *Accuracy*. A Bayesian repeated-measures ANOVA [*time*(2)**trial*(2)**congruency*(3)**group*(2)] on accuracy showed the top model to be *time+trial+congruency+trial*congruency* [BF_{10} = 2.97*e^{27}, error % = 5.2]: extreme evidence for this combination of effects over null. The strongest model (6th) with interaction was *time+trial+congruency+group+trial*congruency+time*group* [BF_{10} = 4.95*e^{26}, error % = 4.6]. The BF_{incl}(*time*group*) = 0.13 indicates that that there is moderate evidence against models with this interaction and this is extreme for both three-ways and the four-way [BF_{incl} < 0.01]. In sum: overall accuracy increased from pretest to posttest [92.9% ± 10.3 to 95.1% ± 8.6], accuracy was higher in the repeat trials than in the switch trials [95.5% ± 8.6 vs. 92.4% ± 10.1], accuracy was lower for incongruent trials [*neutral*: 95.3% ± 8.9; *congruent*: 95.0% ± 8.6; *incongruent*: 91.7% ± 10.5] and there was an expected *trial*congruency* interaction (see Table 2 for these values). All effects involving *time*group* were absent.

Reaction time. Bayesian repeated-measures ANOVA [*time*(2)**trial*(2)**congruency*(3)**group*(2)] showed highly similar effects, the top model being *time+trial+congruency+trial*congruency* [BF_{10} = 5.96*e^{98}, error % = 3.9]: extreme evidence for this combination of effects over null. The strongest model (10th) with interaction was again *time+trial+congruency+group+trial*congruency+time*group* [BF_{10} = 3.77*e^{97}, error % = 9.0]. The BF_{incl}(*time*group*) = 0.06 indicates that that there is strong evidence against models with this interaction and this is extreme for both three-ways and four-way interactions [BF_{incl} < 0.01]. In sum: overall reaction time was longer in the pretest, than in the posttest [1090 ms ± 311 to 1014 ms ± 255], reaction time was shorter in the repeat trials than in the switch trials [920 ms ± 217 to 1185 ms ± 286], there was a *congruency* effect [*neutral*: 987 ms ± 258; *congruent*: 1094 ms ± 300; *incongruent*:

Table 2. Means and standard deviations of local switch costs. Split for trial type and congruency. SD = standard deviation; Acc = accuracy; RT = reaction time.

		Neutral		Congruent		Incongruent	
		Mean	SD	Mean	SD	Mean	SD
Acc	Repeat	96.1%	8.4%	96.5%	7,8%	94.0%	9.4%
	Switch	94.5%	9.4%	93.4%	9.1%	89.4%	11.2%
RT (ms)	Repeat	867	193	939	219	953	231
	Switch	1091	255	1228	282	1236	300

1103 ms ± 309] and there was an interaction effect of *trial*congruency* (also see Table 2 for these values). Again there were no effects involving *time*group*.

3.3.2. N-back

The Bayesian repeated-measures ANOVA on the sensitivity score of the N-back (hit rate – false alarm rate) [*time*(2)**task*(2)**group*(2)] showed the top model to be *time* [BF_{10} = 3.05, error % = 3.1]; there is just moderate evidence of an effect of *time* over null. The strongest model (3rd) with the interaction of interest is *time+group+time*group time* [BF_{10} = 0.68, error % = 3.3], indicating that there is anecdotal evidence against this model over null. The inclusivity factor BF_{incl}(*time*group*) is 0.30, implying that there is moderate evidence against this factor having any effect overall. Tentatively concluding: sensitivity went up from pretest to posttest [78.5% ± 18.8 to 83.3% ± 14.7] and there was no *time*group* interaction.

A Bayesian repeated-measures ANOVA of reaction time on target was performed [*time* (2)**task*(2)**group*(2)]. Again, this showed *time* to be the top model [BF_{10} = 2583.7, error % = 1.1], but with extreme evidence for this model over null. The strongest interaction model (6th) was *time+group+time*group time* [BF_{10} = 286.1, error % = 3.3]. BF_{incl}(*time*-group*) is 0.17, indicating moderate evidence against this interaction effect. In sum: reaction time went down from pretest to posttest [727 ms ± 177 to 657 ± 196] and the *time*group* interaction is absent.

3.3.3. Stop-signal task

After calculating the chance of commission error p(Com) per participant and per test 13 participants were excluded from SSRT analysis based on values below .25 or above .75 for either test, as recommended by Verbruggen et al. (2019). This led to 6 exclusions from the TCC group, leaving 14; and 7 exclusions from the control group, leaving 16. A Bayesian repeated-measures ANOVA [*Time*(2)**Group*(2)] was conducted on SSRT(nth) of the remaining sample resulting in the following factors: BF_{10}(*time*) = 4.7, error % = 1.4; BF_{10} (*group)* = 0.4, error % = 0.7; BF10(*time+group*) = 1.8, error % = 1.7; and BF_{10}(*time+group +time*group*) = 1.0, error % = 1.3. There is moderate evidence for just the factor *time* and no evidence either for or against the complete model with interaction over null. In sum: SSRT went down from pretest to posttest [321 ms ± 69 to 283 ms ± 64]. The interaction effect of *time*group* is unknown as this is underpowered (by BF value). All relevant values for the SSRT sample can be seen in Table 3 (following Verbruggen et al., 2019).

4. Discussion

This randomized controlled trial was conducted to investigate the relationship between motoric and cognitive effects of the multi-modal mind-body exercise TCC. As such we expected to replicate findings on enhancement of EF in aging populations and specifically sought to elucidate which of the components of EF – shifting, updating or inhibition – is targeted by this exercise and how and in which direction this relates to any motoric enhancements. The cognitive results did not meet any of our expectations. None of the three components showed a larger improvement for TCC than control from pretest to posttest; not statistically, but also not numerically in trend. This was the case for global and local switching costs in both accuracy and reaction time in the Task-Switch Task (shifting), sensitivity in the n-back and SSRT in the Stop-Signal Task. Another aim of this

Table 3. Means and standard deviations of stop-signal task variables. Split for TCC/control and the two time points. TCC = Tai Chi Chuan; SST1 = pre-measure stop-signal task; SST2 = post-measure stop-signal task; SD = standard deviation; Go = go trials; Com = commission error; p(Com) = commission error rate; Acc = accuracy; RT = reaction time; SSD = stop-signal delay; SSRT = stop-signal reaction time.

			Go Acc	Go RT	p(Com)	Com RT	SSD	SSRT
TCC	SST1	Mean	95,1%	628	41,1%	522	261	308
		SD	5,7%	111	8,4%	68	78	50
	SST2	Mean	92,9%	612	41,7%	524	277	285
		SD	18,3%	94	10,9%	85	88	64
Control	SST1	Mean	95,8%	645	41,8%	549	256	331
		SD	6,0%	100	12,2%	75	103	82
	SST2	Mean	96,9%	636	38,4%	553	288	280
		SD	4,2%	123	9,1%	97	89	67

study was to replicate beneficial effects of TCC on motor function and look into the possible interaction of cognitive and motoric factors. Here the results did meet posed expectations. Both functional balance, as measured by TUG score, and motor speed, as measured by FTT count, were significantly enhanced more in TCC than in control. This last result could be interpreted as a form of cognitive enhancement as motor speed is related to processing speed, which makes the null-results on cognitive control the more tantalizing.

One explanation for our null findings on the three different types of EF could be that our online intervention did not provide a sufficient quality of TCC, because the instructions were not followed correctly or compliance with practice was low – as one of the drop-outs indicated annoyance as a reason. However, we find this to be unlikely as the self-reports were filled in after every planned session for all but one of the participants (who missed one session). It could also be that the exercises were not challenging and exerting enough. In the scores of the session self-report questionnaires a low difficulty and low physical exertion was reported, while the effort put-in was mid to high. But even low physical exertion would be expected to lead to cognitive enhancement and most telling: motor function was enhanced, both in functional mobility and in motor speed. The most likely explanation of this enhancement is from diligently following the TCC exercises.

So what are possible reasons for this absence of cognitive effects? It might be that the intervention was too short for positive effects on cognitive control to surface (as opposed to motoric improvements), in other words: dosage by duration. Most TCC studies use longer intervention periods of 3 to 6 months, whereas this program took 2 months. This explanation cannot be ruled out; however, effects on EF have been reported with similar (e.g., meditation), but much shorter interventions and most clinical programs such as mindfulness-based stress reduction, show significant effects after just 8 weeks.

Another explanation is an absence of certain factors in this online TCC implementation which might be present in TCC intervention of studies reporting cognitive enhancement, such as: 1) spirituality, 2) social contact and 3) personalized training, although we acknowledge there might be other, such as outdoor practice (Ng et al., 2018).

There are indications that a spiritual dimension is a key component of contemplative practices. In a study comparing a secular and a spiritual style of meditations during a two-week intervention it was shown that the spiritual group had a greater decrease in anxiety and increase in positive mood, than the secular control group (Wachholtz & Pargament, 2005). A similar assessment of the contribution of spirituality to cognitive effects is not known to us. The second absent factor is social contact. In a regular TCC practice session the practitioner has bidirectional interaction with a teacher and is part of a group that performs exercises in unison. There might also be contact outside of the classroom, at least before and after. Social contact can provide a buffer against cognitive decline (Kuiper et al., 2015). This factor might even include physical contact, for example: teachers might put their hand on the lower back to check posture or practitioners might engage in the one-on-one exercise known as "sticky hands". The third factor of note is the lack of personalized teaching. There is no direct monitoring of the level and progress of practitioners and therefore the lesson material is not adapted to the individual case. Both personalized scaling of difficulty and the shaping of behavior (by reward) is largely absent, although the lessons do scale in difficulty and encouragement is offered. We know from computerized cognitive training studies that personalized training works better than general computer games (Peretz et al., 2011). However, previous studies showing effects of TCC also do not incorporate personalized scaling and shaping. In conclusion: though we acknowledge spirituality, social contact and personalization to be absent factors in this intervention, we regard this to be insufficient cause for the null-results found in this study, as two factors that are sufficient cause for cognitive enhancement are clearly present: physical exercise and meditation. Indeed, as outlined in the introduction, either of these two factors in isolation should be sufficient for cognitive enhancement to occur. Though we acknowledge that the aerobic aspect of TCC is categorized as low to mild, this intensity has also been shown to enhance EF in senior populations (Tse et al., 2015) and even to be superior to high intensity (Coetsee & Terblanche, 2017).

Might there be a ceiling effect in this sample? The sample might be in the top tier of cognitive health from the start. The sample does seem to be physically fit: the participants report a high level of physical activity, as can be seen in the demographics. Then again, there was a main effect of time and it could be seen that both groups improved in the three cognitive components. Then there could only be a ceiling effect if this end state was the highest achievable level of this sample, overshadowing any additive effect of TCC. Looking at the absolute numbers and comparing these to other studies with aging populations, together with the absence of any numerical direction of effect; we find this to be unlikely as well.

Therefore, we tentatively conclude that TCC does not have notable effects on EF. This could imply that a physical exercise factor (e.g., aerobic challenge) *and* the meditation factor are not sufficiently present in TCC. Another implication might be that the scientific literature on these domains exaggerates the cognitive effects of these types of interventions and there might be a publication bias, such as has been suggested in reviews on mindfulness-based programs and TCC (Coronado-Montoya et al., 2016; Huang et al., 2017). We lean toward this last explanation and thus regard the publication of studies reporting null-results, such as this one, of paramount importance. We have three suggestions for the field. Firstly, submit and publish all null-effects produced by experiments of sufficient quality of design. Secondly, actively seek to replicate previous findings in these domains. Thirdly, to isolate common factors in TCC – and other contemplative practices – and test their individual and mixed efficacy on both cognition and motor functioning. Another interesting line of inquiry would be to study the timeline of motoric and cognitive effects in more detail and longitudinally, and to include biomarkers that possibly mediate these effects, such as brain-derived neurotrophic factor or oxyhemoglobin levels (Husain et al., 2020; Ng et al., 2019; Voss et al., 2013). The question whether TCC can help to obtain a buffer against cognitive decline can only be answered by accumulating sufficient representative results.

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RG & GB came up with the concept and design of this study. JL shot the instructional videos. JL & NvdB collected the data and monitored the intervention phase. RG analyzed the data and wrote the manuscript, which was redacted by GB.

Disclosure statement

We have no conflicts of interest to disclose.

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Appendix A

Original language was Dutch. Questions and scale translated into English. Only relevant questions reported.

All items had a 5-point Likert scale: 1: Completely not; 2: Somewhat; 3: Neutral; 4: Moderately; Very much so.

Multiple questions per aspect were averaged per session per participant (for *ease* and *effort*). All session aspect scores were averaged across the 20 sessions to obtain grand mean aspect scores.

Introductory text:

"Below you will find a number of questions about your experiences in the previous session. Read every question thoroughly and report to what extent this applied to you. There are no right or wrong answers. Don't think too much and respond with your first associations."

Challenge – Ease

"Was it easy to follow the instructions?"

"How hard or difficult was this session?"

Challenge – Effort

"Did you have the feeling that you were doing Tai Chi?"

"Do you have the idea that you participated well?"

Physical exertion – Aerobic

"Did you have a higher breathing rate?"

Physical exertion – Heart rate

"Did you have a higher heart rate?"

Physical exertion – Muscle ache

"Do you think you will have muscle aches tomorrow?"