N-Back Training and Transfer Effects in Healthy Young and Older Subjects Gauged Using EEG: A Preliminary Study

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***Abstract*-** **Executive function performance of older individuals is lower compared to young adults. We investigate whether N-Back working memory (WM) training improves both trained WM- and untrained cognitive function performance (transfer effects). As previous studies showed that electroencephalogram (EEG) responses, in particular Event Related Potentials (ERPs), vary with task difficulty level and age, we focused on the relation between ERPs-P300 and task difficulty level in young and older adults. We used two groups of healthy young and older participants to assess the effect of N-Back training: cognitive training group (CTG) and passive control group (PCG). CTG performed an N-Back task with 3 difficulty levels (1, 2, 3-Back), and PCG did not undergo any training. Pre- and post-tests were administered to both groups to gauge any transfer effects (spatial memory, attention and fluid intelligence). Our results show age-related differences in P300-ERPs, reaction time and accuracy for N-Back training task and in spatial memory and reasoning pre post-tests. Improvements in the trained task are stronger for CTG young than CTG older individuals. Furthermore, transfer effects to attention (TOVA) were found in both young and older adults for CTG, showing the benefits of the training.**

Keywords-EEG; working memory training; transfer effects; P300 ERP; young and older adults.

I. INTRODUCTION

Cognitive training is a powerful tool to explore the plasticity of the aging brain to improve cognitive functions such as intelligence, episodic memory, working memory, and executive functions [1][2][3]. Morrison and Chein [4], in a review of working memory (WM) training, divided the training approaches in two categories: strategy training (domain specific strategies), and core training (repetition of demanding WM tasks). In our study, we adhered to the second approach, where the participants were exposed several times to a repetition of visual stimuli during a WM task.

Working memory (WM), as defined by Baddeley [2], refers to the temporary storage and manipulation of information necessary to execute complex cognitive tasks. WM training was originally used to enhance WM in neuropsychiatric subjects with a WM deficit, such as attention deficit hyperactivity disorder (ADHD) [5] and several authors studied the mechanisms behind and the effect of WM training [6][7].

The N-back task is a working memory task introduced by Wayne Kirchner in 1958 [8] as a visuo-spatial task with four load factors (‘‘0-Back’’ to ‘‘3-Back’’), and by Mackworth [9] as a visual letter task with up to six load factors. Gevins et al. [10] introduced it into neuroscience by using it as a ‘‘visuomotor memory task’’ with one load factor (3-Back). The N-back task involves multiple processes and is considered a dual task: working memory updating, which involves the encoding of incoming stimuli, the monitoring, maintenance, and updating of the sequence, and stimulus matching (matching the current stimulus to the one that occurred N positions back in the sequence). It reflects a number of core Executive Functions (EFs) besides working memory, such as inhibitory control and cognitive flexibility, as well as other higher-order EFs, such as problem solving, decision making, selective attention, among other functions [11]. The N-Back task requires participants to maintain stimulus information necessary for successful task performance in working memory across multiple trials [11]. It has been shown that the N-Back task consistently activates dorsolateral prefrontal cortex (DLPFC), as well as parietal regions in the adult brain [12]. Schneiders et al. [13] have shown that, using N-Back training, it is possible to achieve an improvement in task performance and an alteration in brain activity, such as a decreased activation in the right superior middle frontal gyrus (BA 6) and posterior parietal regions (BA 40).

Following a series of studies, Jaeggi et al. [14][15] reported that by performing an N-Back task, the effects of WM training transfer to untrained tasks requiring WM (transfer effects) improve upon a complex human ability known as fluid intelligence. The findings of Jaeggi et al. [14] also support the hypothesis that transfer effects to general cognitive functions can be achieved after an N-Back training for tasks that conceptually overlap, albeit only slightly, with the N-Back task. Training of the general fronto-parietal WM network should lead to improvements in cognitive functions that rely on the same network [10]. This general overlap hypothesis predicts that if training considerably engages the fronto-parietal WM network and the transfer task generates a similar activation pattern, an extensive training of this network will yield a general boosting of cognitive functions. An alternative hypothesis predicts that WM training effects transfer only if training improves specific cognitive processes required in both training and transfer tasks. Dahlin et al. [16] found transfer, after WM updating training, to an N-Back task that resembled the original trained task in also relying on updating processes, but not to a Stroop task that involved inhibition but no updating. Furthermore, Dahlin et al. [16] and Li et al. [2] reported that training on an N-Back task improves WM training for both young and older healthy subjects. Interestingly, Dahlin et al. [16] found larger improvements in young healthy subjects, whereas Li et al. [2] found comparable improvements in both groups. The reasons for this difference could be the frequency and duration of the training, and the overlap of the elements of a skill between the trained and the specific transfer task. Despite this difference, both studies demonstrate working memory plasticity in young and older adults, and the possibility to obtain near-transfer effects that are stable in time. So, although the degree of plasticity varies across studies, the potential of the brain to reorganize in response to demands is found in people of all ages [17][18][19].

The aim of our study was to verify whether N-Back task performance improves after N-Back training, and whether transfer effects to other (untrained) cognitive functions are obtained, such as in spatial memory, attention and reasoning, in two different groups of healthy young and older subjects: cognitive training group (CTG) and passive control group (PCG). We recorded EEG responses during all training sessions, and focused on the P300, an ERP component related to working memory [20].

The paper is organized as follows. In Section II, we describe the material and methods (subjects, procedure, EEG recording). In Section III, we focus on the behavioral and P300-ERPs results using WM training and the transfer effects pre- and post-training in young and older adults. Finally, in Section IV, we discuss our results and propose a number of technical and conceptual goals for future studies.

II. MATERIALS AND METHODS

In this section, we describe the participant recruitment, training procedure and EEG recording.

A. *Subjects*

We recruited 17 healthy young subjects (9 females, 8 males, mean age 29 years, range 24-34 years), undergraduate or graduate students from KU Leuven, and 19 healthy older subjects (13 females, 6 males, mean age 62.25 years old, range between 50-69 years old) via posters, social media, and KU Leuven's Academic Center for General Practice. Participants were healthy, with normal or corrected vision, without any history of psychiatric or neurological diseases, not on any medication, and never participated in working memory training.

B. *Cognitive training*

Participants were assigned to two sub-groups, cognitive training group (N=9, young; N=10, older) and passive control group (N=8, young; N=9, older), to evaluate improvements in task performance after WM training and to record any transfer effects to other cognitive tasks (see further for their definition). During all training sessions, EEG was recorded (see also further). For the cognitive training group, all subjects (i.e., young and older ones) performed WM training with visual feedback of the correctness of their behavioral responses and received a monetary reward (with a maximum of 10 € if all responses were correct). The control group did not undergo any training.

C. *Transfer effects*

A battery of cognitive tests were administered before and after training (pre and post-tests, note that for the control group there was no training between tests) to see if there were transfer effects to attention, spatial memory, reasoning, and intelligence. The study was approved by our university's ethical committee and when subjects agreed to participate in the experiment they signed the informed consent form prior approved by the said committee.

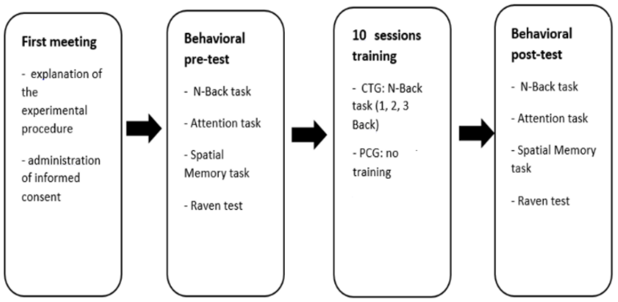

Figure 1. Study design

D. *Procedure*

Subjects participated in an N-back task in which a sequence of stimuli was shown and the task was to decide whether the current stimulus matched one shown N items earlier (Figure 2).

The stimuli were presented for 1000ms followed by a 2000ms Inter-stimulus interval (ISI), jittered by ± 100 ms, during which the picture was replaced by a fixation cross. This is the moment when participants needed to press a button when the stimulus was a target. We had 33% of our pictures as targets.

Sequences with identical difficulty levels (1-back, 2-back, 3-back) were grouped into 2 min. blocks across four sessions. Each session included two repetitions of 3 sequences. In total there were 8 blocks. For each sequence, there were 60 stimuli presented in pseudorandom order. Before starting with the first three sequences, a training session consisting of ten stimuli for each difficulty level was used to explain the N-Back task. Subjects performed an N-Back training during 10 sessions, 3 times per week (30 minutes each time), as shown in Figure 1. This is in line with literature reports on significant training and transfer effects obtained after 3 weeks of training [14][21-24].

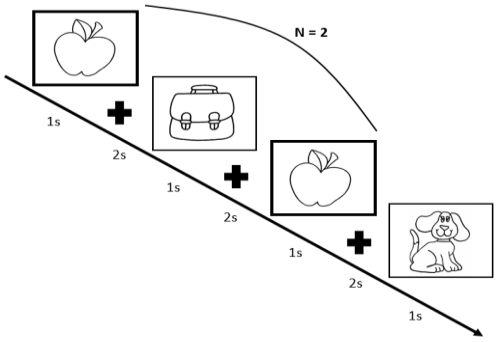

Figure 2. Graphical rendition of 2(N)-back task

All participants were administered a battery of pre- and post-tests to evaluate whether there were transfer effects to other cognitive functions. We used Test of Variables of Attention (TOVA) [25], Spatial Working Memory Test (CORSI) [26] and RAVEN, a fluid intelligence test [27]. The behavioral pre- and post-tests were administered to compare task performance between groups (cognitive training, active control and passive control groups) in the trained (N-Back task) and untrained tasks (TOVA, CORSI and RAVEN test).

N-back task and transfer tasks had similarities and differences [14][27][28]. The spatial memory task (Corsi test) engaged WM updating processes just as the N-Back task, but differed in stimuli (squares in Corsi task vs. pictures in the N-Back task) and task rules (recognition of previously presented items in the N-Back tasks vs. recollection of items in the updating transfer tasks). Given these similarities and differences, we are using near transfer tasks according to Karbach and Kray [29].

In the first experimental session (pre-test), each participant was informed about the experimental procedure and invited to sign the informed consent form. The day after the first meeting, the participants performed the behavioral pre-test session, and from the third meeting, the training groups (CTG) started the training procedure of CTG. At the beginning of each training session, an EOG calibration session was performed to model eye movements and blinks using the AAA method described in Croft and Barry [30].

E. *EEG recording*

EEG was recorded continuously from 32 Ag/AgCl electrodes at a sampling rate of 2 kHz using a SynampsRT device (Neuroscan, Australia). The electrodes were placed at O1,Oz, O2, PO3, PO4, P8, P4, Pz, P3, P7, TP9, CP5, CP1, CP2, CP6, TP10, T7, C3, Cz, C4, T8, FC6, FC2, FC1, FC5, F3, Fz, F4, AF3, AF4, Fp1, Fp2. The reference was placed at AFz and the ground at CPz. Additionally, four electrodes were placed around the eyes, on the upper and lower side of

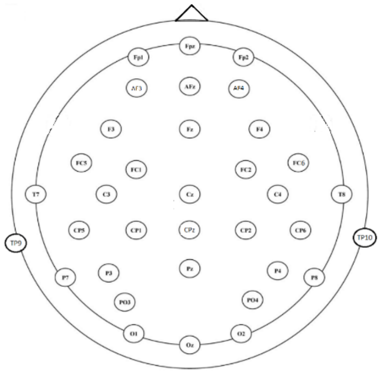

Figure 3. Names and distribution of electrodes.

the left eye (vertical) and near the external canthus of each eye (horizontal), for electro-oculogram recording (EOG, bi-polar recording).

The recorded EEG signal was re-referenced offline from the original reference to the average of two mastoid electrodes (TP9 and TP10), corrected for eye movement and blinking artifacts [30], band-pass filtered in the range of 0.1–30 Hz, and cut into epochs starting 200 ms pre- till 1000 ms post- stimulus onset. Baseline correction is performed by subtracting the average of the 200 ms pre-stimulus onset activity from the 1000 ms post-stimulus onset activity. Finally, the epochs are downsampled to 100 Hz and stored for ERP detection.

Recorded epochs with incorrect button press responses were excluded from further analysis. In addition, epochs with EEG signals greater than 100mV were also excluded. A two-way ANOVA (factors: n-back X target) was performed on all sampled EEG time points between 250 ms to 400 ms. Bonferroni correction for multiple comparisons was used across all samples within this time window.

III. RESULTS

In this section, we describe working memory training (behavioral and ERPs results) and transfer effects.

A. *Working memory training (behavioral)*

We also analyzed changes due to cognitive training by examining behavioral data (accuracy, reaction time (RT)) of CTG during N-Back training (10 sessions) of healthy young and older subjects (Figures 4 and 5). The purpose is to test our second hypothesis: training can improve related cognitive function performance, and transfer to other cognitive functions as shown by significant effects in RT and response accuracy.

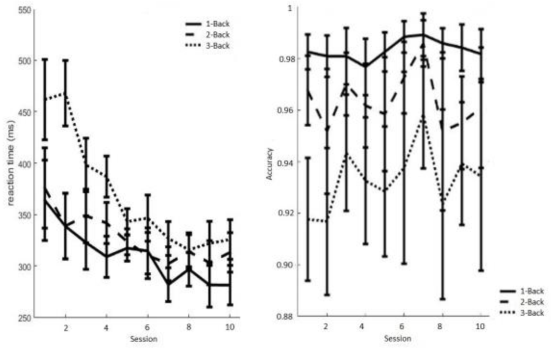

Figure 4. RT and accuracy during 10 sessions of cognitive training in CTG-young. Error bars indicate SEM (Standard error of the mean).

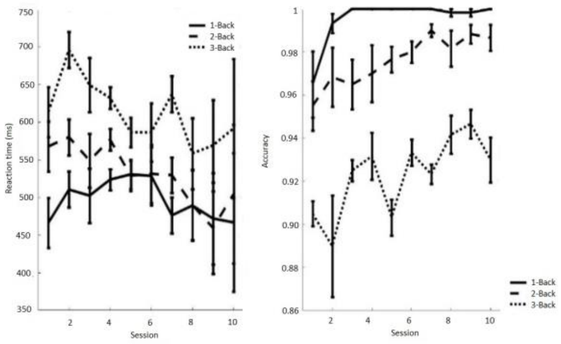

Figure 5. RT and accuracy during 10 sessions of cognitive training in CTG-older. Error bars indicate SEM.

For the CTG-young, we observed a reduction in RT as function of training sessions. To test this, we performed a three-way ANOVA across factors (N-back level, subject and session). We found a significant effect of session ($F_{(9)}$=4.9, p<0.001) confirming that RT indeed decreases with more training. Importantly, the N-Back level x session interaction was significant ($F_{(18)}$=3.01, p<0.001), which indicates that the N-back levels are differentially affected by training. In contrast, when we looked at accuracy, the main effect of session was not significant (p=0.56) indicating that accuracy did not substantially increase as a result of training although there was a main effect of N-back level confirming that task difficulty affected performance ($F_{(2)}$=7.97, p<0.05).

For the CTG-older, we also performed a three-way ANOVA across factors (N-back level, subject and session). We found for RT a significant effect of N-back level ($F_{(2)}$=37.62, p<0.05) indicating that task difficulty affects reaction time. For the accuracy we found significant effects for N-Back level ($F_{(2)}$=119.58, p<0.001) and session ($F_{(9)}$=3.77, p<0.05). Importantly, the N-Back level x session interaction was significant ($F_{(18)}$=2.09, p<0.05) indicating that accuracy improves with training and the gained improvements differ with N-Back level.

B. *Working memory training (ERPs results)*

Neuroimaging studies have shown that during N-Back task performance the most activated brain regions are the lateral premotor cortex, dorsal cingulate and medial premotor cortex, dorsolateral and ventrolateral prefrontal cortex, frontal poles, and medial and lateral posterior parietal cortex [10]. In addition, since several EEG studies showed that the midline electrodes are the most significant ones [31][32], we decided to analyze ERPs using electrodes Fz, Pz, and Cz. Data from mean P300 peak amplitude is presented in Figures 6 and 7 in three different moments (3 sessions/each moment) during training (first-, middle- and last sessions) for young and older adults.

P300 peak amplitude data from midline electrodes (Fz, Cz, Pz) were analyzed with a three-way ANOVA (N-Back level x target x session). P300 peak amplitude (target minus no-target) was higher for the N-Back levels that were easier (1 and 2-Back), and was lower for the more difficult one (3-Back), especially for healthy older subjects. P300 peak amplitude (difference between target and no-target) was largest for the frontal electrode (Fz) and decreased for the central (Cz) and posterior electrodes (Pz).

Significant differences were found in healthy young subjects for CTG (Figure 6) between first (1st) and last (10th) training session for 3-Back task in channel Fz ($F_{(1)}=6.4155$, $p<0.05$) and in channel Cz ($F_{(1)}=3.9479$, $p<0.05$), and between first and middle session (5th session) for 3-Back task in channel Fz ($F_{(1)}=7.2620$, $p<0.01$), in channel Cz ($F_{(1)}=6.0811$, $p<0.05$), and in channel Pz ($F_{(1)}=5.4272$, $p<0.05$).

Furthermore, statistically, P300 amplitude between the 1st and last session (10th) showed higher amplitude for 3-Back task compared to the other N-Back difficulty levels (1 and 2-Back), indicating that young adults improved more for the most difficult task (3-Back). The P300 amplitude was largest for the frontal electrode (Fz) and decreased for the central (Cz) and posterior electrodes (Pz) in young adults for the difference between 1st and 10th session (Figure 6, right). We compared also 1st and middle (5th) session where we could already seen significant improvement for the most difficult task (3-Back), showing that 5 training sessions of N-Back training for healthy young adults could be sufficient to have significant improvement in the trained task. Taken together, these data support the observation that the P300 amplitude increase with training sessions, and that also for the 3-Back task, although the most difficult one, WM training was effective.

As to the healthy old subjects of CTG (CTG-old): we also analyzed the P300 amplitudes of the midline electrodes (Fz, Cz, Pz) with a three-way ANOVA (N-Back level x target x session) for CTG-old. We found significant differences between the first and the last session for 3-Back task in channel Pz ($F_{(1)}=6.2091$, $p<0.05$), showing that 3-Back task became easier for the participants. Furthermore, similar to the previous results for healthy young subjects, P300 amplitude in the first session was higher for the N-Back difficulty levels that were easier (1 and 2-Back), and lower for the more difficult one (3-Back). Also in this case, P300 amplitude (difference between target and non-target) was larger for the frontal electrode (Fz) than for the central (Cz) and posterior electrodes (Pz). After the training with older adults, the P300 became higher for the most difficult task (3-Back) in parietal region, showing that WM training can modify the amplitude (Figure 7). These findings confirm the results of Gevins et al. [35] who reported that training on an N-Back shows EEG changes in responses to changes in the mental effort required for task performance. We compared also 1st and middle (5th) session, but in contrast to young healthy adults, we did not find any significant improvement for the most difficult task (3-Back), showing that for healthy older subjects are necessary 10 training sessions of N-Back training. These data support the observation that the P300 amplitude increase with training sessions, and that also for the 3-Back task, although the most difficult one, WM training was effective.

Salminen et al. [36] showed after N-back training benefits for both young and older subjects in terms of behavioral response accuracies, with differences in improvement between young and older adults. Also Friedman, and Simpson [33] found changes in ERP amplitudes of young and older adults during oddball task performance. Given these observations, we looked for differences in P300 components of young and older healthy subjects. Our results showed significant effects for the interaction between age differences and target minus non-target for 2-Back task in channel Fz ($F_{(1)}=13.3309$, $p<0.001$), in channel Cz ($F_{(1)}= 6.4395$, $p<0.05$), and in channel Pz ($F_{(1)}=9.6903$, $p<0.01$).

C. *Transfer effects (Pre- and Post-tests)*

Means for each task are presented in Table I for the pre- and post-tests between young and older subjects. In Figures 8 and 9, a multivariate ANOVA (MANOVA) was conducted on intra and inter-groups (CTG and PCG young and older) and between sessions (pre- and post-tests). For young subjects, significant effects for accuracy in N-Back task between CTG and PCG ($F_{(1)}=6.21$, $p<0.05$), for pre- and post-testing, were observed. No significant differences in the other cognitive tests (CORSI and RAVEN) were found. For the N-Back task, significant effects were found for RT between CTG and PCG, for pre- and post-tests ($F_{(1)}=40.9$, $p<0.001$), for task difficulty level ($F_{(2)}=4.92$, $p<0.05$), for group x pre- and post-test interaction ($F_{(1)}=9.14$, $p<0.05$), and for pre- and post-test x N-Back level interaction ($F_{(2)}=3.54$, $p<0.05$).

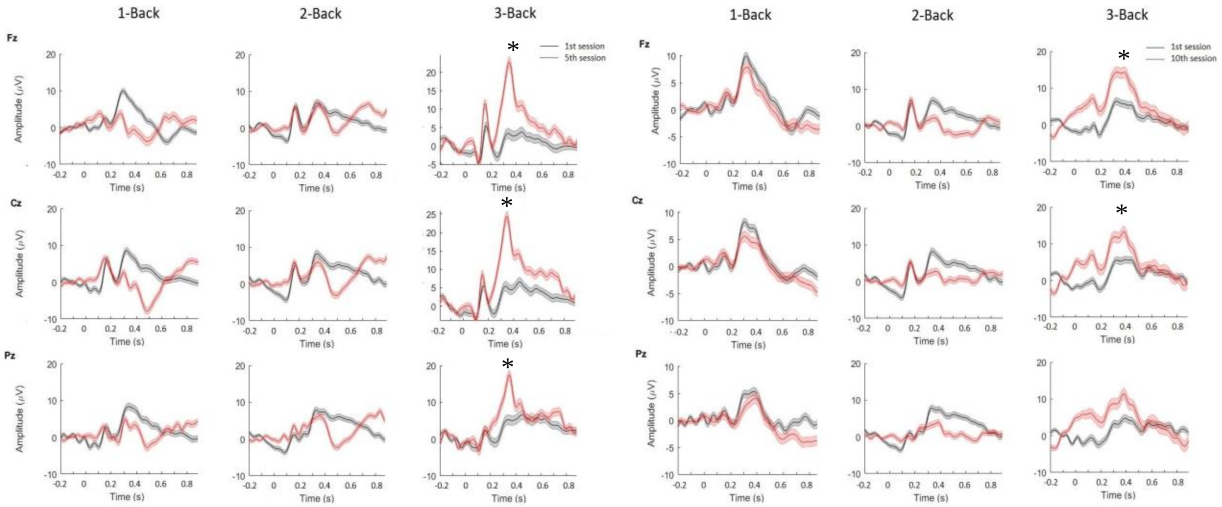

Figure 6. P300-ERPs amplitude (target minus non-target) in 9 subjects of the CTG-young group. Differences between 1st and 5th session (middle session, left), and between 1st and last session (10th session, right) are shown for channels Fz, Cz, and Pz (row-wise). Significance was measured using three-way ANOVA ($p < 0.05$). Error bars indicate SEM.

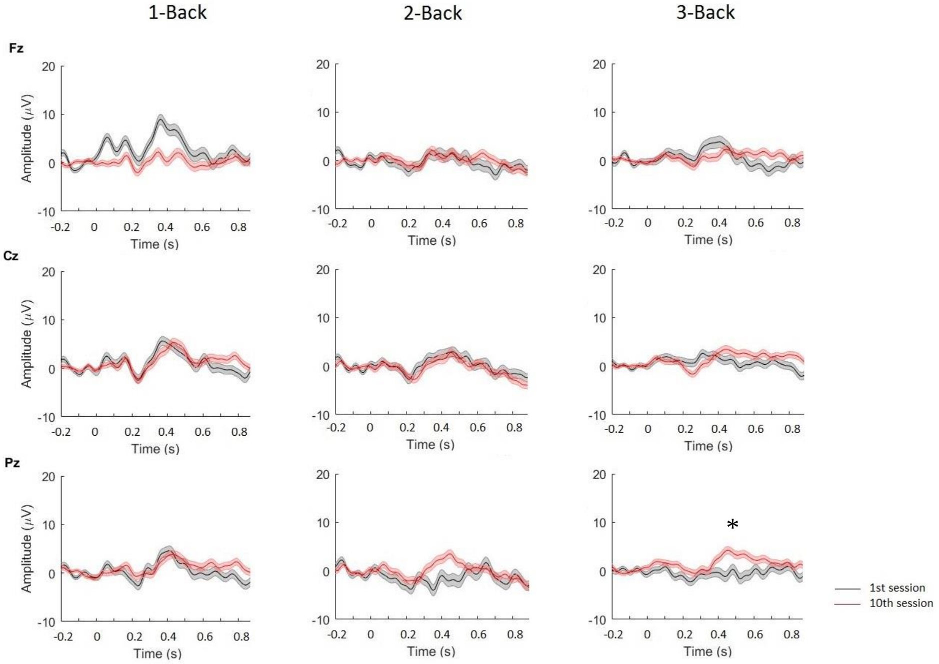

Figure 7. P300-ERPs amplitude in 10 subjects of the CTG-older group. Differences between 1st and last session (10th session) are shown for channels Fz, Cz, and Pz (row-wise). Significance was measured using three-way ANOVA ($p < 0.05$). Error bars indicate SEM.

For healthy older subjects, we found significant effects for accuracy in N-Back task between CTG and PCG ($F_{(1)}=7.26$, $p<0.05$) for group, and in TOVA between CTG and PCG ($F_{(1)}=30.88$, $p<0.001$) for group. No significant differences in CORSI and RAVEN accuracies were found between groups.

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Significant effects were found for RT between CTG and PCG for the N-Back task, for training x N-Back level interaction ($F_{(2)}=3.54$, $p<0.05$).

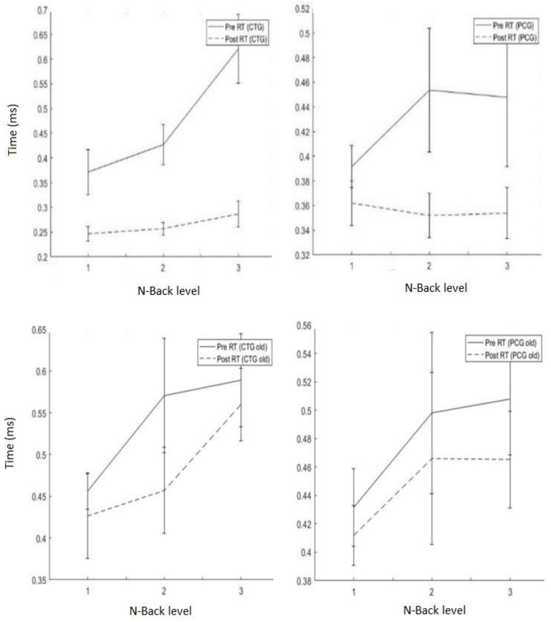

Figure 8. RT (correct responses) in the performance from pre to post-test in the *n*-back task of 2 groups of young (top row) and older subjects (bottom row): CTG (left column), and PCG (right column). Error bars indicate SEM.

Since Dahlin et al. [34] showed that younger adults gain more benefits from cognitive training than older adults, but Bherer, Westerberg, and Bäckman [36] showed the opposite (older subjects gained more positive effects than younger ones), we analyzed the differences between young and older adults. We used a multivariate ANOVA (MANOVA) for the factors group (young and older) in the CTG, and session (pretest and post-test, Figures 10 and 11). Significant effects for accuracy in CORSI test ($F_{(1)}=6.18$, $p<0.05$) for group, as well for RAVEN ($F_{(1)}=24.97$, $p<0.001$) for group, and in training ($F_{(1)}=5.7$, $p<0.05$). No significant differences in the N-Back and TOVA results between groups were found. For the N-Back task (Figure 13), significant effects were found for RT between CTG young and older for group ($F_{(1)}= 27.98$, $p<0.001$), for training ($F_{(1)}=24.83$, $p<0.001$), for N-Back task ($F_{(2)}=9.12$, $p<0.001$), and for age (group) x training effects interaction ($F(1)=8.06$, $p<0.05$).

TABLE I. PERCENT CORRECT (MEANS AND STANDARD DEVIATION) OF PRE- AND POST-TEST PERFORMANCE (ACCURACY) BETWEEN TRAINING GROUP AND PASSIVE CONTROL GROUPS IN TRAINED (N-BACK) AND UNTRAINED TASKS, FOR HEALTHY YOUNG AND OLDER SUBJECTS.

	Young subjects				Older subjects			
Task	Cognitive training group		Passive control group		Cognitive training group		Passive control group	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
N-Back	92.76±3.36	98.33±1.46	94.66±4.36	95.66±2.5	94.66±1.66	97.66±0.86	92.9±2.06	92.33±3.6
TOVA	84.4±10.4	93.2±4.2	85.2±8.8	90±6.4	92.6±3	96±3.4	106±5.2	106.4±3.4
CORSI	58.66±6.66	69.33±16.66	61.33±14.66	62.66±18.66	46.66±6.66	55.33±7.33	58±11.33	60±7.33
RAVEN	94.16±6	97±4.6	92.33±8.66	93±6.66	69.3±15.5	84.33±1.83	82.83±8	85±5.83

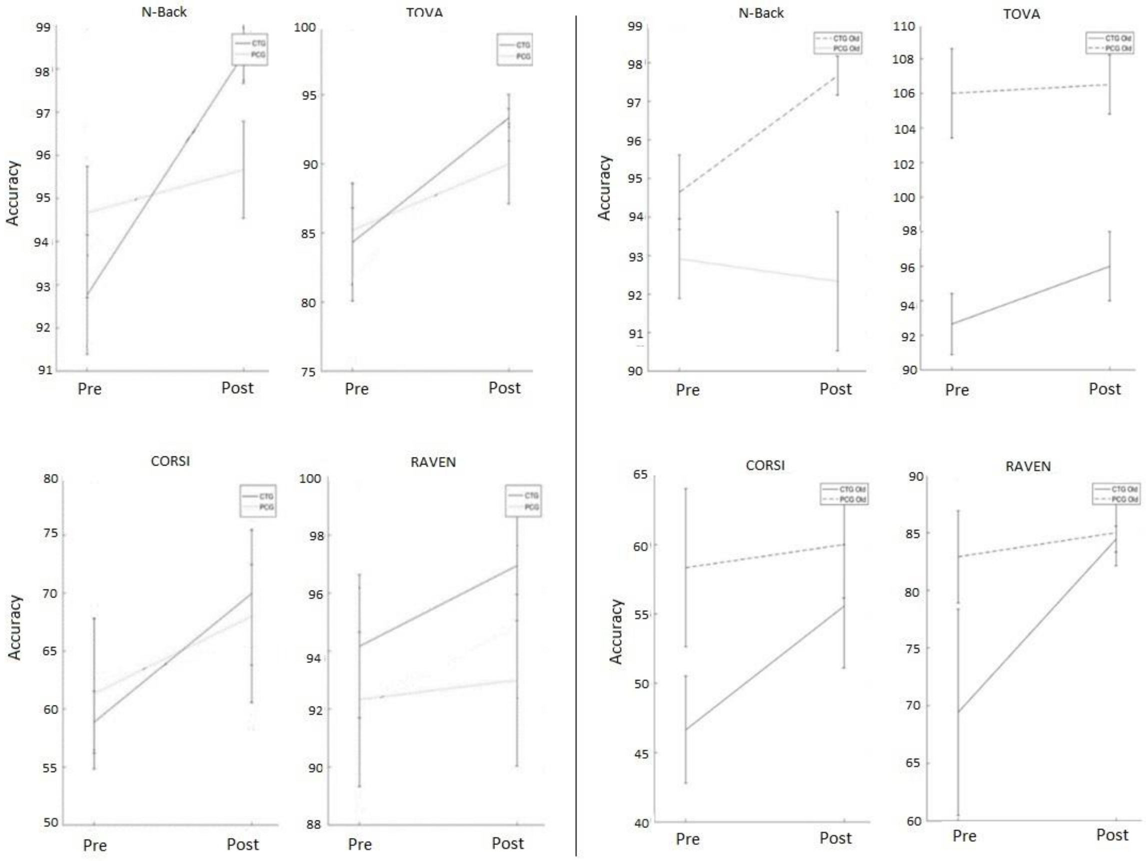

Figure 9. Left: pre- to post-test correct performance (in %) of CTG and PCG groups of healthy young subjects for the N-back task, TOVA test, CORSI test, and RAVEN test. Right: idem but for the 2 groups of healthy older subjects. Error bars indicate SEM.

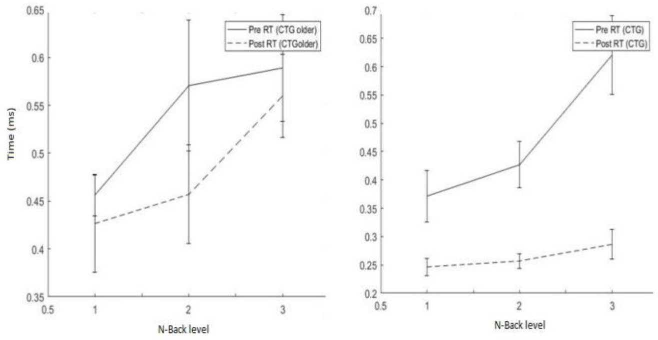

Figure 10. RT for correct responses in pre- and post-test of the N-back task between CTG groups of young (left panel) and older subjects (right panel). Error bars indicate SEM.

In summary, with our pre- and post-training tests on other untrained cognitive functions, we wanted to verify whether any transfer effects could be obtained after N-Back training. Our results indicate clear improvements in attention, which is in line with the outcomes of Dahlin et al. [34] who showed larger improvements for younger adults than for older ones.

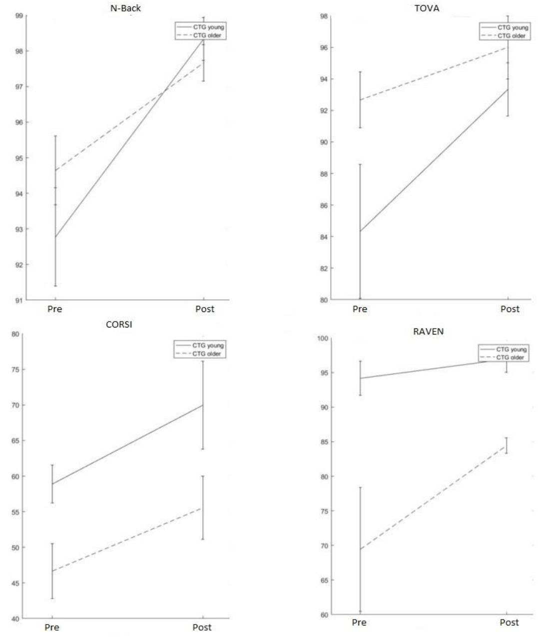

Figure 11. Top row: percent correct performance of CTG young and older) for pre- to post-test of the N-Back task (left) and TOVA test (right). Bottom row: idem but for the CORSI- (left) and RAVEN test (right). Error bars indicate SEM.

IV. DISCUSSION

We investigated whether cognitive training using an N-Back task only improves performance in this task or transfers to other tasks. To assess this, we performed 10 N-Back training sessions in one group (CTG) of young and older adults, and assessed their cognitive performance with a battery of cognitive tasks (TOVA, CORSI and RAVEN test) before and after training. During training, CTG participants performed the 1,2,3-Back task. Furthermore, a second group of participants (PCG) for young and older adults performed no training but was subjected to the same battery of cognitive tests. We found for healthy young subjects that training indeed improves performance of the CTG group compared to the PCG group. Therefore, there is a clear improvement for CTG on the task they were trained on (N-Back task). In contrast, the transfer of training effects into other tasks is more nuanced: the transfer was significant for the attention (TOVA) test, but only for CTG, but there was a trend for spatial memory (CORSI) and fluid intelligence (RAVEN) tests that was larger for CTG than for PCG. These results are in line with the conclusions of Jaeggi et al. [14] who showed that, when using a working memory task, not only working memory improves but also fluid intelligence. However, the results are not in line with those of Dahlin et al. [34] who found that, whereas working memory training improves performance of a related working memory task, other cognitive functions did not improve.

For healthy older adults, we found a significant improvement in N-Back task performance for CTG compared to PCG, and in TOVA task performance for CTG compared to PCG, and a trend of improvement in CTG for the CORSI and RAVEN tests compared to PCG. These results are in line with the studies of Yang et al. [37] and Dahlin et al. [34] who showed that the capacity of plasticity in the ageing brain improves cognitive functioning. One explanation for transfer effects being significant only for the attention task (TOVA), and not for the spatial memory (CORSI) and fluid intelligence tasks (RAVEN), for both groups (young and older), maybe due to our small sample size.

Furthermore, we wanted to compare the effect of cognitive training in young and older subjects in CTG and PCG, and P300 ERP amplitude during N-Back task performance in CTG, for both groups. The results of CTG showed that cognitive training improves performance of the N-Back task in RT, and that the transfer effects were significant for the RAVEN and CORSI tests, but not for TOVA, which is in line with the Jaeggi et al. [14] results. Although both young and older healthy subjects improved their performance after WM training, younger healthy subjects showed a larger effect following cognitive training compared to older healthy subjects, which is in line with the results of Brehmer et al. [20] and Dahlin et al. [34]. We observed significant differences in P300 amplitude between young and older subjects for N-Back level of the task, target stimuli and sessions (first vs last, first vs middle) in 3-Back task, indicating that 5 training sessions could be enough to improve the trained WM task. In this way, we complemented the study of Friedman et al. [33] who used a simple oddball paradigm to observe the differences of ERP amplitude in young and older adults, showing the number of training sessions that could be necessary to improve the N-Back task.

An issue that deserves consideration is why N-Back training in our study did not produce transfer effects in CORSI test (spatial memory), while in Dahlin et al. [34] study they observed transfer effects to another memory task (near-transfer effects). Furthermore, as the EEG results from our study suggest a change in the ERPs-P300 during cognitive training, our future study will consider not only behavioral data (accuracy and RT) but also P300-ERPs to change in real time the difficulty level of the task, in order to avoid fatigue or boredom for the subject.

V. CONCLUSION

As cognitive training is becoming important during one's life-span, to maintain cognitive plasticity and postpone cognitive decline, we decided to study the power of this tool in search of the benefits that can be gained by young and older adults. We showed that N-Back training not only improves WM but also transfers to another cognitive function (i.e., attention). The results provide evidence that it is indeed possible to improve the trained task (working memory), but also transfer to other cognitive tasks. Furthermore, our findings are promising to be used with a larger cohort of healthy older subjects and patients with cognitive decline.

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REFERENCES

[1] V. Pergher, B. Wittevrongel, J. Tournoy, B. Schoenmakers, J. Arsenault, and M. M. Van Hulle "N-Back training and transfer effects in healthy young subjects using EEG", BRAININFO 2017, The Second

International Conference on Neuroscience and Cognitive Brain Information, IARIA, July 2017, pp. 1-7, ISSN: 2519-8653, ISBN: 978-1-61208-579-1.

[2] S. C. Li, F. Schmiedek, O. Huxhold, C. Röcke, J. Smith, and U. Lindenberger, “Working memory plasticity in old age: practice gain, transfer, and maintenance”, Psychol. Aging 23, pp. 731–742, 2008.

[3] A. Baddeley, “Working Memory and Conscious Awareness”, Theories of memory, pp. 11-20, 1992.

[4] J. H. Smith-Spark, and J. E. Fisk, “Working memory functioning in developmental dyslexia”, Memory, 15(1), pp. 34-56, 2007.

[5] T. Klingberg, “Training and plasticity of working memory”, Trends Cogn Sci 14, pp. 317–324, 2010.

[6] C. C. von Bastian, and K. Oberauer, “Effects and mechanisms of working memory training: a review”, Psychol Res 78, pp. 803–820, 2014.

[7] J. Au, E. Sheehan, N. Tsai, G. J. Duncan, M. Buschkuehl, and S. M. Jaeggi, “Improving fluid intelligence with training on working memory: a metaanalysis”, Psychon Bull Rev 22, pp. 366 –377, 2015.

[8] W. K. Kirchner, “Age differences in short-term retention of rapidly changing information”, J Exp Psych, pp. 1-17, 1958.

[9] J. F. Mackworth, “Paced memorizing in a continuous task”, Journal of Experimental Psychology, 58(3), p. 206, 1959.

[10] A. S. Gevins, S. L. Bressler, B. A. Cutillo, J. Illes, J. C. Miller, J. Stern, and H. R. Jex, “Effects of prolonged mental work on functional brain topography”, Electroencephalography and clinical neurophysiology, 76(4), pp. 339-350, 1990.

[11] M. J. Kane, and R. W. Engle, “The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective”, Psychonomic bulletin and review, 9(4), pp. 637-671, 2002.

[12] A. M. Owen, K. M. McMillan, A. R. Laird, and E. Bullmore, “N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies”, Human brain mapping, 25(1), pp. 46-59, 2005.

[13] J. A. Schneiders, B. Opitz, C. M. Krick, and A. Mecklinger, “Separating intra-modal and across-modal training effects in visual working memory: an fMRI investigation”, Cerebral Cortex, 21(11), pp. 2555-64, 2011.

[14] S. M. Jaeggi, “Improving fluid intelligence with training on working memory”, Proc. Natl. Acad. Sci. 105, pp. 6829– 6834, 2008.

[15] S. M. Jaeggi, “The relationship between n-back performance and matrix reasoning implications for training and transfer”, Intelligence 38, pp. 625–635, 2010.

[16] E. Dahlin, L. Nyberg, L. Bäckman, and A. S. Neely, “Plasticity of executive functioning in young and older adults: immediate training gains, transfer, and long-term maintenance”, Psychol. Aging 23, pp. 720–730, 2008.

[17] P. B. Baltes, U. Lindenberger, and U. M. Staudinger, “Life span theory in developmental psychology”, Handbook of child psychology: Theoretical models of human development (Vol. 1, pp. 569-664). Hoboken; 2006.

[18] E. Bialystok, and F. I. Craik, (Eds.) “*Lifespan cognition: Mechanisms of change*”, Oxford University Press, USA; 2006.

[19] A. B. Morrison, and J. M. Chein, “Does working memory training work? The promise and challenges of enhancing cognition by training working memory”, Psychonomic Bulletin & Review, 18, pp. 46–60. 2011.

[20] L. Bherer, A. F. Kramer, M. S. Peterson, S. Colcombe, K. Erickson, and E. Becic, “Training effects on dual-task performance: Are there age-related differences in plasticity of attentional control?”, Psychology and Aging, 20 (4), pp. 695–709, 2005.

[21] J. Chein, and A. Morrison, “Expanding the mind's workspace: Training and transfer effects with a complex working memory span task”, Psychonomic Bulletin and Review, 17 (2), pp. 93–199, 2010.

[22] E. Dahlin, L. Backman, A. S. Neely, and L. Nyberg, “Training of the executive component of working memory: Subcortical areas mediate transfer effects”, Restorative Neurology and Neuroscience, 27 (5), pp.405–419, 2009.

[23] Y. Brehmer, H. Westerberg, and L. Bäckman, “Working-memory training in younger and older adults: training gains, transfer, and maintenance”, Training-induced cognitive and neural plasticity, p. 72, 2012.

[24] L. L. Richmond, A. B. Morrison, J. M. Chein, and I. R. Olson, “Working memory training and transfer in older adults”. Psychology and aging, 26(4), p. 813, 2011.

[25] L. M. Greenberg, and I. D. Waldmant. "Developmental normative data on the test of variables of attention (TOVA™)." Journal of Child Psychology and Psychiatry 34 (6), pp. 1019-1030, 1993.

[26] R. P. Kessels, M. J. Van Zandvoort, A. Postma, L. J. Kappelle, and E. H. De Haan, “The Corsi block-tapping task: standardization and normative data”, Applied neuropsychology, 7(4), pp. 252-258, 2000.

[27] J. Persson, and P. A. Reuter-Lorenz, “Gaining Control: Training Executive Function and Far Transfer of the Ability to Resolve Interference [retracted]”, Psychological Science, 19(9), pp. 881-888, 2008.

[28] X. Zhao, Y. Wang, D. Liu, and R. Zhou, “Effect of updating training on fluid intelligence in children”, Chinese Science Bulletin, 56(21), pp. 2202-2205, 2011.

[29] J. Karbach, and J. Kray, “How useful is executive control training? Age differences in near and far transfer of task-switching training’, Dev Sci 12, pp. 978–990, 2009.

[30] R. J. Croft, and R. J. Barry, “Removal of ocular artifact from the EEG: a review”, Neurophysiologie Clinique/Clinical Neurophysiology, 30(1), pp. 5-19, 2000.

[31] S. Watter, G. M Geffen, and L. B. Geffen, “The n-back as a dual-task: P300 morphology under divided attention”, Psychophysiology, 38(06), pp. 998-1003, 2001.

[32] A. M. Brouwer, M. A. Hogervorst, J. B. Van Erp, T. Heffelaar, P. H. Zimmerman, and R. Oostenveld, “Estimating workload using EEG spectral power and ERPs in the n-back task”, Journal of neural engineering, 9(4), p. 045008, 2012.

[33] D. Friedman, G. V. Simpson, “ERP amplitude and scalp distribution to target and novel events: effects of temporal-order in young, middle-aged and older adults”, Cogn Brain Res. 2: pp. 49–63, 1994.

[34] E. Dahlin, A. S. Neely, A. Larsson, L. Backman, and L. Nyberg, “Transfer of learning after updating training mediated by the striatum”, Science 320, pp. 1510–1512, 2008.

[35] A. Gevins, and M. E. Smith, “Neuropsychological measures of cognitive workload during human-computer interaction”, Theoretical Issues in Ergonomics Science, 4(1-2), pp. 113-131, 2003.

[36] T. Salminen, P. Frensch, T. Strobach, and T. Schubert, “Age-specific differences of dual n-back training”, Aging, Neuropsychology, and Cognition, 23(1), pp. 18-39, 2016.

[37] L. Yang, R. T. Krampe, and P. B. Baltes, “Basic forms of cognitive plasticity extended into the oldest-old: retest learning, age, and cognitive functioning”, Psychology and aging, 21(2), p. 372, 2006.