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The link between TCC, Task-switching and Gait speed in older adults

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Abstract

Background. With an increase in longevity the number of older adults in our society increases each year. As a result more people are faced with age-related cognitive decline, the structural deterioration of the brain which results in a reduction of cognitive capability. As more people experience the detrimental effects of cognitive decline the need to preserve cognitive function throughout aging arises. Tai Chi Chuan (TCC) is considered a valuable multi-facetted countermeasure as it combines physical exercise with meditation, both of which benefit cognitive- and executive functioning in older adults. It is however unclear if motor skill performance is correlated with executive functioning performance, this study aims to examine this relationship. **Method.** To evaluate the effect TCC has on motor skill and cognitive functioning 44 participants partook in a 10-week online video or online TCC-course. They were evaluated on motor tasks: Timed-up-and-go task (TUG) and the One-legged-standing-task (OLST), an executive functioning task: Task-switch task (TST) and self-reported their evaluations on statements pertaining to each session using a Likert-scale survey. **Results.** TCC-participants significantly improved on the TUG ($p < .01$) indicative of a better gait speed compared to the control group. However no significant differences between the two groups on the OLST were apparent. Furthermore the two groups did not differ on RT or accuracy on the TST. Although correlations between the TUG/OLST ($r = -.495$, $n = 23$, $p < .05$) and SC RT/SC accuracy ($r = 431$, $n = 44$, $p < .01$) were significant no correlations were found between motoric measures (TUG/OLST) and task-switch measures (SC RT/SC accuracy). This means that although TCC participants improved on the TUG, they did not improve on SC accuracy or SC RT. .Self-reported response frequencies indicate that the course might not have been challenging enough. **Conclusion.** A ten-week TCC-intervention is beneficial for increasing dynamic balance / gait speed in older adults ($p < .01$). TCC did not improve the performance of participants on the OLST (static balance). There were no differences apparent between the two conditions in performance on the TST outcomes (accuracy and RT). The correlation between motor skill and executive function: TST could therefore not be attested. Future research might benefit from including more challenging visual- and vestibular conditions in the OLST to investigate the effect of TCC on more challenging static balance conditions. In addition to this it is advisable to investigate the interconnectivity between the motor- and cognitive domain by relating TCC to other executive function tasks (e.g. Stop-signal task or N-back task). Lastly, research would benefit from an intervention with two TCC-groups: one with online sessions, one with actual group meetings. This way social factors beneficial to cognitive functioning can be deduced.

Key words: Tai Chi Chuan - Aging - Gait - Balance - Task-switch - Cognition - Executive function.

Introduction

Why preserving cognitive function throughout aging is necessary.

With new advances in technology, medicine and improved living conditions the average life expectancy is rising constantly. Oeppen & Voepel (2002) state that female life expectancy in the record holding country, Japan, has increased with three months each year. This would mean that Japanese females born four years later in time would be expected to live one year longer on average. Oeppen & Voepel (2002) subsequently state “World life expectancy more than doubled over the past two centuries, from roughly 25 years to about 65 for men and 70 for women”. Life expectancy and year of birth show a positive linear relationship indicating that the later in time the year of birth, the higher the life expectation (Oeppen & Voepel, 2002). Within the Netherlands the current average life expectancy for women is roughly 81 years (Geoba, 2016).

With the increase in longevity comes an increase in people of old age (55+ years). Old age is associated with a decrease in both white- (myelinated axons / glial cells) and grey (neuronal) matter in the brain (Resnick et al., 2003). The frontal and parietal lobes are more susceptible to volume loss compared to the occipital and temporal lobes of the brain (Resnick et al., 2003). Volume loss in these regions can lead to a reduction in cognitive capability known as cognitive decline. Imaging studies of healthy adults suggest an association between age related decline in white matter volume and deficits in cognitive performance (Brickman et al., 2006). Although brain atrophy is a normal result of aging, it may be reduced for individuals who remain medically and cognitively healthy (Resnick et al., 2003).

Due to the increase in people becoming of old age and the detrimental effect brain atrophy can have on cognitive functioning, the need to preserve cognitive functioning in older adults arose. Age related cognitive decline and preservation of cognitive functioning in older adults have become the subjects of countless research projects (Brehmer et al., 2014; Cabeza, 2001; Deak et al., 2016; Eckert, 2011; Naqvi et al., 2013 and others).

Executive functioning

The term ‘executive function’ describes a general-purpose mechanism that modulates the operation of multiple cognitive sub-processes and regulates human cognition (Miyake, 2000). Executive function is generally divided into three main components: *Shifting*, *Updating* and *Inhibition* (Miyake, 2000; Fisk & Sharp, 2004; Dai et al., 2013 and others), but can also include attentional control, planning and verbal fluency (Jurado, 2007). The term *shifting* pertains to switching between tasks, operations or mental sets (Miyake, 2000). *Updating* requires the coding and monitoring of task relevant information and revision of information in the working memory no longer relevant for the current task (Morris & Jones, 1990). The last main executive function *inhibition* refers to one's ability to suppress a dominant response when necessary (Miyake, 2000).

Preserving cognitive function

One way cognitive functioning can be preserved and improved upon is by staying physically active. Multiple studies have reported the positive effects physical excercise has on body and cognition (Alpert et al., 2009; Fang et al., 2013; Kramer et al., 2005; Lopez-Lopez, Leroith & Torres-Aleman, 2004; Prakash et al., 2015). Some of these positive effects have been attributed to the direct effect physical excercise has on the body and the brain, such as increased vasculature and production of neurotrophic factors (Fang et al., 2013; Kramer et al., 2005; Lopez-Lopez, Leroith & Torres-Aleman, 2004).

Meditation is also deemed effective to remain cognitively vital throughout aging (Chambers, Chuen Yee Lo & Allen, 2008; Kabat-Zinn, 2003; Lupien et al., 1998; Zeidan et al, 2010). Lupien et al., (1998) researched the effect of cortisol, stress hormone, levels on hippocampal atrophy and memory deficits in elderly. They found that high cortisol levels related to decreased hippocampal volume. This emphasizes the importance of stress reduction techniques such as meditation and relaxation techniques in maintaining cognitive function throughout aging.

While meditating, practitioners purposely pay attention to present moment experiences in a non-judgmental way (Kabat-Zinn, 1994). Research done by Zeidan and colleagues (2010) indicates that meditation can be an effective measure to increase sustained attention and executive processing efficiency on cognitive tasks. Participants who received a twenty-minute meditation training four times a week showed improved visuo-spatial processing, working memory and executive functioning when compared to controls. These results are similar to those of a study done by Chambers, Chuen Yee Lo & Allen (2008), in which they let novice meditators participate in a 10-day meditation program. The meditation intervention group showed improvements in working memory capacity, reaction time and sustained attention, however there was no indication that attention switching capacities were enhanced by the intervention (Chambers, Chuen Yee Lo & Allen, 2008).

Tai Chi Chuan and cognitive functioning

Activities that incorporate multiple behavioral interventions are expected to be an effective strategy against cognitive decline. One popular physical exercise and meditation activity is Tai Chi Chuan (TCC), a practice where the practitioners execute slow movement patterns using fluid, circular motions while paying attention to breathing, balance and relaxation. TCC is considered to be an aerobic exercise of mild intensity (Chang et al., 2010). The results of a meta-study done by Wang and colleagues (2010) suggest that Tai Chi interventions are associated with several positive physical and psychological improvements: according to Wang and colleagues (2010), “Tai Chi may be associated with improvements in psychological well-being including reduced stress, anxiety, depression and mood disturbance, and increased self-esteem”. TCC involves choreographed and complex movements that show similarities with dancing. Research on professional dancers suggests that dancing increases balance, gait and the gray matter volume in the hippocampus, which may benefit memory related task performance (Alpert et al., 2009; Hüfner et al., 2011).

Tai Chi Chuan and executive function: task-switching

Out of the three sub-constructs deemed important for executive functions (Miyake 2000) the focus of this paper is the shifting aspect. Shifting proved to be a better predictor of performance of older adults on complex executive functioning tasks than inhibition (Hull, 2008). Furthermore, physical activity, which is a component of TCC, has been shown to positively influence the task-switch performance of older adults (Hillman, 2006; Themanson, Hillman & Curtin, 2006). These factors make the shifting aspect am interesting function to examine.

Research done by Smiley-Oyen et al. (2008) compared the effect of aerobic or non-aerobic exercise on the performance on executive control tasks. These tasks were divided into those that relied heavily on executive control (e.g. task-switch, inhibition and responding to incompatible stimuli) and those that not so heavily relied on executive control (reaction time, compatible stimuli, tasks that did not involve stopping or switching). They found that the two groups did not differ on the low-executive control tasks and that aerobic group outperformed the non-aerobic group on the high-executive control tasks (Smiley-Oyen et al., 2008). This would suggest that practicing TCC, which is considered a moderate aerobic activity (Chang et al., 2010), would have the same beneficial effects for task-switch performance.

Fong and colleagues (2014) also researched the relationship between Tai Chi Chuan / endurance exercises and the task-switching aspect of executive functioning. They divided 64 participants into four group based on age and history of physical activity: older adults performing endurance exercises, older adults performing TCC, older adults with a sedentary lifestyle and young adults. As to be expected the young adults showed the best performance compared to the three older adult groups. Although the older adult groups did not show differences in switch cost, both the endurance exercise and the TCC group had a faster general reaction time on the task-switch task compared to the sedentary lifestyle group (Fong et al., 2014). Fong and colleagues explain that it might be the physical activity that influences the performance on the task-switch task and ameliorates the age-related cognitive decline (Fong et al., 2014).

Hawkes (2012) examined the effect of aerobics, TCC and meditation on task-switch performance. In accordance with her hypothesis all training groups outperformed the sedentary control group on switch reaction time. Interestingly she also found that only the Tai Chi group and the meditation plus exercise group, and not the aerobic fitness group, demonstrated lower switch costs. This result could be interpreted that it is the combination of exercise and meditation (e.g. TCC) that is the cause of lower switch costs and thus an improved task-switch performance.

Tai Chi and motor skill

Research done by Wong et al. (2001) indicates that older adults participants who were experienced practitioners of TCC (varying between 2 to 35 years of TCC experience) outperformed sedentary older adults on several challenging static and dynamic balancing tasks. The tasks consisted of standing on one leg (static), under normal conditions or blindfolded or with sway referenced vision (the enclosure was slightly tilted while the platform to balance on was horizontal) and rhythmic shifting of weight (dynamic), either side to side or front to back or multidirectional (Wong et al., 2001).

Wong and colleagues (2011) later compared the training specific effect of swimming and TCC on motor control. They concluded that both swimming and TCC shortened the movement time of elderly but only the TCC group improved on dynamic balancing in the most challenging conditions (e.g balancing with closed eyes or with sway-referenced vision or using a sway-referenced support).

Tsang et al. (2013) researched the effect of TCC on a finger-pointing task with a choice paradigm. The visual cue was presented on a screen under three conditions: 1) a black ball (touch it as fast and accurately as possible) 2) a white ball (do not touch it) or 3) both black and white balls (touch only the white ball). Older adults that performed TCC for at least 1,5 hours per week for more than 3 years showed a faster movement time (finger to screen) and accuracy (closeness to the center of the black ball) compared to older adults who did not perform TCC.

Audette and colleagues (2006) compared the effects of TCC vs brisk walking on the strength, balance and flexibility in elderly women. They found that engaging in a Tai Chi course for 3 hours per week for three months benefitted strength, balance and flexibility more than the brisk walking did.

The link between motor skill and executive function

The effects TCC has on motor skill and on executive functioning separately have been examined multiple times (Audette et al., 2006; Fong et al., 2014; Hawkes, 2012; Tsang et al., 2013; Wong et al., 2001; Wong et al., 2011 and others). However, the effect TCC has on both motor skill and executive functioning and the possible relationship between those domains has not been the subject of much research. Currently available literature on the subject however indicates there might be such a relationship (Nadkarni et al., 2013; Hausdorff & Buchman, 2013; Hausdorff, 2005 & Holtzer et al., 2006). For example, the cognitive region of the cerebellum appears to be related not only to processing speed but also to gait speed. The cognitive region of the cerebellum processes relevant sensory motor information to enable the execution of motor tasks, which links motor ability to processing ability. In addition to this cerebral volume seems to be associated with gait speed and the processing of information. (Nadkarni et al., 2013). Nadkarni and colleagues (2013) add that, amongst community-dwelling older adults, the areas of the brain associated with executive function processes show the strongest relationship with gait speed. Slow gait is also a risk factor for the development of mild cognitive impairment and a more rapid cognitive decline (Hausdorff & Buchman, 2013).

Research done by Hausdorff and colleagues (2005) further emphasizes the interconnectivity between the motor- and cognitive domain. They show in their research that walking in older adults is associated with executive function or higher cognitive resources more so than with memory or general cognition (Hausdorff et al., 2005). It turns out that a steady gait is associated with increased performance on an executive functioning task (the Stroop-task).

Holtzer and colleagues (2006) examined the link between gait velocity and cognition by testing 186 cognitively normal older adults. Factor- and regression analysis showed that in the normal condition (walking) verbal IQ, speed / executive attention and memory were all predictive of gait speed. In the interference condition, walking and reciting alternate letters of the alphabet, only speed / executive attention and memory remained predictive of gait speed. The speed / executive attention factor is comprised of several timed tests of attention, problem-solving and executive function that all rely on processing speed (Holtzer et al., 2006). This again shows that gait speed and some executive functions are dependent on processing speed, as mentioned before in research done by Nadkarni and colleagues (2013).

The current study

The aim of the present study is to increase understanding and provide insight into the effects that multi-facetted behavioral interventions like Tai Chi Chuan have on both cognitive- and motoric outcomes. This study hopes to add to the body of knowledge pertaining to the preservation of cognition in older adults and the counterbalancing of age related cognitive decline. Furthermore, the aim is to examine the link between motoric skill and cognitive functioning. Such interconnectivity could prove to be invaluable for future interventions focused on counterbalancing age-related cognitive decline and decreasing mobility.

The experimental research design: a randomized controlled trial

The participants are randomly assigned to either the TCC- (twenty online TCC sessions) or the control group (twenty online informative videos). In the TCC-condition participants watch videos in which an experienced Tai Chi teacher performs and explains various TCC exercises. As there is no way to interact with the teacher the participants have to rely on the video for guidance. They are however able to rewind the video if something is unclear. To challenge the participant the exercises get increasingly difficult throughout the intervention. Before and after the twenty sessions the participants are required to do various executive functioning- and motor skill tasks and fill in questionnaires. In addition to this participants fill in a self-report questionnaire after each session in which statements about that session are scored on a five-point Likert-scale. The motor skill tasks consist of the One-legged standing task (OLST), which measures balance, and the Timed-up-and-go task (TUG), which measures gait / balance. The executive functioning task consists of the Task-switch task (TST) (Jersild,1927) which measures the switching aspect of executive functioning.

Research Questions

The research questions I aim to answer in this thesis is:

1.Does Tai Chi increase task-switch performance and gait speed in older adults? 2. Is an increased performance in motoric functioning (balance/gait) associated with an increased performance in executive functioning (task-switch performance)?

Hypothesis and operationalization

Based on the examined literature I hypothesize that the TCC group will outperform the control group on the Task-switch task, the One-Legged Standing Task and the Timed-up-and-go task. If this is the case I hypothesize that the TCC-practitioners will improve on some or several of the following factors: they will show a higher accuracy, a lower reaction time and/or a lower switch-cost on the Task-switch task. The participants in general are expected to spend less time on repeat-trials (applying the same rule again) and on switch-trials (switching between rules).

The TCC post-test practitioners are also expected to spend less time on the Timed-up-and-go task and more time on the One-legged-standing-task, which is indicative of a better balance and faster gait speed. The link between switching and gait/balance should become apparent from a correlation between motor skill (balance/gait) and task-switch variables(accuracy- and reaction time switch-cost). This would indicate that an improved gait or balance influences task-switch performance or vice versa. A possible link should become apparent when averaging pre- and post-test for each of the four variables (TUG time, OLST time, SC RT and SC acc) and comparing these using bivariate correlations.

Research done by Nadkarni et al. (2013) shows that gait speed shows a strong relationship with areas of the brain related to executive function processes. Based on this fact a correlation between the TUG / OLST – and task-switch task outcomes might be found. Such a finding would be in accordance with Nadkarni et al. (2013) and might attest their findings that balance and/or gait speed are linked to performance on executive function tasks (TST). These results would also reflect the findings of Hausdorff et al. (2005) that a steady gait is associated with increased performance on executive functioning tasks.

Methodology

Participants

Older adults (55+) were enrolled in various ways. Flyers detailing the research were distributed not only in person but also strategically placed at locations where the target audience would likely be. Advertisements were placed online on the website: onderzoekmachine.nl and on several online forums for older adults. The ANBO (an older adult interest group) was also contacted to distribute information about the research. Furthermore, a notification was placed in the HOVO (higher education for elderly) newsletter and in the newsletter of the Professorenwijk in Leiden. Lastly, participants were asked to notify others about the research. Participants that exercised three times a week, were physically impaired or had extensive experience with meditation/yoga/TCC were excluded from the second run of the research. The participants were randomly divided over the two conditions (Tai Chi Chuan / control group). The TCC group watched online TCC-lessons at home on their own computer. Twice a week participants received a link to a TCC lesson on Youtube.com or a control condition video on NPO.nl. In the videos an experienced Tai Chi instructor performed Tai Chi exercises whilst giving instructions on how to do so properly (Breintraining Universiteit Leiden, 2015) (**Figure 1 & 2**).

Figure 1: *TCC exercise explanation..*

Figure 2: *TCC exercise execution example.*

The participants are expected to stand in front of their computer and imitate the movements of the instructor whilst following his instructions. Participants engaged in these sessions twice a week for approximately 60 – 90 min per session. The control group sat in front of their own computers and watched online informative videos, on a variety of subjects (e.g. religion, dilemma's doctors are faced with in their profession and meditation), at home twice a week for the same amount of time (NPO, 2012) (**Figure 3 & 4)**.

Figure 3: *NPO documentary example.*

Figure 4: *NPO documentary impression.*

In total the course was comprised of twenty online sessions. All participants were required to sign a consent form detailing the course of the research. In total 54 older adults were enrolled in the research. This pool of participants is comprised of two research groups, one group took part in the research from May – September 2015 and the other from November 2015 – May 2016. The two groups followed the same course except the first group was not examined on the OLST on the post-test. The OLST was erroneously omitted from the first run of the research and it was later re-added in the second run of the research. Therefore the OLST-statistic has a lower amount of participants in each condition (more on this in the result section). The table below presents a summary of demographic and questionnaire related information about the participants per group (**Table 1)**. Amongst the dropped out participants were two cases related to injuries (shoulder and foot), one was related to disability (was not able to see properly) and eight cases related to personal affairs / reasons.

Table 1 | Descriptive statistics TCC / NPO groups and MET-groups (M ± SD).

Measures	**Group**	
	TCC	**Control**
Sample Size	20	24
Gender (M/F)	11/9	12/12
Age	63.5 ± 6.36	63.58 ± 7.74
IPAQ level	2.4 ± 0.59	2.29 ± 0.75
MET-min p/w	3581.06 ± 3038.05	4612.21 ± 4155.33

IPAQ activity		
	Sample Size	**MET-minutes p/w**
Low	5	622.4 ± 490.06
Average	19	1609.36 ± 870.98
High	20	7431.23 ± 2985.01

TCC, Tai Chi Chuan; IPAQ, International Physical Activity Questionnaire. MET-min p/w, Metabolic Equivalent minutes per week

Questionnaires

The IPAQ (International Physical Activity Questionnaire) (Craig et al., 2003) developed to measure health-related physical activity. The IPAQ short form contains questions about walking, moderate- and vigorous activities per week. In addition to this questions address the time spent sitting down. The answers are then weighed according to intensity of the activity and the duration. (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. More taxing activities are assigned more energy requirement points or Metabolic Equivalents (METs). The METs per week are added up and compared to cut-off points and requirements for three different categories of activity: low, average and high (See Appendix A1 and A2 for more information).

The MMSE (Mini Mental State Examination) (Kok & Verhey, 2002) is a questionnaire designed to measure cognitive impairment. It is used to assess the severity and progression of dementia in particular. The answers on the questions are scored and awarded points if answered correctly. The points are added up and compared to a cut-off point (See Appendix B for more information).

Self-report questionnaires

In addition to this participants filled in a self-report questionnaire after each session of the course. This online questionnaire is comprised of statements about the current session to which they have to respond on a 5-point Likert-scale (Not at all – Very much). These self-report scores provide insight into the difficulties participants experienced while following the TCC- or the control group program. The TCC group self-report questionnaire consists of 26 questions that address topics that pertain to the session like comprehension of instructions, relaxation, attention, breathing, physical capability, and pain (see appendix C1 for the TCC group version of the self-report questionnaire). The control group self-report questionnaire consists of 14 questions addressing topics like comprehension of the video, attention while watching, breathing and interest in the subject of the session (see appendix C2 for the control group version of the self-report questionnaire). The two questionnaires contained questions specific to the condition (e.g TCC: Were you able to twist from the waist? / control: Did you find the subject of the video interesting?) and questions that were in both questionnaires (e.g Were you relaxed during this session/video?). The self-report questionnaire for the TCC group contained more questions to address each aspect of the intervention. The control group watched videos and had less aspects to review after each session, thus the questionnaire was less extensive.

These self-reports provide insight into how the TCC-intervention was perceived and experienced. For this purpose several questions of the TCC-questionnaire are compiled together to provide insight into various dimensions of the intervention: Physical Intensity, Capability, Discomfort and Toughness. The following three statements of the questionnaire provide insight into the experienced physical intensity of the course: ‘Did you experience heavier breathing during this session?’, ‘Do you think you will have muscle pain tomorrow?’ and ‘Did you have a faster heartbeat during this lesson?’. The statements: ‘Were you able to twist your waist properly?’, ‘Were you able to stand up straight and move properly?’ and ‘Were you able to keep your hand and wrist straight?’ provide a summary in the physical capabilities of the participants. Because discomfort might influence results from the TCC-course two statements reflect this factor: ‘Did you experience pain during this session?’ and ‘Did you experience joint or muscle stiffness during this session?’. Furthermore an overall experience of the toughness of the course is covered by the statements:

‘Were you able to follow the instructions?’ and ‘How tough was this session?’. Lastly the ability to balance is addressed by the question ‘Were you able to keep your balance during this session’ (see appendix C1).

Motor tasks

The Timed-up-and-go (TUG) (Mathias et al, 1986) measures a participant’s mobility, gait and balance. A chair is placed facing the wall at a distance of three meters. The participant is seated on the chair and asked to walk to the wall and back to the chair as fast as possible. The time spent walking to the wall and back is measured. A faster time is an indication of better mobility, balance and gait.

The One-legged standing task (OLST) (Franchignoni et al., 1998) measures the participant’s ability to balance on one leg. The participant is required to stand as long as they can without losing balance. The time spent standing on one leg is measured. The more time spent standing on one leg, the better the balance.

Task-switch task

This task measures the participant’s ability to switch from one task to another. Participants are shown a combination of letters, numbers and signs (e.g. 4B, 1t or 3!). The task consists of three different conditions: a letter, number and a mixed condition. The combinations randomly appear in one of the four quadrants of the screen. In the letter condition the participant is asked to only pay attention to the letter presented in the combination. If it is a lower-case letter the participant is required to press Z, in case of a capital letter the participant is required to press M. The conditions were counterbalanced by presenting equal amounts of ‘press Z’ trials as ‘press M’ trials per session. The order in which they were presented was random but the trials added up to an equal quantity (e.g 15 ‘press Z’ and 15 ‘press M’ trials).

In the number condition the participant is required to press Z in case of a number smaller than five and M in case of a number higher than five. In the mixed condition the rule that is to be applied is determined by the quadrant the combination appears in. The upper two quadrants pertain to the number condition, the lower two quadrants to the letter condition **(Figure 5)**. When a participant switches from the upper rule (number) to lower rule (letter) a delay in reaction time can be measured: the switch cost or local switch cost. This is the difference between the switches within the switch block (e.g. rule A→ rule B or B→A) and the repeats within the switch block (e.g. A→A or B→B). The lower the switch cost the faster a participant is able to apply the different rules and the better the switching aspect of executive function. In addition to the switch cost a mix cost- or global switch cost is measured. This is the difference between the pure blocks (in which only one stimulus dimension is presented: numbers or letters) and mix blocks (in which multiple stimulus dimensions are presented: e.g numbers and letters) (Philipp et al., 2008)

Congruency is the way in which similarities or dissimilarities between the previous and the current task influence the performance on the current task. Within the switch condition congruency is defined as the influence the redundant digit/number/symbol in the combination has on the performance of the participant. In this case congruency addresses the similarities or dissimilarities between the two stimuli. Three different situations are possible: incongruent, congruent and neutral. In the incongruent condition the redundant symbol elicits a response opposite to the desired response, for example the participant is asked to pay attention only to digits and '4B' appears. Given the fact that the digit dictates the response the participant is required to press Z on the keyboard. However, the distractor (letter condition) demands the opposite and the participant would be required to press M on the keyboard: a conflicting or incongruent combination. A congruent situation is one in which both the cue and the distractor elicit the same response (e.g.'4a'). In the neutral condition the distractor bears no meaning and demands no response (e.g.'6?'). It is the expectation that participants will react slower to incongruent combinations than to neutral and congruent combinations (Kiesel, Wendt & Peters, 2007) . The participants will most likely respond to congruent combinations faster than to neutral combinations.

Figure 5: *Explanation of the task-switch task: the switch block.*

Statistical analysis

One-way analysis of variance (ANOVA) was utilized to test if the groups (TCC/control) differed significantly on demographic- and questionnaire related outcomes prior to the intervention.

Two-way repeated measures anova's (RMA) were used to detect differences between groups over time on TUG and OLST variables.

Two-way repeated measures ANOVA with a 2 (pre- and post-test) x 2 (block: pure block / mix-block) design were also utilized to detect differences between the two groups on global switchcost / mix-cost for accuracy and reaction time.

Three-way repeated measures ANOVA with a 2 (pre- and post-test) x 2 (trial: switch-repeat) x 3 (incongruent, congruent, neutral) design were used to detect differences between the two groups over time on switch and congruence for accuracy and reaction time.

To meet the assumption of sphericity RMAs were subjected to the Greenhouse-geiser adjustment when Mauchly's W proved to be significant. In case both the Mauchly's W statistic and Huyn-Feldt statistic exceed .750, the Huyn-Feldt correction is used. Pearson product-moment correlation coefficient (Pearson's r) was used to determine if a correlation existed between motoric

(TUG, OLST) and task-switch outcome variables (Acc switchcost and RT switchcost). Each of the the 4 variables (TUG, OLST, ACC SC and RT SC) consisted of a pre- and post-test measure. These were averaged (e.g. TUG pre-test + TUG-post-test / 2 = TUG) over their pre- and post-measure.

Eta-squared ($\eta 2$) expressed the effect size when a significant main or interaction effect was found. The alpha was set at .05 for statistical significance. Additionally the frequency distribution of the self-report survey answers were inspected to better understand the perceived difficulty and intensity of the TCC-course

Results

Participants

The one-way ANOVAs pointed out that the TCC and the control group did not differ significantly on Age, the MMSE score and the IPAQ score (**Table 1**). Found significant differences post-intervention can therefore not be ascribed to age, mental state or physical activity differences between the groups prior to the intervention.

TUG

Two-way RMA revealed a main effect of Time [$F(1,42) = 25.944$, $p < .001$, $\eta 2 = .382$] (**Table 2**, **Figure 6**). The means were significantly higher on the pre-test (5.64 seconds) compared to the post-test (5.20 seconds). Overall participants were faster on the TUG on the post-test and completed the task in less seconds.

Table 2 | TUG time on pre- and post-test in seconds (M ± SD).

Time	Mean
Pre-test	5.639 ± .141
Post-test	5.205 ± .150

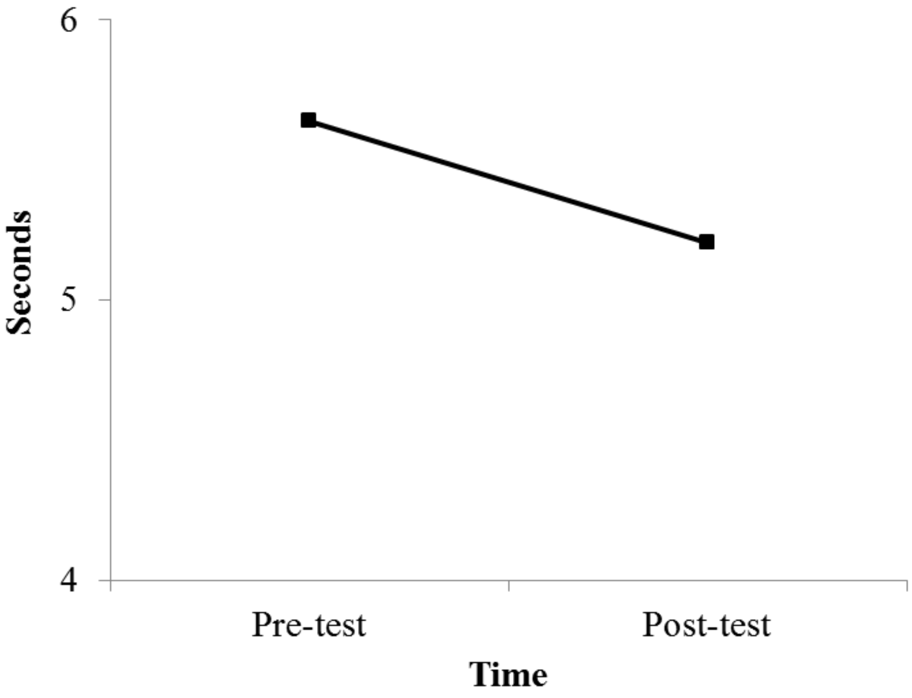


Figure 6: *TUG time in seconds between pre- and post-test.*

In addition an interaction was found for Time x Group [$F(1,42) = 25.944$, $p < .001$, $\eta 2 = .382$] (**Table 3**, **Figure 7**). Both groups were significantly faster on the post-test compared to the pre-test, but the TCC group improved more (needed less time on average to perform the task) than the control group did. This means that the TCC-condition (-.663 sec on average) was more beneficial to the performance on the TUG-task than the control condition (-.206 sec on average) was.

Table 3 | TUG time on pre- and post-test for TCC and Control group in seconds (M ± SD).

Group	**Time**	
	Pre-test	**Post-test**
TCC	5.642 ± .208	4.979 ± .222
Control	5.636 ± .190	5.430 ± .203

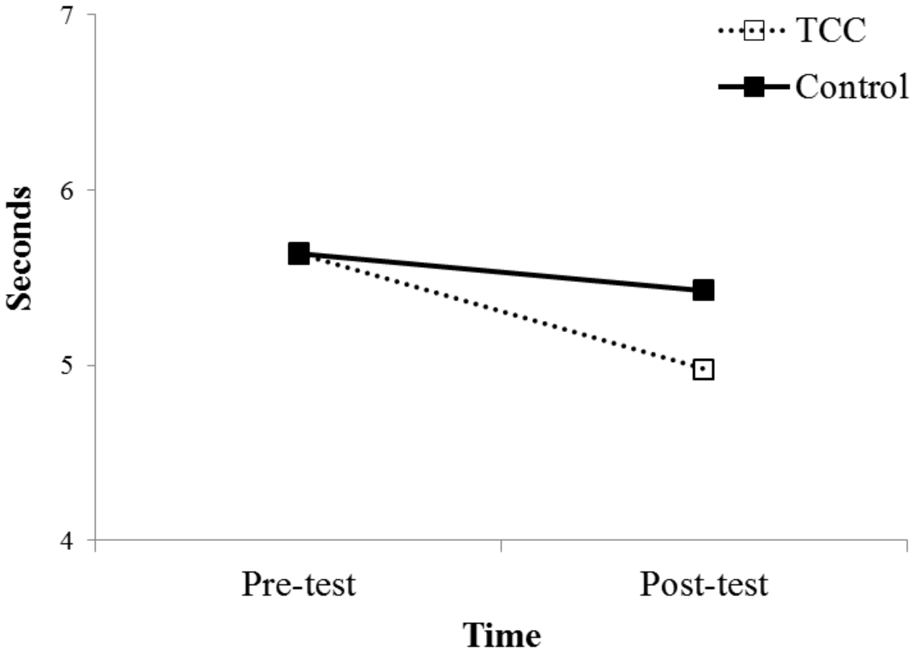


Figure 7: *TUG time for the TCC- and control-group between pre- and post-test (in seconds).*

OLST

Two-way RMA revealed that there was not a main effect of Time [$F(1,21) = .862$, $p = .364$, $\eta2 = .039$] nor was there an interaction effect for Time x Group [$F(1,21) = .057$, $p = .813$, $\eta2 = .003$] (**Table 4**). This means that there was no significant difference between pre- and post-test on OLST time for all participants and no significant difference between the two groups. On this statistic the TCC-intervention seems to have had no effect. It is important to note that the OLST-test statistic had a considerably lower sample size due to the fact that the OLST was erroneously omitted from the post-test in the first run of the research. The reduced amount of participants might have distorted results amongst participants or groups.

Table 4 | OLST time on pre- and post-test for TCC and Control group in seconds (M ± SD).

Group	Time	
	Pre-test	**Post-test**
TCC	41.178 ± 19.629	45.102 ± 16.011
Control	29.245 ± 19.191	31.560 ± 23.139

Accuracy, switch and congruence

Three-way repeated measures ANOVA revealed a significant main effect of Time [$F(1,42) = 10.890$, $p = .002$, $\eta 2 = .206$], indicating that all participants differed significantly on accuracy between the pre- and post-test. Inspecting of the means and the graph reveals that there was an increase in accuracy (2.2 %) between pre- and post-test, which means that all participants improved in accuracy over time (**Table 5**, **Figure 8**). Considering the fact that both groups improved over time regardless of condition, as there was no interaction effect between group and time, this might have been due to a learning effect. This would indicate mean that participants did better on the post-test because they already experienced the pre-test.

Table 5 | Accuracy on pre- and post-test in percent (M ± SD).

Time	Mean
Pre-test	92.9 % ± 1.4 %
Post-test	95.1 % ± 1.2 %

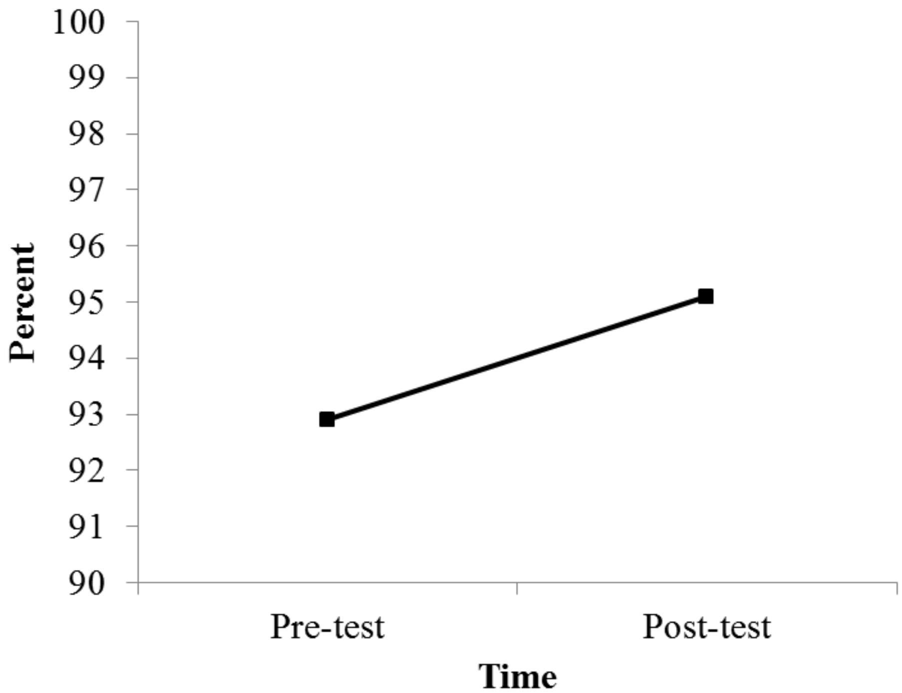


Figure 8: *Participant's mean accuracy between pre- and post-test (in percent).*

Also a significant main effect of Switch, [$F(1,42) = 45.310$, $p < .001$, $\eta 2 = .519$] was found: switching between repeat and switch proved to decrease accuracy significantly for all participants (**Table 6 + Figure 9**). Overall participants have a higher average accuracy on repeat trials (95.6 %) compared to switch trials (92.4 %). Changing in which rule to apply causes a decrease in accuracy.

Table 6 | Accuracy per switch in percent (M ± SD).

Switch	Mean
Repeat	95.6 % ± 1.2 %
Switch	92.4 % ± 1.4 %

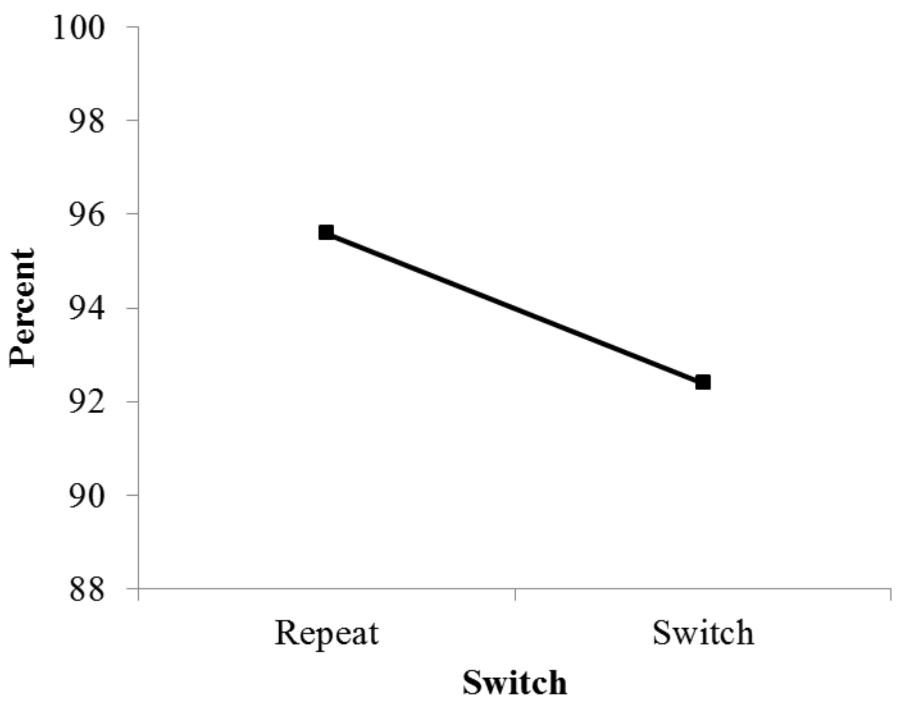


Figure 9: *Accuracy per switch (in percent).*

Also a significant main effect of Congruence, [$F(1.31,84) = 29.320$, $p < .001$, $\eta 2 = .411$] was found: an incongruent-, congruent or neutral redundant number, letter or symbol had an influence on accuracy (**Table 7 + Figure 10**). Overall participants have a higher average accuracy on neutral trials (95.3%) compared to congruent (95%) and Incongruent trials (91.7%).

Table 7 | Accuracy per congruence in percent (M ± SD).

Congruence	Mean
Congruent	95 % ± 1.2 %
Incongruent	91.7 % ± 1.4 %
Neutral	95.3 % ± 1.3 %

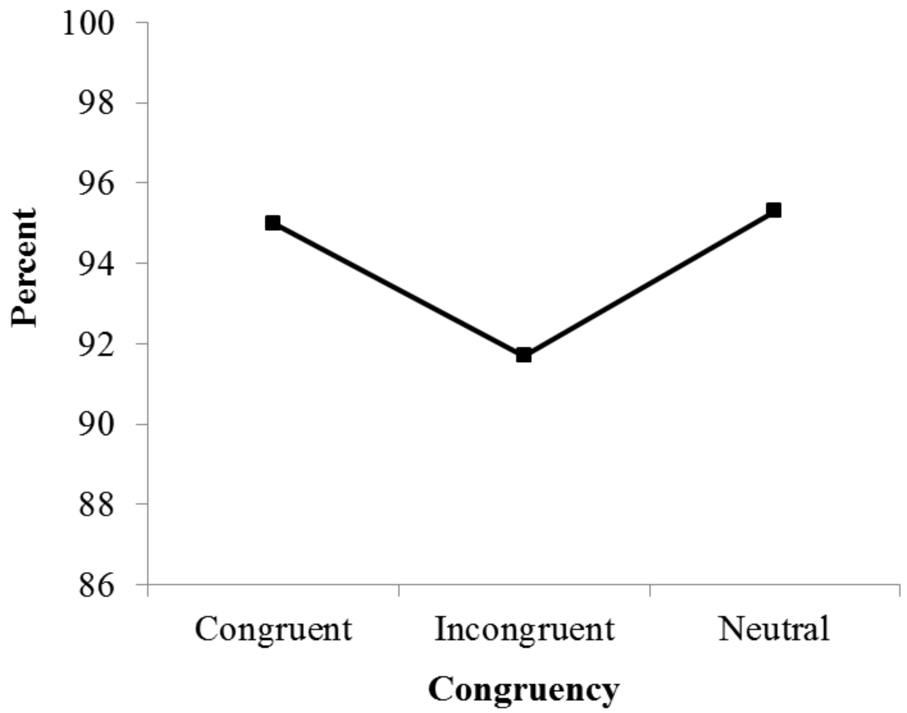


Figure 10: *Accuracy per congruence (in percent).*

In addition to the main effects an interaction effect was found for Switch x Congruence [$F(1.475, 84) = 12.552$, $p < .001$, $\eta 2 = .230$] (**Table 8 + Figure 11**). Overall the participants have a higher accuracy on repeat trials (96.6 % / 94.1 % / 96.2 %) compared to switch trials (93.3 % / 89.4 % / 94.4 %). In addition to this the switch condition seems to influence the accuracy per congruence. On the repeat trials participants have a slightly higher accuracy on the congruent condition (96.6 %) compared to the neutral trials (96.2%) and both congruent and neutral trials score higher than the incongruent trials (94.1%). However on the switch trials participants have the highest accuracy (94.4 %) on the neutral condition. On both repeat and switch incongruent trials have the lowest accuracy (94.1 % and 89.4 %). It seems that in the repeat condition congruent trials lead to a higher accuracy than neutral trials. In the switch condition however neutral trials lead to a higher accuracy than congruent trials.

Table 8 | Switch condition accuracy for each congruence in percent (M ± SD).

Group	Switch	
	Repeat	**Switch**
Congruent	96.6 % ± 1.1 %	93.3 % ± 1.3 %
Incongruent	94.1 % ± 1.3 %	89.4 % ± 1.6 %
Neutral	96.2 % ± 1.2 %	94.4 % ± 1.4 %

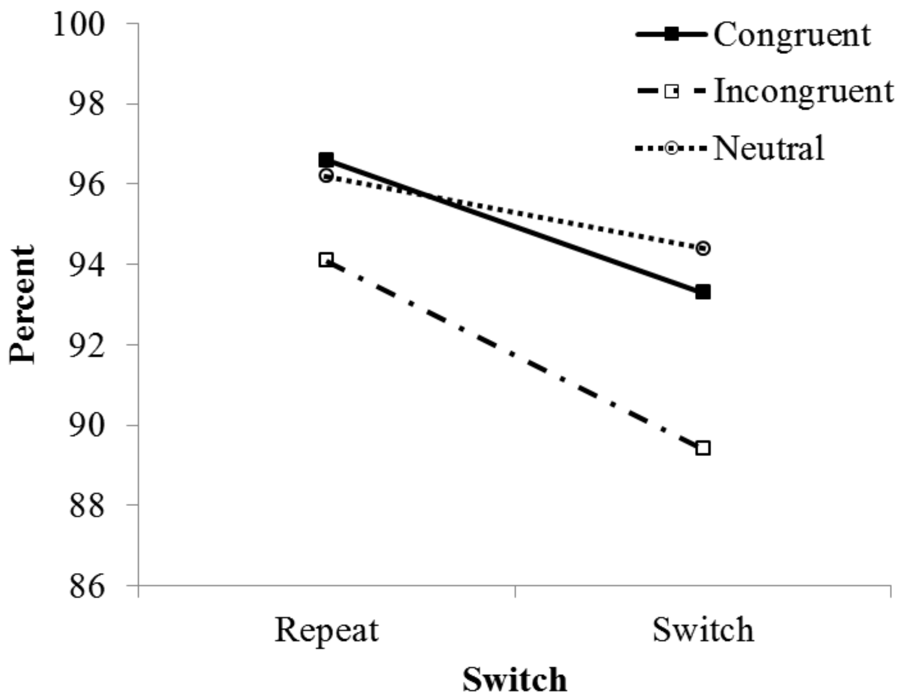


Figure 11: *Switch trial Accuracy per congruence (in percent).*

Accuracy pure- and mix-block

Two-way RMA lead to a significant main effect for Time [$F(1, 42) = 7.428$, $p < .01$, $\eta 2 = .150$] (**Table 9 + Figure 12)**. Inspection of the means reveal that participants overall had a higher accuracy on the post-test (96.2%) compared to the pre-test (93.9%). This might again be the result of a training effect.

Table 9 | Accuracy on pre- and post-test in percent (M ± SD).

Time	Mean
Pre-test	93.9 % ± 1.3 %
Post-test	96.2 % ± 0.7 %

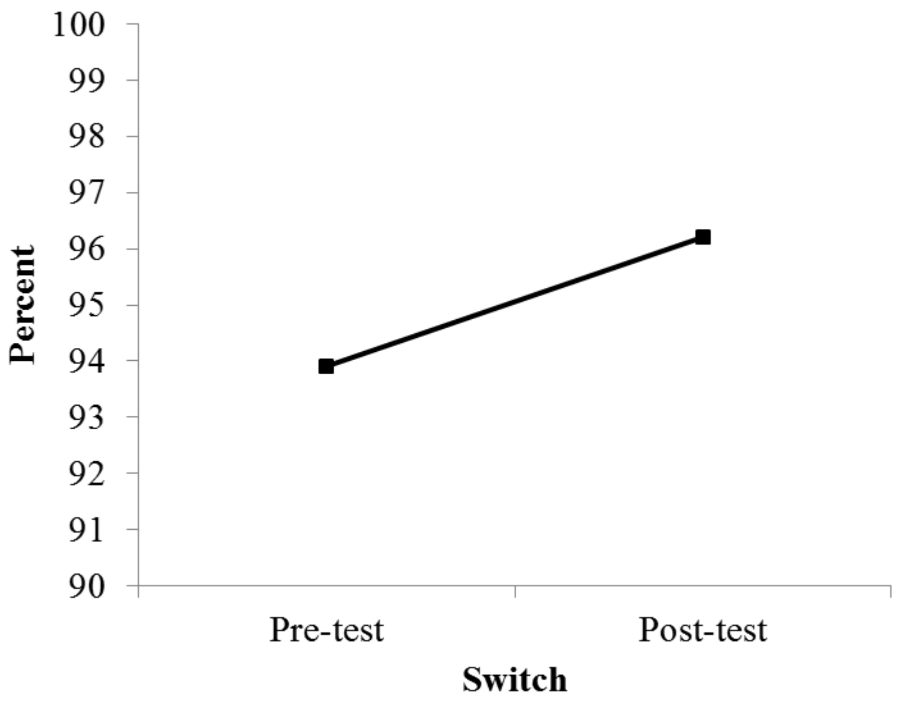


Figure 12: *Accuracy on pre- and post-test (in percent).*

Furthermore, Switch [$F(1, 42) = 6.099$, $p < .05$, $\eta2 = .127$] (**Table 10 + Figure 13)** turned out to be significant. The means indicate that participants had a higher accuracy on pure blocks (96.1%) compared to mix-blocks (93.9%). This effect is most likely explained by the fact that in the pure block condition only one rule has to be taken into account (e.g. is the number higher or lower than 5 / Is it a capital or lower case letter) instead of multiple rules in the mix-block condition.

Table 10 | Accuracy on Pure- and Mix-block in percent (M ± SD).

Time	Mean
Pure Block	96.1 % ± 0.8 %
Mix-Block	93.9 % ± 1.3 %

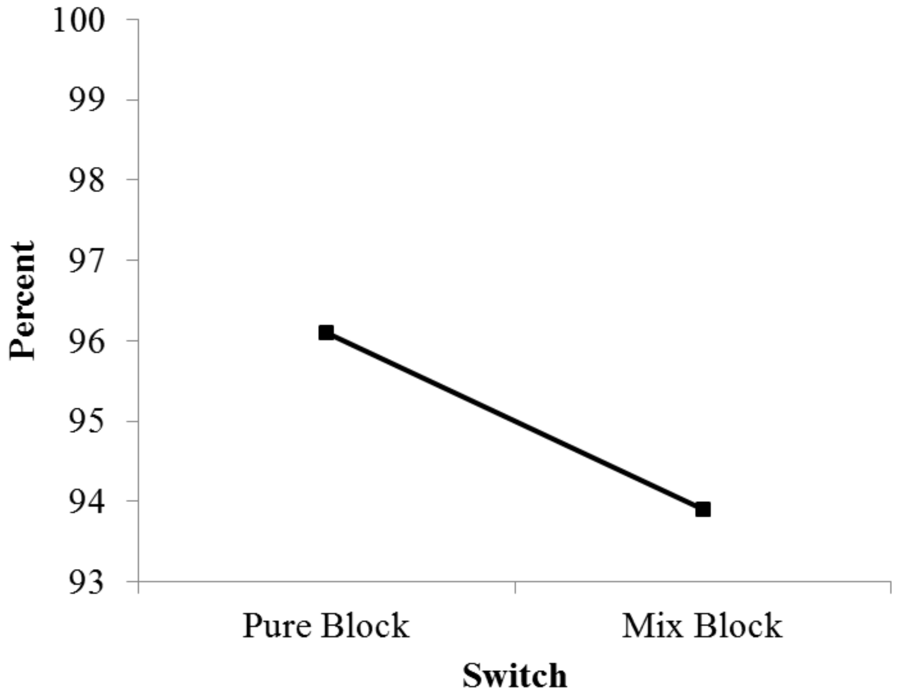


Figure 13: *Accuracy on Pure- and mix-blocks (in percent).*

Reaction time, switch and congruence

Three-way repeated measures ANOVA revealed a significant main effect of Time [$F(1,42) = 10.030$, $p < .01$, $\eta 2 = .193$] (**Table 11** + **Figure 14**). Regardless of intervention group membership all participants reacted faster on the post-test (1020.55 ms) compared to the pre-test (1099.15 ms).

Table 11 | RT on pre- and post-test in ms (M ± SD).

Time	Mean
Pre-test	1099.15 ± 41.46
Post-test	1020.55 ± 31.57

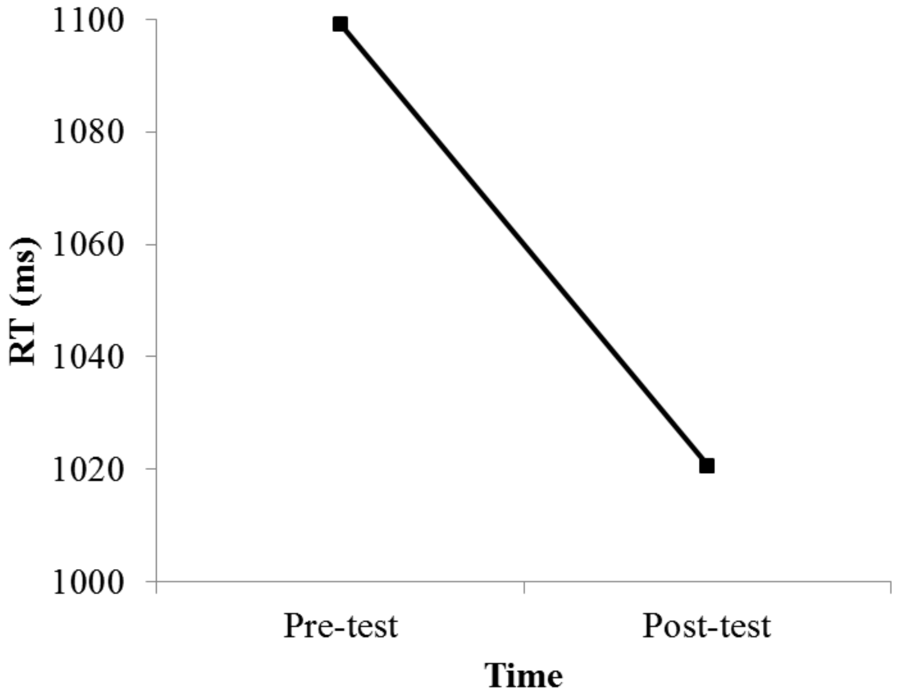


Figure 14: *Participant's mean accuracy between pre- and post-test (in percent).*

There was also a main effect of Switch [$F(1,42) = 194.984$, $p < .001$, $\eta 2 = .823$] (**Table 12 + Figure 15**): switching between repeat and switch proved to increase reaction time significantly for all participants: reaction time on switch-trials (1196.81 ms) was significantly longer compared to repeat-trials (922.89 ms).

Table 12 | RT per switch in ms (M ± SD).

Switch	Mean
Repeat	922.89 ± 29.51
Switch	1196.81 ± 41.58

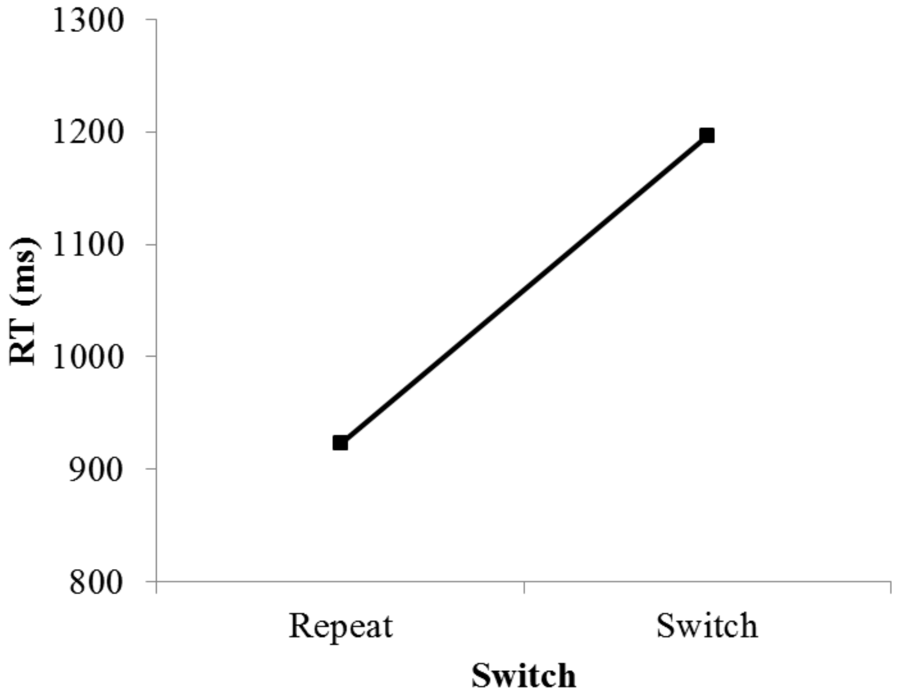


Figure 15: *RT for repeat/switch trials (in ms).*

Also a main effect for Congruence, [$F(1.648,84) = 116.528$, $p < .001$, $\eta 2 = .735$] was found, the role of the distractor number/letter or symbol caused an increase in reaction time (**Table 13 + Figure 16**). The mean reaction time of incongruent trials (1101.74 ms) proved to be the longest, followed by congruent (1092.25 ms) trials and neutral trials (985.56 ms). It seems the participants reacted the fastest to the redundant number/letter or symbol when it did not elicited a certain response.

Table 13 | RT per congruence in ms (M ± SD).

Switch	**Mean**
Congruent	1092.25 ± 36.68
Incongruent	1101.74 ± 37.87
Neutral	985.56 ± 31.22

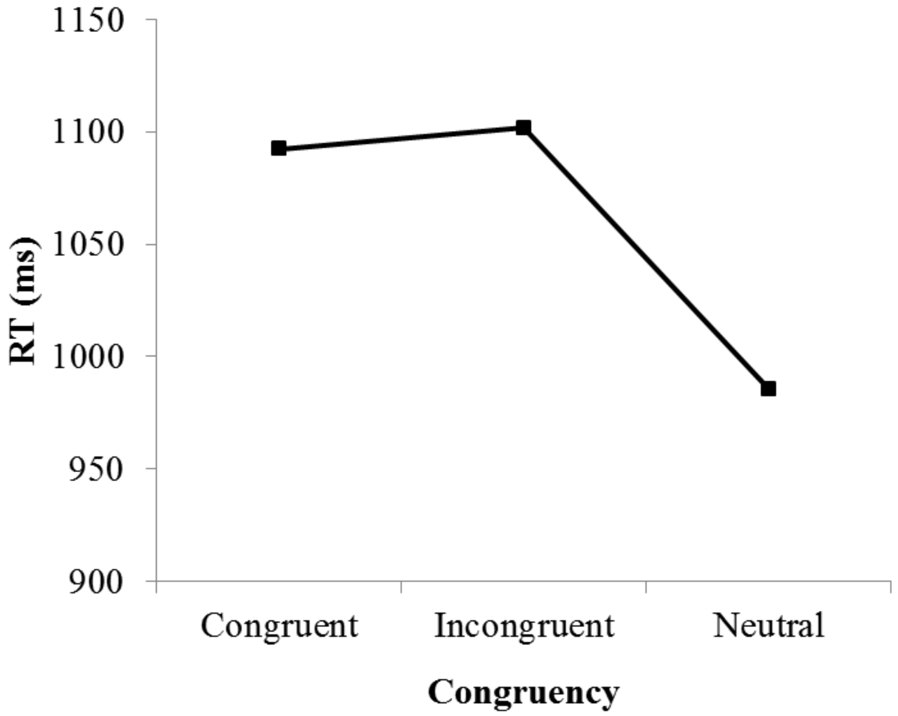


Figure 16: *RT per congruence (in ms).*

There was also an interaction effect apparent for Switch x Congruence [$F(1.92,84) = 36.254$, $p < .001$, $\eta 2 = .463$], indicating that a switching between repeat and switch caused different changes in reaction time per congruence (congruent, incongruent, repeat) (**Table 14**, **Figure 17**). Participants overall reacted faster to repeat trials (942.42/955.66/870.58ms opposed to 1242.08/1247.82/1100.53 ms). In addition to this participant reacted faster to neutral trials (870.58/1100.53 ms) than to congruent trials (942.42/1242.08 ms) and incongruent trials (955.66/1247.82 ms). It seems that participants react faster when the redundant digit/number/symbol does not elicit a response, perhaps neutral trials need less processing than congruent and incongruent trials. This opposes the hypothesis that congruent trials would lead to the fastest RT. The fact that participants react faster to congruent trials than to incongruent trials is probably explained by the fact that the congruent stimuli elicit the same response instead of the opposed response.

Table 14 | Switch trial RT for each congruence in ms (M ± SD).

Group	Switch	
	Repeat	**Switch**
Congruent	942.42 ± 30.80	1242.08 ± 42.69
Incongruent	955.66 ± 32.23	1247.82 ± 45.39
Neutral	870.58 ± 26.37	1100.53 ± 37.64

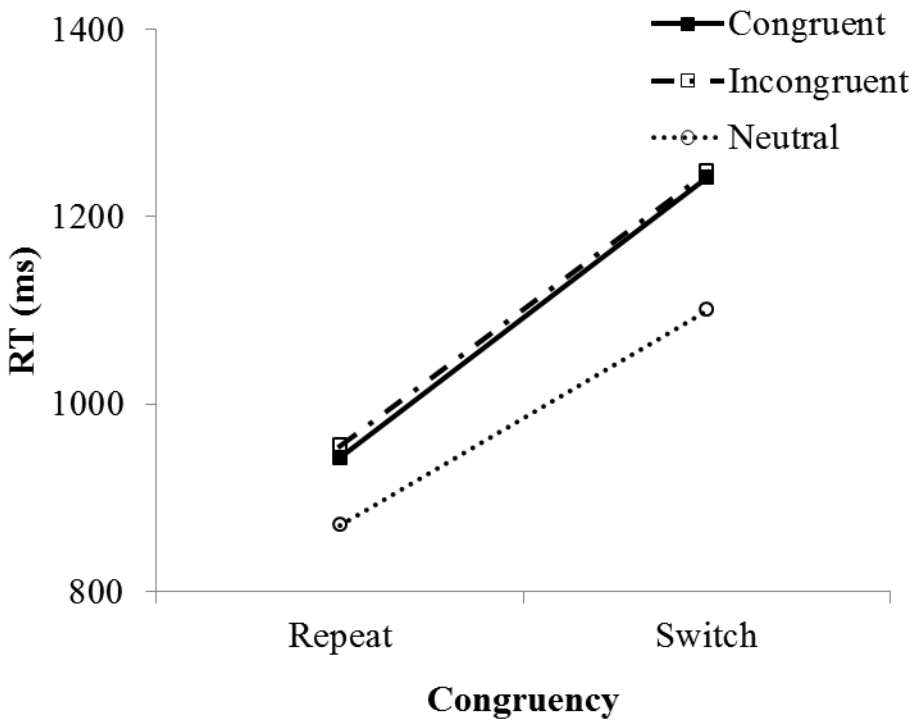


Figure 17: RT on *switch/repeat trials per congruence (in ms).*

Reaction time pure- and mix-block

Two-way RMA lead to a significant main effect for Switch [$F(1, 42) = 6.510$, $p < .05$, $\eta 2 = .703$] (**Table 15 + Figure 18)**. Inspection of the means and the graph reveals that participants overall responded slower to the mix-block (1056.19 ms) than to the pure blocks (867.86 ms). This makes sense considering the fact that in the pure block participants only needed to apply one rule and the stimuli were thus easier to interpret.

Table 15 | RT on Pure- and Mix-block in ms (M ± SD).

Time	Mean
Pure Block	867.86 ± 69.18
Mix-Block	1056.19 ± 34.15

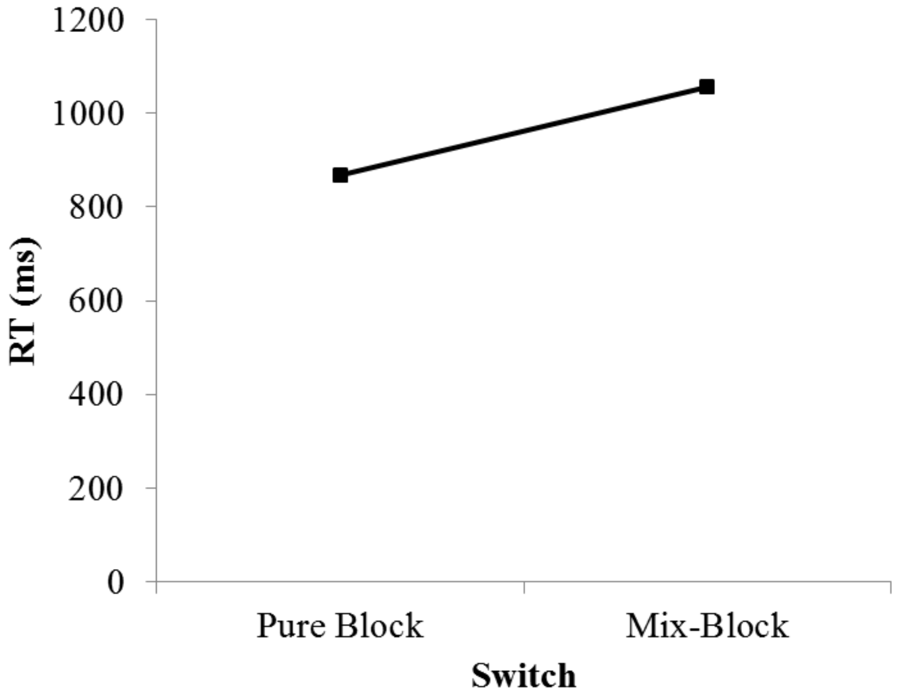


Figure 18: *Pure- and mix-block RT (in ms).*

The correlation between motor skill (TUG/OLST) and executive function (switch-cost acc and RT)

The four variables to be checked for a possible correlation each consist of a pre- and post-test measure. These measures were averaged per variable resulting in averages for TUG, OLST, SC Acc and SC RT (**Table 16**). These variables were subsequently checked using bivariate correlation analyses (**Table 17**).

Table 16 | Average means for TUG, OLST, SC_Acc and SC_RT (M ± SD).

Variable	**Mean**
TUG	5.43 ± 0.92
OLST	36.49 ± 18.77
SC_Acc	.031 ± .026
SC_RT	275.26 ± 126.21

Table 17 | Correlation between TST- and motoric variables (Pearson's r).

Variables	TUG	OLST	SC_Acc	SC_RT
TUG	-			
OLST	-.495*	-		
SC_Acc	-.001	-.153	-	
SC_RT	.220	-.395	.431**	-

Correlation significant (2-tailed): * $p < .05$, ** $p < .01$, *** $p < .001$.

The variables TUG and OLST turned out to be negatively correlated (r = -.495, n = 23, $p < .05$) (**Table 17 + Figure 19**). This correlation was to be expected given the fact that both the TUG and OLST share measured factors (balance/gait). The means indicate that when a participant improves on the TUG (performs the task faster) the time on the OLST is generally longer (able to stand on one leg longer). Likewise when a participant is able to stand on one leg for a longer period of time he or she likely is able to walk to the wall and back faster.

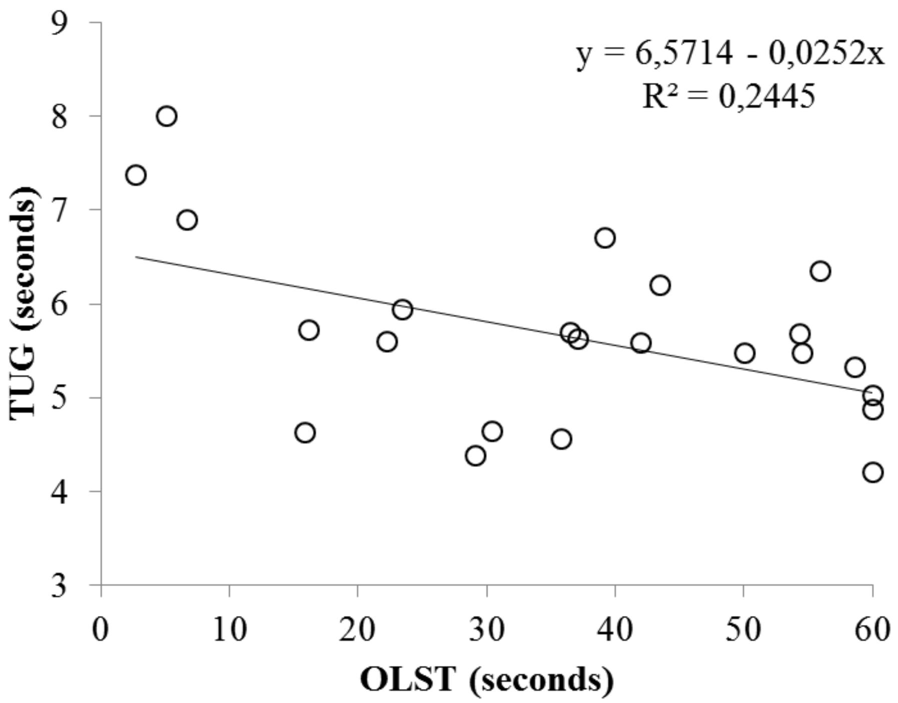


Figure 19: *Negative correlation between average TUG and OLST variables.*

Furthermore, SC_RT and SC_Acc turned out to be positively correlated (r = 431, n = 44, $p < .01$) (**Table 17 + Figure 20)**. The variable SC_RT reflects the reduction in RT due to switching between a repeat and switch trial and the variable SC_Acc reflects the reduction in accuracy due to switching between repeat and switch trial (e.g. a participant with a score of x = 14,8 and y = 523 scored lost 14,8 percent in accuracy and 523 ms in RT on average between pre- and post-test due to switching between repeat and switch trials) . The scatter plot indicates that the larger the reduction in accuracy due to switching was, the longer the reaction time due to switching was. This indicates that a faster reaction is accompanied by a higher accuracy on switch-trials. A possible explanation is that the participants were faster in recognizing which rule to apply and what the correct response was. The hypothesized correlation between motoric variables (TUG, OLST) and switch-cost variables (SC_Acc, SC_RT) did not turn out to be significant. This means that improving on motoric variables does not increase performance in terms of a higher switch accuracy or a faster switch reaction time. Thus motoric variables were not predictive of switch cost accuracy / switch cost accuracy or vice versa.

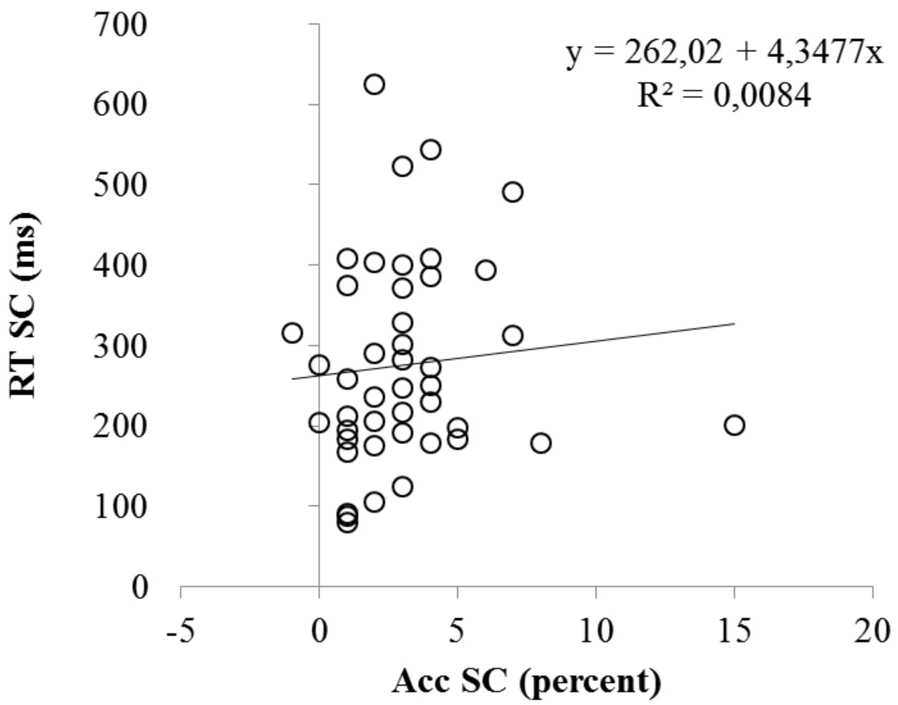


Figure 20: *Positive correlation between average SC_Acc and SC_RT.*

Self-reported evaluations

Physical intensity

The majority of participants report not having experienced heavy breathing (60.2%) or only slight heavy breathing (23.6%), not expecting muscle pain the next day (82.63%) and report no elevation in their heartbeats (61.4%) or slight elevation (13.6%) or were neutral in this respect (24.8%) (**Table 18**). Overall the TCC-course was not experienced as very taxing on the body.

Discomfort

Discomforting factors might harm the participants ability to perform the exercises properly and benefitting from the TCC-course. However the majority of the participants report no pain (63.1%) or slight pain (25%) and report feeling no muscle stiffness (41%) or feeling slight muscle stiffness (42.4%) (**Table 18**). Discomfort does not seem to be an issue with the current TCC-course design.

Table 18 | Frequency distribution self-report variables (frequency + percent)

	Response				
Statement	Not at all	Somewhat	Neutral	Reasonably	Very much
Breathing heavily	253 (60.2%)	67 (16%)	99 (23.6%)	1 (.2%)	0 (0%)
Muscle pain	347 (82.63 %)	30 (7.13%)	38 (9%)	4 (1%)	1 (.24%)
Heartbeat	258 (61.4 %)	57 (13.6%)	104 (24.8%)	1 (.2%)	0 (0%)
Pain	265 (63.1 %)	105 (25%)	43 (10.23%)	6 (1.43%)	1 (.24%)
Muscle stifness	172 (41%)	178 (42.4%)	52 (12.3%)	13 (3.1%)	5 (1.2%)
Twist waist	2 (.5%)	56 (13.3%)	62 (14.8%)	245 (58.3%)	55 (13.1%)
Stand straight	0 (0%)	13 (3.1%)	27 (6.4%)	296 (70.5%)	84 (20%)
Wrist straight	3 (.7%)	13 (3.1%)	52 (12.4%)	242 (57.6%)	110 (26.2%)
Balance	0 (0%)	18 (4.3%)	52 (12.4%)	268 (63.8%)	82 (19.5%)
Instructions easy	4 (1%)	61 (14.5%)	107 (25.5%)	200 (47.6%)	48 (11.4%)
Tough session	57 (13.6%)	160 (38.1%)	136 (32.3%)	60 (14.3%)	7 (1.7%)

The frequencies are the combined responses for twenty sessions per participant (420 responses per statement)

Physical capability

Participants report being able to twist at the waist reasonably- (58.3%) or very well (13.1%). However a substantial amount of participants (13.3%) report being somewhat able to twist at the waist (**Table 18**). This might have interfered with their ability to perform the exercises. The majority of the participants report being able to stand up reasonably- (70.5%) or very well (20%). Lastly, the majority of the participants say to be able to balance reasonably- (63.8%) or very well (19.5%).

Course toughness

The participants seemed to be divided on the matter of interpreting the instructions. The majority finds the instructions to be reasonably easy to understand (47.6%) and a smaller group found the instructions very easy to follow (11.4%). However there is also a group of participants that found the instructions somewhat hard to understand (14.5%). On the toughness of the course in general the responses were also divided: some found it not hard at all (13.6%) while others found the course to be reasonably hard (14.3%). The majority of the responses were divided between somewhat difficult (38.1%) and averagely difficult (32.3%) (**Table 18**).

Discussion and conclusion

1. Does Tai Chi increase task-switch performance and gait speed in older adults? 2. Is an increased performance in motoric functioning (balance/gait) associated with an increased performance in executive functioning (task-switch performance)?

TCC and motoric functioning in older adults

Results of this research indicate that TCC is beneficial to balance and mobility in older adults. Older adults in the TCC-condition were able to perform the TUG-task faster compared to older adults in the control-condition. These findings reflect the findings of research done by Audette (2006) on the effects of Tai Chi vs Brisk walking on the strength, balance and flexibility in elderly women. She concluded that a 3 month Tai Chi course (3 hours per week) was more beneficial to strength, balance and flexibility than brisk walking was. The beneficial effects of TCC on balance have also been attested in research done by Wong et al. (2001), in this research TCC practitioners outperformed healthy older adults in challenging balance conditions (e.g. rhythmic forward-backward weight shifting). Found results support the notion that TCC is beneficial to the balance in older adults (Audette, 2006; Wong et al., 2001).

However the second measure of balance included in this research makes matters less clear cut. The OLST did not reveal any significant differences between TCC and the control group on the pre- and post-test. This begs the question: what differences are there between the TUG- and the

OLST-task that might explain this? The main difference between these two balance tasks is that of static (one-legged stance) vs dynamic balancing (balance + gait). The OLST task requires the participant to balance in place, while the TUG-task requires the participant to balance while walking. Previous research has yielded different results for static and dynamic balancing (Wong et al., 2001). The results of this research replicate those found by Wong et al. (2001) which showed no significant differences between group on static postural control (balancing on one leg) but did show differences on dynamic postural control (balancing on a swaying surface). This shows that TCC might be more beneficial to dynamic balancing compared to static balancing. Interestingly results on the static postural balancing differ for conditions in which the participant is standing under conflicting somatosensory, visual or vestibular conditions (e.g. blindfolded or standing on an inclined / 'sway-referenced' platform) (Tsang et al., 2004). TCC-practitioners seem to be better able to maintain balance in these more challenging conditions. Similar results have been found in research done by Wong et al. (2011). They compared elderly participants in two low-impact exercise groups (swimming, and TCC) to a control group. They found that swimming and TCC both improved hand-eye coordination on a sequential-pointing task. In addition to this only the TCC group improved on dynamic balancing under challenging conditions. These challenging conditions ranged from balancing while blindfolded to open-eyed balancing in a sway-referenced enclosure (Wong et al., 2011). This suggests that TCC benefits balance when relying on visual or vestibular conditions. As the current research does not examine these reduced visual or vestibular conditions, the absence of results on the OLST-task might be explained in the light of the research by Tsang et al. (2004) and Wong et al. (2011). The OLST only had one balance condition: open-eyed and did not include a sway referenced room or an inclined platform to balance on. It might be that TCC-group participants did improve compared to the control group on static balancing but not in the less challenging conditions.

TCC and Task-switching

Participants regardless of group responded faster and more accurately in homogeneous conditions (apply one rule) compared to heterogeneous (switch between rules) conditions. Previous studies show similar results (Fong et al., 2014; Philipp et al., 2008 & Themanson, Hillman & Curtin, 2006) This is explained by the fact that in the heterogeneous condition participants have an additional rule to keep in mind when judging the stimulus. This additional rule causes more mistakes and a slower reaction time.

Furthermore participants reaction time and accuracy were influence by congruence on both trial and block level. On trial level the redundant number/digit/symbol in the stimulus combination influenced the accuracy and reaction time of the participants. On block level the switch between pure- or mix-blocks affected the accuracy and reaction time of participants as well. As hypothesized the participants responded faster and more accurately to congruent- opposed to incongruent conditions. This finding supports the notion that incongruent stimuli lead to longer reaction times and higher error rates (Kiesel, Wendt & Peters, 2007). In general the results for each congruence followed the same pattern for repeat and switch conditions: the participants did best for the neutral condition (fastest RT, highest accuracy), followed by the congruent and the incongruent condition (slowest RT, lowest accuracy). The only exception to this pattern are the results of accuracy on the repeat trials: the participants did slightly better on the congruent trials than on the neutral trials. The assumption that congruent trials would lead to the fastest RT and highest accuracy did not hold true as neutral trials turned out to elicit the fastest reaction time in all conditions and the highest accuracy in nearly all switch conditions. A possible explanation is that the redundant symbol did not elicit a response at all in the neutral condition. The symbol might not have needed as much processing as a digit or number associated with either a congruent or incongruent rule.

Based on previous research on the effect of physical activity on the performance on executive control tasks (Smiley-Oyen et al., 2008; Hawkes, 2012) it was the assumption that the TCC practitioners would improve more over time than their control counterparts. This however did not turn out to be the case: neither of the groups developed significantly over time on the global/mix- or (local) switch costs. This opposes research by Smiley-Oyen et al. (2008) that aerobic exercise is beneficial to the performance on tasks that rely heavily on executive control (e.g. TST). Considering the fact that TCC is considered a moderately aerobic activity (Chang et al., 2010) the assumption was that similar results would be apparent on the TST. The absence of these results might be explained by two reasons: 1) the Stroop-task, the executive task used in the research of Smiley-Oyen et al., is more sensitive to the influence of physical activity than the TST is or 2) the length of the intervention, which according to Smiley-Oyen (2008) leads to more robust fitness gains, was too short (10 weeks in the current research vs 8 months of aerobic exercise in the other research).

The results also contradict the research by Hawkes (2012) who concluded that it was the combination of exercise and fitness, not solely physical exercise, that leads to lower local switch costs on the TST. Considering that TCC contains both exercise and meditation similar results were expected, however the local switch costs of the two groups did not differ significantly.

Interconnectivity motoric (TUG/OLST) and task-switch outcomes (RT/Acc)

Based on previous research it was hypothesized that the research would reflect an interconnectivity between task-switch performance and motoric variables: balance and/or gait speed (Hausdorff et al., 2005; Holtzer et al., 2006; Nadkarni et al., 2013). Nadkarni and colleauges (2013) concluded that areas of the brain associated with executive function show the strongest relationship with gait speed. Holtzer and colleagues (2006) also attested the relationship between gait speed and some executive functions in their research. Also Hausdorff and colleagues (2005) found a similar result in their research: walking in older adults is associated with executive function or higher cognitive resources more so than with memory and general cognition. However, improved performance on motoric tasks (in this case TUG) could not be linked to an improved performance on the TST. It seems the participants in the TCC condition mostly improved only on balance and gait during the intervention. This might mean that TCC improves TUG-times solely because TCC is a form of physical exercise. The improved gait and balance possibly explains why the TCC practitioners outperformed the control group (who did not exercise). As mentioned before the absence of any between group differences on the OLST hints that TCC might be more beneficial to dynamic as opposed to static balance.

Based on previous research the expectation was that the TCC-group would differ from the control group considering the beneficial effects aerobic exercise or the combination of exercise and mediation would have on the task-switch performance (Audette, 2006; Fong et al., 2014; Hawkes, 2012; Hillman, 2006; Smiley-Oyen, 2008; Themanson, Hillman & Curtin, 2006; Tsang et al., 2013). The absence of this effect might be explained by the fact that the intensity of the physical exercise aspect of TCC, which is mildly aerobic (Chang et al., 2010), is not high enough to bring about the beneficial effects on cognitive functioning related to task-switching. The frequencies reported on the self-report support this notion and indicate that the majority of participants report not having experienced heavy breathing (60.2%) or only slight heavy breathing (23.6%), not expecting muscle pain the next day (82.63%) and report no elevation in their heartbeats (61.4%), slight elevation in their heartbeats (13.6%) or were neutral in this respect (24.8%).

Limitations and future research

It must be taken into account that the number of participants associated with the OLST condition was small: 11 in the TCC condition and 12 participants in the control condition. The results that were derived from this group of participants might not be sufficiently applicable for a larger population. In the future research involving an OLST needs to have at least 15 participants per condition.

It is also worth noting that the participants practiced alone in the comfort of their home. For this reason the way in which participants followed the instructions and performed the exercises could only be inspected indirectly (through self-report feedback) but not directly (through participant teacher interaction).

Another important aspect of the intervention is the absence of contact with other TCC-practitioners, which is normally the case in actual tai chi group lessons. It might be that this social aspect contributes to the positive effect tai chi has on body and cognition. For example people might be more inclined to do their best and get motivated when they see their peers performing the same exercises. In addition to this some participants have experienced some difficulties with operating a computer. It is advisable to replicate this research with both an at home e-course TCC condition and a TCC course in which the group-members meet for each session. In this way effects that are caused by social factors can be isolated. In addition to this the majority of the participants were averagely active (19/44 participants) or highly active (20/44 participants), only a few were reported to have a low activity on the IPAQ scale (5/44 participants). This might have influenced the efficacy of the TCC-intervention. It is advisable to include more participants with a low activity score on the IPAQ as it might be that it is this group that benefits the most from engaging in TCC . It could be that a significant difference between the control and the TCC group will be found in that scenario. This would however suggest that it is solely physical exercise that brings about the beneficial effects of TCC on task-switching.

The influence of TCC on the dynamic balancing as opposed to static balancing in older adults might warrant more research in this area. Current research could not investigate the relationship between TCC and static balancing under more challenging conditions. Future research should implement varying degrees of somatosensory or vestibular conditions for static balancing to fully understand the extent to which TCC influences balancing in older adults.

This paper tried to single out the effect of TCC on the performance on the TST and motoric variables to explore a possible link between these variables. Although this research could not conclude there was such a link, this might still exist between TCC, motor tasks and other cognitive tasks (e.g. Stop-signal task or the N-back task). It is recommended to explore this possible relation between other motoric- and cognitive tasks. Such a finding could attest the interconnectivity between the motor- and cognitive domain and could prove to be invaluable for future healthcare programs focused on counterbalancing age-related cognitive decline and decreasing mobility in older adults.

Furthermore, it is of importance to research what length of the TCC course, what intensity per session and what frequency per week brings about the physical and cognitive benefits described by other research papers. Based on this information an ideal TCC-course could be devised and the interconnectivity of motoric- and cognitive functioning could be more thoroughly researched.

Conclusion

The results of this research suggest that a 10-week TCC-intervention can produce significant improvements in gait and dynamic- (TUG: balancing while moving) as opposed to static balancing (balancing in place on one leg) in older participants. There were no differences apparent between the two conditions in performance on the TST. The hypothesized interconnectivity between the motoric- (TUG/OLST) and cognitive domain (TST) could not be confirmed. Future research might benefit from more challenging conditions on the OLST which incorporate visual- and vestibular conditions. It is advisable to replicate this research for the other executive functioning tasks (e.g. the Stop-signal task or the N-back task) to assess the influence of TCC on other aspects of executive functions. Furthermore, it might be of importance to examine the extent to which the social aspect of TCC-exercise is beneficial to task-switching performance. The interconnectivity between motoric- and executive functioning remains an interesting subject to explore in future research and could prove to be invaluable in future healthcare interventions focused on counterbalancing age-related cognitive decline.

Appendices

Appendix A1   International Physical Activity Questionnaire (IPAQ) (TCC)

1. Denkt u aan alle zware lichamelijke activiteiten die u deed in de afgelopen 7 dagen. Zware lichamelijke activiteiten zijn activiteiten waar u meer dan tien minuten mee bezig bent, veel lichamelijke inspanning kosten en voor een veel snellere ademhaling zorgen.
Als u denkt aan de afgelopen 7 dagen, op hoeveel van deze dagen heeft u zware lichamelijke activiteiten verricht zoals zware lasten tillen, spitten, aerobics of wielrennen? (0 – 7)

2. Op de dagen dat u zwaar lichamelijk actief was, hoeveel tijd heeft u daar dan gewoonlijk aan besteed?

- Indien méér dan 1 uur per dag, aantal uren per dag:
- Indien minder dan 1 uur per dag, aantal minuten per dag:
- Weet niet / niet zeker

3. Denkt u aan activiteiten die matige lichamelijke inspanning kosten en die u in de afgelopen 7 dagen heeft verricht. Matig intensieve lichamelijke activiteit laat u iets sneller ademen dan normaal. Denkt u weer alleen aan activiteiten die u ten minste 10 minuten per keer heeft verricht.
Als u denkt aan de afgelopen 7 dagen, op hoeveel van deze dagen heeft u matig intensieve lichamelijke activiteit verricht, zoals het dragen van lichte lasten, fietsen in een normaal tempo of licht sporten? Laat wandelen hier buiten beschouwing. (0-7)

4. Op de dagen dat u matig lichamelijk actief was, hoeveel tijd heeft u daar dan gewoonlijk aan besteed?

- Indien méér dan 1 uur per dag, aantal uren per dag:
- Indien minder dan 1 uur per dag, aantal minuten per dag:
- Weet niet / niet zeker

5. Als u denkt aan de afgelopen 7 dagen, op hoeveel dagen heeft u tenminste 10 minuten per keer gewandeld? Denk hierbij aan wandelen op het werk en thuis, wandelen om van de ene naar de andere plaats te komen, en al het andere wandelen dat u deed tijdens recreatie, sport of

vrijetijdsbesteding. (0-7)

6. Op de dagen dat u ten minste 10 minuten per keer wandelde, hoeveel tijd heeft u daar dan gewoonlijk aan besteed?

- Indien méér dan 1 uur per dag, aantal uren per dag:
- Indien minder dan 1 uur per dag, aantal minuten per dag:
- Weet niet / niet zeker

7. Hoeveel tijd bracht u gewoonlijk zittend door gedurende een doordeweekse dag in de afgelopen 7 dagen? Bijvoorbeeld: zittend achter een bureau, tijd die zittend wordt doorgebracht met vrienden, zittend lezen, studeren of tv kijken.

- Indien méér dan 1 uur per dag, aantal uren per dag:
- Indien minder dan 1 uur per dag, aantal minuten per dag:
- Weet niet / niet zeker

Appendix A2 International Physical Activity Questionnaire scoring protocol (short form)

Category 1 Low

The lowest level of physical activity. The individuals who do not meet the criteria for either Moderate or High activity have a 'low' physical activity level.

Category 2 Moderate

For a participant to be scored as moderately active he/she needs to meet one of the following criteria:

1) Three or more days of vigorous-intensity activity of at least 20 minutes per day.

2) Five or more days of moderate-intensity activity and/or walking of at least 30 minutes per day.

3) Five or more days of any combination of walking, moderate-intensity or vigorous intensity activities achieving a minimum of 600 MET-minutes per week.

Category 3 High

For a participant to be scored as highly active one of the two following criteria need to be met:

1) Three or more days of vigorous-intensity activity for a total of at least 1500 MET-minutes per week.

2) Seven or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 3000 MET-minutes per week.

Appendix B   Mini-Mental State Examination (MMSE)

1. a. Welk jaar is het ? 0 – 5 punten

   b. Welk seizoen is het?
   c. Welke maand van het jaar is het?
   d. Wat is de datum vandaag?
   e. Welke dag van de week is het?

2. a. In welke provincie zijn we nu? 0 – 5 punten

   b. In welke plaats zijn we nu?
   c. In welke instelling zijn we nu?
   d. Wat is de naam van deze afdeling?
   e. Op welke verdieping zijn we nu?

3. Ik noem nu drie voorwerpen. Wilt u die herhalen nadat ik ze alle drie gezegd heb? Onthoud ze want ik vraag u ze over enkele minuten opnieuw op te noemen. (Noem ‘appel’, ‘sleutel’, ‘tafel’, neem 1 seconde per woord.) (1 punt voor elke goed antwoord, herhaal maximaal 5 keer tot de participant de drie woorden weet) 0 – 3 punten

4.a Wilt u van de 100 zeven aftrekken en van wat overblijft weer zeven aftrekken en zo doorgaan tot ik stop zeg? (Herhaal eventueel 3 maal als de persoon stopt, herhaal dezelfde instructie, geef maximaal 1 minuut de tijd) Noteer hier het antwoord.

of

4.b Wilt u het woord “worst” achterstevoren spellen?. 0 – 5 punten

Noteer hier het antwoord.

5. Noemt u nogmaals de drie voorwerpen van zojuist. 0 – 3 punten
   (Eén punt voor elk goed antwoord).

6. Wat is dit? En wat is dat? 0 – 2 punten

(Wijs een pen en een horloge aan. Eén punt voor elk goed antwoord).

7. Wilt u de volgende zin herhalen: “ Nu eens dit en dan weer dat”. 0 – 1 punten

(Eén punt als de complete zin goed is)

8. Wilt u deze woorden lezen en dan doen wat er staat? 0 – 1 punten

(papier met daarop in grote letters: “Sluit uw ogen”)

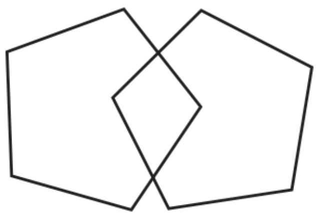
9. Wilt u dit papiertje pakken met uw rechterhand, het dubbelvouwen en het op uw schoot leggen? (Eén punt voor iedere goede handeling).

0 – 3 punten

10. Wilt u voor mij een volledige zin opschrijven op dit stuk papier?
(Eén punt wanneer de zin een onderwerp en een gezegde heeft en betekenis heeft).

0 – 1 punten

11. Wilt u dit figuur natekenen?
(Eén punt als het figuur geheel correct is nagetekend. Er moet een vierhoek te zien zijn tussen de twee vijfhoeken. 0 – 3 punten



Appendix C1 Self-report Survey TCC group

Helemaal niet / Enigszins / Neutraal / Behoorlijk / Zeer

1. Kon u de instructie makkelijk volgen?
2. Hoe zwaar of moeilijk vond u deze sessie?
3. Had u het gevoel dat u met Tai Chi bezig was?
4. Heeft u het idee dat u goed mee heeft gedaan?
5. Voelt u zich ontspannen?
6. Hoezeer ervaart u een gevoel van stress?
7. Had u tijdens de sessie het gevoel scherp en alert te zijn?
8. Had u gedurende de sessie een slaperig gevoel, of dommelde u weg?
9. Kon u makkelijk en natuurlijk ademhalen?
10. Had u het gevoel dat iets uw ademhaling blokkeerde?
11. Kon u zich makkelijk concentreren op uw bewegingen?
12. Als u van de oefening afdwaalde kon u makkelijk met uw aandacht terugkeren?
13. Had u een snellere ademhaling?
14. Had u een verhoogde hartslag?
15. Had u last van lichamelijke stijfheid?
16. Denkt u dat u morgen spierpijn zal hebben?
17. Heeft u pijn ervaren tijdens de sessie?
18. Lukt het om tijdens het bewegen uw spieren te ontspannen?
19. Lukt het om met uw buik adem te halen?
20. Lukt het goed om uw balans te bewaren?
21. Voelt u wanneer uw voet vol of leeg is?
22. Voelt u uw zwaartepunt, hoog of laag?
23. Lukt het uw aandacht in een deel van uw lichaam te brengen en weer terug te trekken?
24. Lukt het om vanuit uw middel te draaien?
25. Lukt het om goed rechtop te staan en te bewegen?
26. Lukt het om uw hand en pols zo veel mogelijk in één lijn te houden?

Appendix C2 Self-report Survey Control group

Helemaal niet / Enigszins / Neutraal / Behoorlijk / Zeer

1. Kon u de video makkelijk volgen?
2. Hoe zwaar of moeilijk vond u deze aflevering?
3. Had u het gevoel dat u bezig was met kijken?
4. Heeft u het idee dat u mee heeft gedaan met de video?
5. Voelt u zich ontspannen?
6. Hoezeer ervaart u een gevoel van stress?
7. Had u tijdens de video het gevoel scherp en alert te zijn?
8. Had u gedurende de video een slaperig gevoel, of dommelde u weg?
9. Had u een snellere ademhaling?
10. Had u een verhoogde hartslag?
11. Vindt u deze video interessant?
12. Zou u deze video aan iemand anders aanraden?
13. Heeft u het idee iets geleerd te hebben?
14. Denkt u dat u iets in de video gaat toepassen in uw dagelijks leven?

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