N-Back Training and Transfer Effects in Healthy Young Subjects Using EEG

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***Abstract*- We investigate whether N-Back working memory (WM) training improves both trained WM- and untrained cognitive function performance (transfer effects). Previous studies showed that EEG responses, in particular Event Related Potentials (ERPs), can be used as a measure of working memory load during cognitive task performance. Here, we used three groups of young healthy participants to assess the effect of N-Back training: cognitive training group (CTG), active control group (ACG) and passive control group (PCG). The cognitive training group performed an N-Back task with 3 difficulty levels (1, 2, 3-Back), the active control group used the same task but with lower difficulty levels (0, 1, 2-Back), and the control group no N-Back training at all. Pre- and post-tests were administered to all three groups to gauge any transfer effects (partial memory, attention, reasoning and intelligence). Our results showed that training improved N-Back task performance for CTG participants compared to ACG and PCG participants. In contrast, transfer effects were not so clear across cognitive tasks but transfer effects were present and stronger in CTG compared to ACG for attention (TOVA test).**

Keywords-EEG; working memory training; transfer effects; P300 ERP.

I. INTRODUCTION

Working memory (WM), as defined by Baddeley [1], refers to a brain system that provides 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) [2] and several authors studied the mechanisms behind and the effect of WM training [3][4].

The N-back task is a working memory task introduced by Wayne Kirchner in 1958 [24] as a visuo-spatial task with four load factors (‘‘0-Back’’ to ‘‘3-Back’’), and by Mackworth [23] as a visual letter task with up to six load factors. Gevins et al. [5] introduced it to the field of neuroscience by using it as a ‘‘visuomotor memory task’’ with one load factor (3-Back). The 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 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 others [6]. The N-Back task requires participants to maintain simultaneously stimulus information necessary for successful task performance in working memory across multiple trials [6]. It has been shown that the N-Back task consistently activates dorsolateral prefrontal cortex (DLPFC), as well as parietal regions in the adult brain [7]. Schneiders et al. [8] have shown that, using a 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. [9][10] reported that by performing an N-Back task, the effects of WM training transfer to untrained tasks requiring WM (transfer effects) and improve upon a complex human ability known as fluid intelligence. Jaeggi et al.’s [9] findings support the hypothesis that transfer effects to general cognitive functions can be achieved after single and dual N-Back training for tasks that conceptually overlap, albeit only slightly, with the N-Back. Training of the general fronto-parietal WM network should lead to improvements in cognitive functions that rely on the same network [2]. 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. [11] 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.

The aim of our study was to verify whether N-Back task performance improves and whether transfer effects to other (untrained) cognitive functions are obtained, such as spatial memory, attention and reasoning, in three different groups of healthy young subjects: cognitive training group (CTG), active control group (ACG) and passive control group (PCG).

The paper is organized as follows. In Section 2, we describe the material and methods (subjects, procedure, EEG recording). In Section 3, we focus on the behavioral and ERPs results using a WM training and on the transfer effects pre and post-training. Finally, in Section 4, 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 participants, procedure and EEG recording.

A. *Subjects*

We recruited 16 healthy young subjects (6 females, mean age 29 years, range 24-34 years), undergraduate or graduate students from KU Leuven and non- students. Participants were healthy, reported normal or corrected vision, no history of psychiatric or neurological diseases, they were not taking any medications and never participated in working memory training. Participants were assigned to three sub-groups, cognitive training (N=6), active control (N=5) and passive control group (N=5), to evaluate improvements in task performance after the 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). In the cognitive training group, 3 subjects performed WM training with visual feedback on the correctness of their behavioral response and other 3 subjects with monetary reward (with a maximum of 10 € if all responses are correct), however, the sample turned out to be too small to reveal any significant differences. The active control group performed the same training task, but the difficulty level was lower (0, 1, 2-Back task) and with monetary reward (max. 10 €/session). The control group did not undergo any training. 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 these tests) to see if there were transfer effects in attention, spatial memory, reasoning and intelligence. The study was approved by our university's ethical committee and informed consent was obtained from our subjects prior to their participation in the experiment.

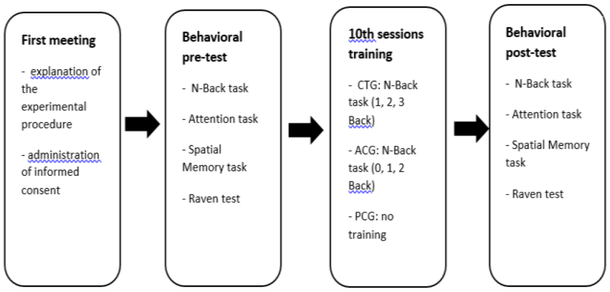


Figure 1. Study design

B. *Procedure*

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

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

Sequences with identical difficulty levels (all 0-back, 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 administered to explain the N-Back task.

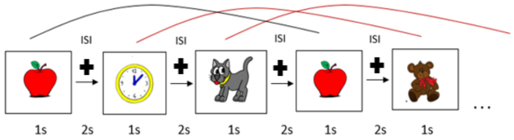


Figure 2. Graphical rendition of 3(N)-back task

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 [9][12]-[15].

TABLE 1. COMPARISON (MEAN) OF PRETEST AND POSTTEST PERFORMANCE (ACCURACY) BETWEEN TRAINING GROUP (N=6), ACTIVE (N=3) AND PASSIVE CONTROL GROUPS (N=5) IN THE TRAINED (N-BACK) AND IN UNTRAINED TASKS.

Task	Training group		Active control group		Passive control group	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
N-Back task	21*	5*	19*	6.3*	16*	13*
TOVA task	7.8*	3.3*	9.3*	3*	7.4*	5*
Corsi task	8.8**	10.4**	8.7**	9.7**	9.2**	9.4**
Raven task	3.5*	1.8*	6*	3.3*	4.6*	4.2*

*Incorrect responses **Correct responses

All participants were administered a battery of pre- and post-tests to evaluate whether there were transfer effects to other cognitive functions (attention, spatial memory, reasoning and intelligence). We used Test of Variables of Attention (TOVA) [16], Spatial Working Memory Test (CORSI) [17] and Raven test [19]. 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 [9][19][20]. 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 [21].

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 two training groups (CTG, ACG) started their training procedure of CTG and ATG participants were not informed about the group to which they were assigned or its purpose. At the beginning of each training session, an EOG calibration session was performed to capture eye movements and blinks using the method described in Croft & Barry [22].

C. *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 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 & TP10), corrected for eye movement and blinking artifacts [22], band-pass filtered in the range of 0.1–315Hz, 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 down sampled to 64 Hz and stored for ERP detection.

Recorded epochs with incorrect responses were excluded from further analysis. In addition, epochs with EEG signals greater than 100mV were excluded from analysis. A two-way ANOVA (factors: n-back X target) was performed on all sampled EEG time points between -300 ms to 700 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 pre and post-tests.

A. *Working memory training (behavioral)*

In Figures 3 and 4, we analyzed changes due to cognitive training by examining behavioral data (accuracy, reaction time (RT)) of CTG and ACG during N-Back training (10 sessions). The purpose is to test our second hypothesis: training can improve related cognitive function performance, and also transfer to other cognitive functions, in terms of RT and response accuracy revealed significant effects.

For the CTG, we observed a reduction in RT with an increased number 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 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 active control group (ACG), RT decreases. It is significant for N-Back x session ($F_{(18)}=1.95$, $p<0.05$), and for subject x session interactions ($F_{(18)}=4.84$, $p<0.001$). This indicates that the number of training sessions is subject and task-specific. Accuracy differences were significant for N-Back x subject interaction ($F_{(4)}=6.8$, $p<0.001$), N-Back x session interaction ($F_{(18)}=2.31$, $p<0.05$)~~,~~ and for subject x session interaction ($F_{(18)}=2.54$, $p<0.05$), which means that N-Back and training session are subject-specific, and N-Back is affected by the number of training sessions.

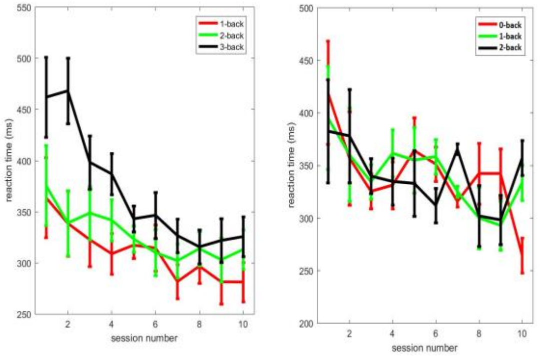


Figure 3. Left, RT during 10 sessions of cognitive training in CTG; right, RT during 10 sessions of cognitive training in ACG. Error bars indicate SEM.

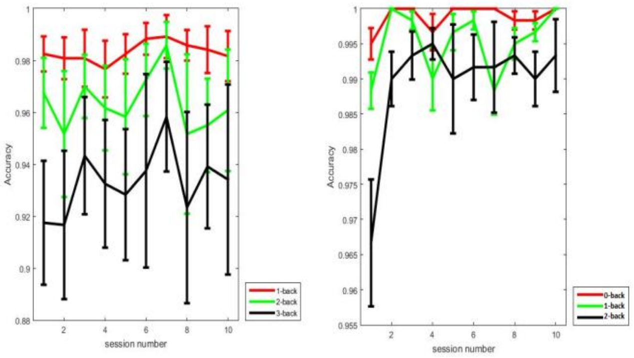


Figure 4. Left, accuracy during 10 sessions of cognitive training in CTG; right, accuracy during 10 sessions of cognitive training IN ACG. Error bars indicate SEM.

We observed significant effects between the two groups (CTG, ACG): the accuracy between CTG and ACG was significant for N-Back ($F_{(1)}=8.26$, $p<0.05$)~~,~~ and group ($F_{(1)}=18.39$, $p<0.001$). The RT in the two groups was significant for session ($F_{(9)}=3.44$, $p<0.001$) and group ($F_{(1)}=7.02$, $p<0.05$).

B. Working memory training (ERPs results)

As 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 [5], and several studies showed that the midline electrodes are the most significant [25][26], we decided to analyze ERPs using electrodes located over these areas: Fz, Pz, and Cz. Figure 5 has shown a peak in P300 amplitude in three different moments (3 sessions/each moment) during training (first-, middle- and last sessions).

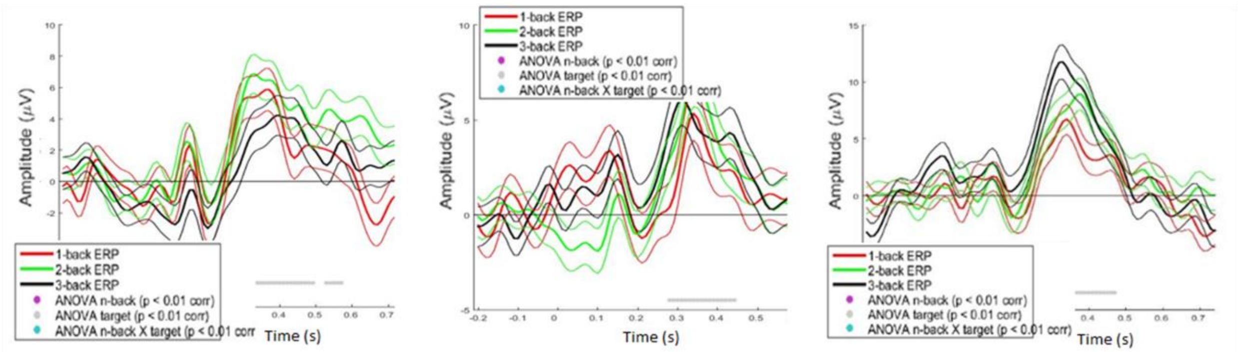
Data from mean P300 peak amplitude is presented in Figures 5 and 6. P300 peak amplitude data from midline electrodes (Fz, Cz, Pz) were analyzed with a three-way ANOVA (N-Back, target, and N-Back x target). P300 peak amplitude (target minus no-target) was higher for the N-Back difficulty levels that were easier (1 and 2-Back), and was lower for the more difficult one (3-Back). 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). Furthermore, the P300 peak amplitude decreased progressively from the easiest task (0 or 1-Back) to the most difficult one (3-Back).

As a result of working memory training, the P300 peak became higher also for the most difficult task (3-Back). All together, these data support the observation that the P300 peak amplitude decreases with increased task load/difficulty, and with WM training it is possible to increase it also for the more difficult task.

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

Means for each task are presented in Table 1 for the pre- and post-tests. In Figures 7 and 8, a multivariate ANOVA (MANOVA) was conducted between groups (CTG, ACG and PCG) and between sessions (pre- and post-tests). Significant effects for accuracy in N-Back task between CTG and PCG ($F_{(1)}=6.21$, $p<0.05$), and between CTG and ACG ($F_{(1)}=14.21$, $p<0.05$) for pre- and post-testing, were observed as well as significant effects in pre- and post-testing for accuracy in TOVA between CTG and ACG ($F_{(1)}=8.18$, $p<0.05$) and between ACG and PCG ($F_{(1)}=5.24$, $p<0.05$). No significant differences in CORSI and RAVEN test accuracies between groups 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 ($F_{(2)}=3.54$,



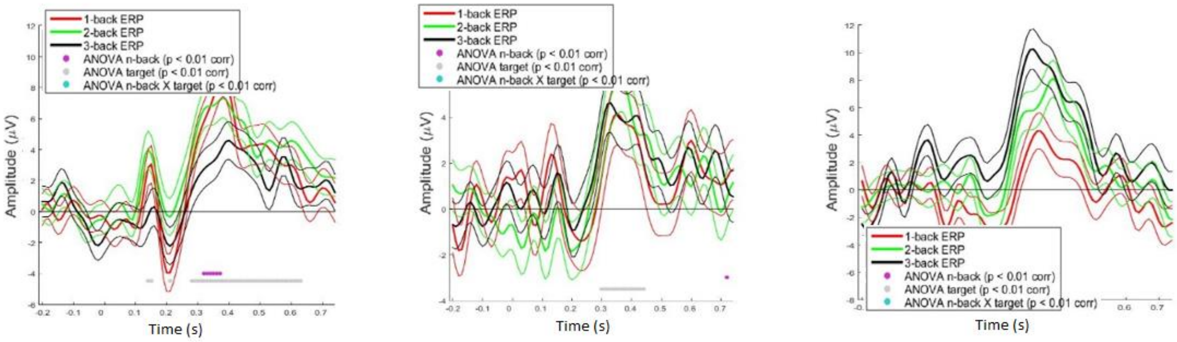


Figure 5. Pick of **P300**-ERPs (Fz and Cz, target minus non-target) in 6 subjects (CTG) in the **first** sessions of training (left), the **middle** (center) and the **last** ones (right). Significance measured using two-way ANOVA ($p < 0.01$, Bonferroni corrected for multiple comparisons. Error bars indicate SEM.

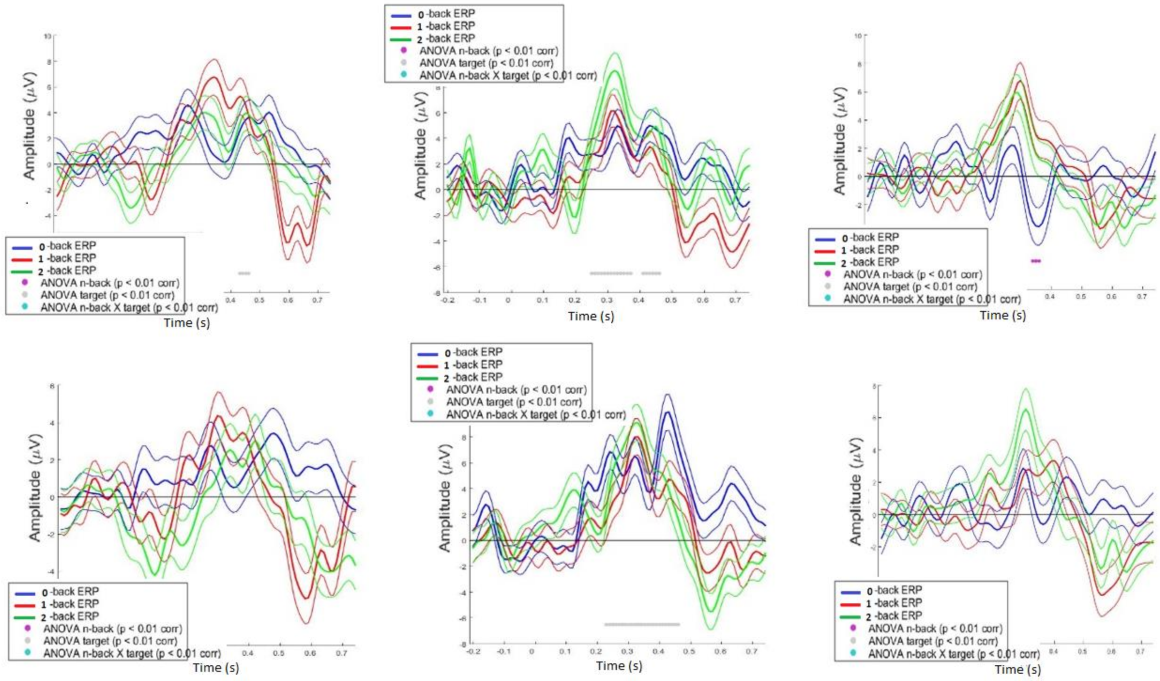


Figure 6. Peak of **P300**-ERPs (Fz and Cz target minus non-target) in 6 subjects (ACG) in the **first** sessions of training (left), the **middle** (center) and the **last** ones (right). Significance measured using two-way ANOVA ($p < 0.01$, Bonferroni corrected for multiple comparisons. Error bars indicate SEM.

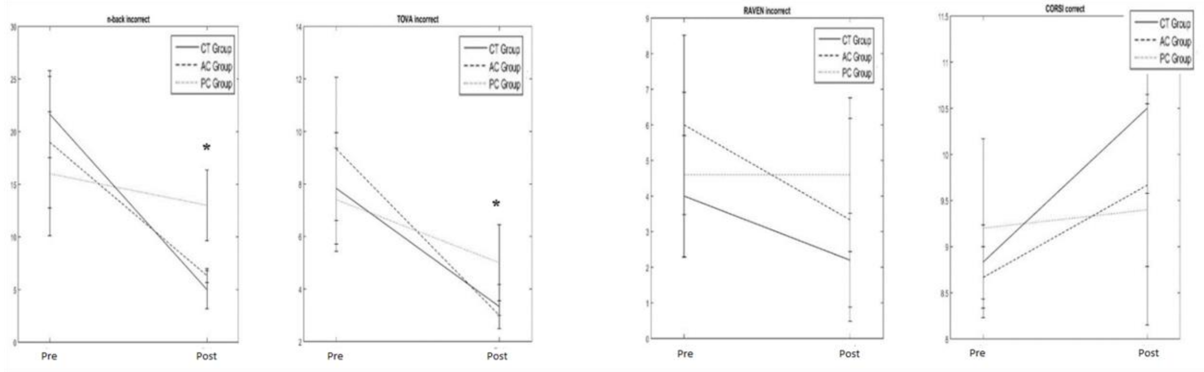


Figure 7. % incorrect performance of 3 groups for pre- to post-test in N-back task (1st figure, left), TOVA test (2nd figure), RAVEN test (3rd figure) and % correct performance in CORSI test (4th figure, right). Error bars indicate SEM. An asterisk indicates a significant difference between pre and post-tests

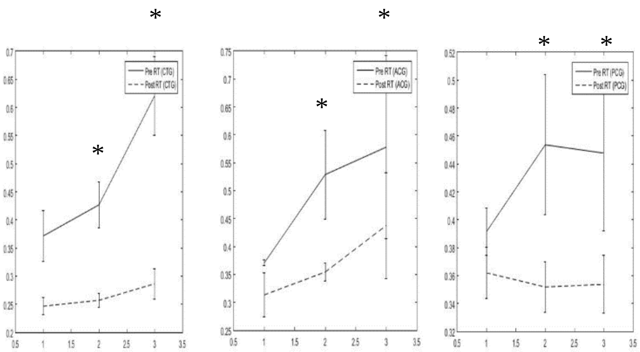


Figure 8. RT for correct responses for pre- and post-testing in the N-Back task of CTG (left), ACG (right), and PCG (bottom). Error bars indicate SEM. An asterisk indicates a significant difference between pre and post-tests.

$p<0.05$); between CTG and ACG for pre- and post-test ($F_{(1)}=25.6$, $p<0.001$), and for task difficulty level ($F_{(2)}=7.45$, $p<0.001$), and between ACG and PCG for pre- and post-test ($F_{(1)}=10.48$, $p<0.05$).

In summary, with our pre- and post-training tests, we wanted to verify whether any transfer effects could be obtained after N-Back training. Our results show clear improvements in attention.

IV. DISCUSSION

We investigated whether cognitive training using an N-Back task improves only N-Back task performance or does it transfer to other tasks. To assess this, we performed 10 N-Back training sessions in one group of participants (CTG) and assessed their cognitive performance for a battery of cognitive tasks (N-Back, TOVA, CORSI and Raven test) before and after training. During training, CTG participants performed the 1-,2-3-Back version of the N-Back task. To assess whether the level of difficulty affected training outcome, a second group of participants (ACG) performed the same experiment but with the 0-,1-2-Back versions of the N-Back task. Finally, a third group of participants (PCG) performed no training but was subjected to the same battery of cognitive tests. We found that training indeed improves performance for the CTG group compared to both the ACG and the PCG groups. Therefore, there is a clear improvement for the trained group on the task they were trained on. In contrast, the transfer of training effects into other tasks is more nuanced and although there was a trend for training effects in CTG to be stronger than for ACG this was only significant for the TOVA tests. These results are in contrast with the conclusions of Jaeggi at al. (2008) [9] who showed that a working memory task improves working memory and also fluid intelligence, and the study of Dahlin et al. [11] found that working memory training improves another working memory task but not other cognitive functions.

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. [11] they observed transfer effects to another memory task. In our view, this difference could be related to the size of the sample. Furthermore, as the EEG results from our study suggest a change in the P300 during the cognitive training, future study will consider not only the behavioral data (accuracy and RT), but also P300 component to change in real time the difficulty level of the task, avoiding too much fatigue or boredom for the subject.

In conclusion, we showed that N-Back training not only improves WM but also transfers improvement to another cognitive function (attention). The results provide evidence that it is possible to improve not only performance of tasks that include the same cognitive function (working memory), but also other cognitive tasks, as attention in our case.

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