Training and Transfer Effects Achieved with N-Back Task in Older Subjects Evidenced with EEG

Nele Vanbilsen
KU Leuven - University of Leuven,
Department of Psychology,
Leuven, Belgium
email: nele.vanbilsen@student.kuleuven.be

Valentina Pergher, Benjamin Wittevrongel
KU Leuven - University of Leuven, Department of Neurosciences, Laboratory for Neuro- & Psychophysiology, Leuven, Belgium
email: valentina.pergher@kuleuven.be, benjamin.wittevrongel@kuleuven.be

Jos Tournoy
Faculty of Medicine, Department of Experimental Medicine,
Division of Gerontology and Geriatrics,
KU Leuven - Leuven, Belgium
email: jos.tournoy@uzleuven.be

Birgitte Schoenmakers
Academic Centre of General Practice,
KU Leuven - University of Leuven,
Leuven, Belgium
email: birgitte.schoenmakers@med.kuleuven.be

Céline Gillebert
KU Leuven – University of Leuven, Department of Psychology,
Laboratory for Experimental Psychology,
Leuven, Belgium
email: celine.gillebert@kuleuven.be

Marc M. Van Hulle
KU Leuven - University of Leuven, Department of Neurosciences,
Laboratory for Neuro- & Psychophysiology,
Leuven, Belgium
email: marc.vanhulle@med.kuleuven.be

***Abstract*—Working Memory (WM) and cognitive functions decrease with age. Although WM training has been extensively studied, transfer effects to other cognitive functions are still inconclusive. We examined whether 10 sessions of N-Back training could improve not only the trained task but also lead to significant transfer effects to similar cognitive functions (near-transfer), such as spatial memory, and to different cognitive functions, such as intelligence and attention (far-transfer). We analyzed behavioral, as well as electroencephalogram (EEG) data recorded during task performance. Our results showed significant differences in N-Back performance and near-transfer effects, but no evidence for far-transfer effects.**

Keywords-N-Back; transfer effects; EEG; P300; cognitive training.

I. INTRODUCTION

Working Memory (WM) has been intensively researched in the last decade. Baddeley [1] describes WM as a brain system that provides temporary storage and manipulation of information necessary to complete complex tasks. With age, cognitive functioning has been shown to decline especially in terms of WM as it is the earliest symptom a person experiences [2]. The possibility to trigger the aging brain's plasticity processes by cognitive training seems promising as several studies reported a slowdown in WM decline [3][4] and even an improved cognitive functioning [4][5].

Following a series of studies, it has been reported that, after intensive WM training, improvements in the trained task can be obtained [3], although a generalization to other non-trained functions (transfer effects) is still unclear [6][7]. Jaeggi et al. [7][8] used an N-Back task for cognitive training and showed improvements not only in the trained task but also transfer effects to other cognitive functions, such as fluid intelligence. The latter is an example of a far-transfer effect as the brain regions activated during N-Back task performance overlap only slightly with those involved in fluid intelligence [7]. In support of the overlap theory, previous studies assume a partial overlap with the fronto-parietal network to be sufficient to exhibit also an improvement in other cognitive functions. A second hypothesis states that WM training effects transfer only if cognitive training improves specific cognitive processes required in both training and transfer tasks. Dahlin et al. [9] found transfer, after WM updating training, to an N-Back task that resembled the original trained task in also relying on updating processes (near-transfer effect), but not to a Stroop task that involved inhibition but no updating.

Motivated by the previous findings on the effectiveness of the N-Back task [10], we decided to also use it in our cognitive training experiment. The N-back task was originally developed by Wayne Kirchner in 1958 [11] as a four load factors (''0-Back'' to ''3-Back'') visuo-spatial task for measuring WM. The N-Back task involves different processes, such encoding, monitoring, maintenance, updating of the sequence, and stimulus matching. It reflects a number of core Executive Functions (EFs), besides working memory, such as inhibitory control and cognitive flexibility, problem solving, decision making, selective attention, and other functions [12]. The task requires participants to maintain stimulus information and decide if the currently shown picture is the same as the one presented N times before (Figure 1). Owen et al. [6] reported the following brain areas to be activated during this task in healthy subjects: lateral premotor cortex, dorsal cingulate and medial premotor cortex, dorsolateral and ventrolateral prefrontal cortex, frontal poles, and the medial and lateral posterior parietal cortex.

The N-Back task can be measured behaviorally and with EEG. Brouwer et al. [13] showed a clear differentiation between N-Back levels and the amplitudes of certain Event-Related Potentials (ERPs). In particular, the P300 component, defined as a positive deflection in EEG amplitude that appears approximately 300 ms after stimulus presentation. The P300 amplitude is inversely proportional to task difficulty level. P300 has been related to updating working memory [14], executive functions [15], and stimulus evaluation and categorization [16].

In the present study, we examined whether N-Back training improves the trained task in healthy older adults compared to a passive control group that did not undergo any training, and whether we could detect near- and far-transfer effects to untrained cognitive functions. We hypothesize improvements in the trained task and near/far-transfer effects in the training group, but no significant outcomes for the passive control group.

In Section 2, we describe the materials and methods used in our study. In Section 3, we report our results and discuss them briefly, and formulate our conclusions, in Section 4.

II. Materials and Methods

In this section, we describe our subject recruitment, used cognitive tests, N-Back training, and EEG recording.

A. Subjects

We recruited 15 healthy older participants (9 females and 6 males), between 55 and 70 years old (*M* = 60.98, *SD* = 0.11) from Senior Centers in Leuven, Belgium (Table 1). The selection criteria were: Mini Mental State Examination (MMSE) score above 27, no history of neurological or psychiatric diseases, no experience with WM training, normal vision, and not taking any medication that could interfere with cognitive functioning. Power estimation for sample size was calculated and indicated N = 8 based on accuracy, and N = 8 based on ERP-P300, in the case of the pre-post N-Back task. Our participants were assigned to either a training group (N = 8) or a passive control group (N = 7). The passive control group only completed two sessions of cognitive testing and did not undergo any WM training. The training group completed 10 sessions of WM training in 4 weeks, and performed 2 sessions of cognitive tests before and after training. During the first session, participants were informed about the goals of our study and what would be done with the recorded data. When they agreed to participate, they read and signed the informed consent form. The study was prior approved by our university hospital's ethical committee.

TABLE I. DEMOGRAPHICS

a. **F=female, *M= male

DEMOGRAPHICS	TRAINING GROUP		PASSIVE CONTROL GROUP		GLOBAL VARIABLES (over groups)	
	M	***SD***	***M***	***SD***	***M***	***SD***
Age	62.25	4.83	59.71	4.68	60.98	4.77
Education	10	3.5	6	1.27	8.33	3.2
Sex (F**)	4	(4M*)	5	(2M*)	9	(6 M*)
MMSE	29.75	0.46	29.86	0.38	29.8	0.41

B. Pre-post cognitive tests

The battery of cognitive tests included the Test Of Variables of Attention (TOVA), CORSI and RAVEN tests, and was used to detect behavioral differences before and after training, in the training and control group. The TOVA test is a cognitive test that gauges attention [19], the CORSI block tapping test is used to assess visuo-spatial short-term WM [20], and the RAVEN test is used for measuring abstract reasoning and intelligence [21]. The CORSI test is used to assess near-transfer effects, the TOVA and RAVEN tests to assess far-transfer effects.

C. N-Back task

Considering the encouraging results of Jaeggi et al. [7][8], using a N-Back task, subjects were administered an adapted version of the N-Back task shown in Figure 1. Participants had to decide whether the presented picture is the same as the one presented N times before. The task was divided into four difficulty levels (0-back, 1-back, 2-back and 3-back). Each level consisted of 100 stimuli (i.e., meaningful drawings) presented in pseudorandom order. Participants were required to have answered 70% of the current trials correctly before passing to the next level. For each block of 100 stimuli, 33% of them were target and the stimuli were presented during 1 s followed by a 1.5 s inter-stimulus interval (ISI) and 0.5 s of feedback presentation (red frowny/green smiley). Between stimuli, participants were shown a crosshair centered on the screen. They received a monetary reward (max 20 euros per session) and were informed of the reward at the end of each session. In total, there were 10 sessions of N-Back training for 4 weeks.

 ISBN: 978-1-61208-649-1

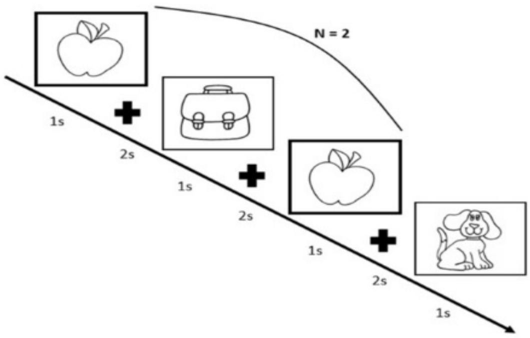

Figure 1. Example stimulus sequence of the N-Back task (2-Back) with its timeline.

D. EEG Recordings

EEG was recorded continuously with a SynAmpsRT device (Compumedics, Australia (www.compumedics.com.au)) at a sampling rate of 2kHz and using 32 Ag/AgCl electrodes. The electrodes were placed at O1, Oz, O2, PO3, 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, with the reference placed at AFz and the ground at CPz. We placed four electrodes around the eyes for Electro-Oculogram Recording (EOG) following the instructions given by Croft and Barry [22] for removing eye movement and blinking artifacts [23]. The recorded EEG signal was re-referenced offline to the average of the two mastoid signals (average mastoid reference, TP9 & TP10), band-pass filtered in the 0.1 – 30 Hz range, and cut into epochs starting from 100 ms pre- till 1500 ms post-stimulus onset. Baseline correction was performed by subtracting the average of the 100 ms pre-stimulus onset activity from the 1500 ms post-stimulus onset activity. Finally, the epochs were downsampled to 1000 Hz and stored for ERP component detection. A two-way ANOVA (N-Back level x session) was applied to the P300 amplitudes, calculated as the average over a time window between 250-400 ms, for channels Fz, Cz and Pz. Epochs with incorrect behavioral responses were excluded from further analysis. In addition, epochs with EEG signals greater than 50μV were also excluded as they could be motion artifacts.

III. RESULTS

In this section, we discuss the results of N-Back training and near/far-transfer effects to other cognitive tasks.

A. Behavioral Responses – training

To assess differences in behavioral performance of healthy older subjects that underwent N-Back training, we examined the response accuracy and Reaction Time (RT) of our participants. We hypothesize that RT decreases and accuracy level increases following N-Back training. The responses to the stimuli were divided into four categories: hit (target and button press), false alarm (non-target and button press), correct rejection (non-target and no button press), and miss (target and no button press). We performed a two-way ANOVA looking at the interaction between sessions and N-Back level, and we found a significant effect of accuracy for N-Back level ($F(2) = 12.2$, $p<0.001$), sessions ($F(9) = 9.93$, $p<0.001$), and for the interaction N-Back x sessions ($F(27) = 3.57$, $p<0.001$). For RT we found significant results for N-Back level ($F(2) = 6.98$, $p<0.05$) and sessions ($F(9) = 10.09$, $p<0.001$). Both findings confirm that cognitive training increases accuracy and reduces RT of healthy older subjects (Figure 2).

B. ERPs responses – training

As several studies showed that, during an 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 [6], and that the P300 amplitude is defined over the midline electrodes (channels Fz (frontal), Pz (posterior), and Cz (central)), we decided to analyze the P300 amplitude using a 32 electrodes cap that covered these brain areas. Furthermore, as Dahlin et al. [9] reported that training with an N-Back task improves WM in older healthy subjects, based on a functional Magnetic Resonance Imaging (fMRI) study, we hypothesize that the P300 amplitude increases at the end of the training. Grand-averaged epochs (time window between 250 and 400 ms) for target to non-target trials, for each difficulty level of the N-Back task (0, 1, 2, and 3), are shown in Figure 3. A two-way ANOVA (N-Back level x time) was used to detect significant modulations of P300 amplitude, for all three channels (Fz, Cz, Pz). Based on our results, we observed that the P300 amplitude changed significantly pre-post training mostly for central and posterior (Cz and Pz) channels. We found significant results pre-post training in channel Cz ($F(1) = 11.7$, $p<0.001$) for 2-Back, and in channel Pz ($F(1) = 7.37$, $p<0.05$) for 2-Back, and ($F(1) = 3.83$, $p<0.05$) for 3-Back. No significant pre-post training differences were found for channel Fz.

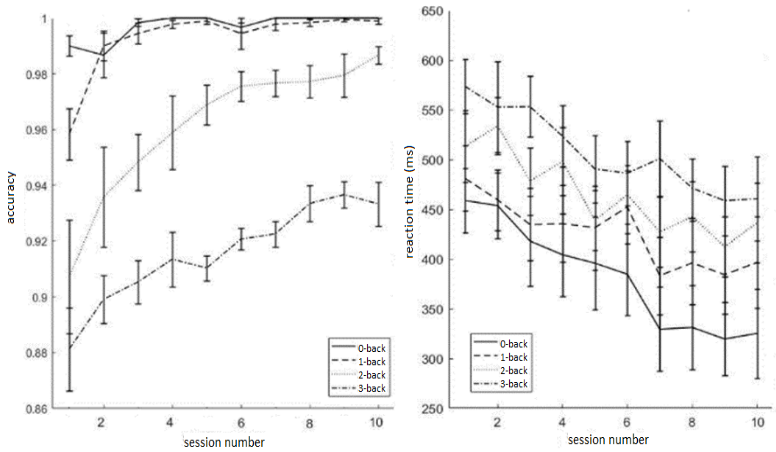

Figure 2. Mean accuracy (left) and reaction time (right) during N-Back training. Error bars indicate SEM (Standard error of the mean)

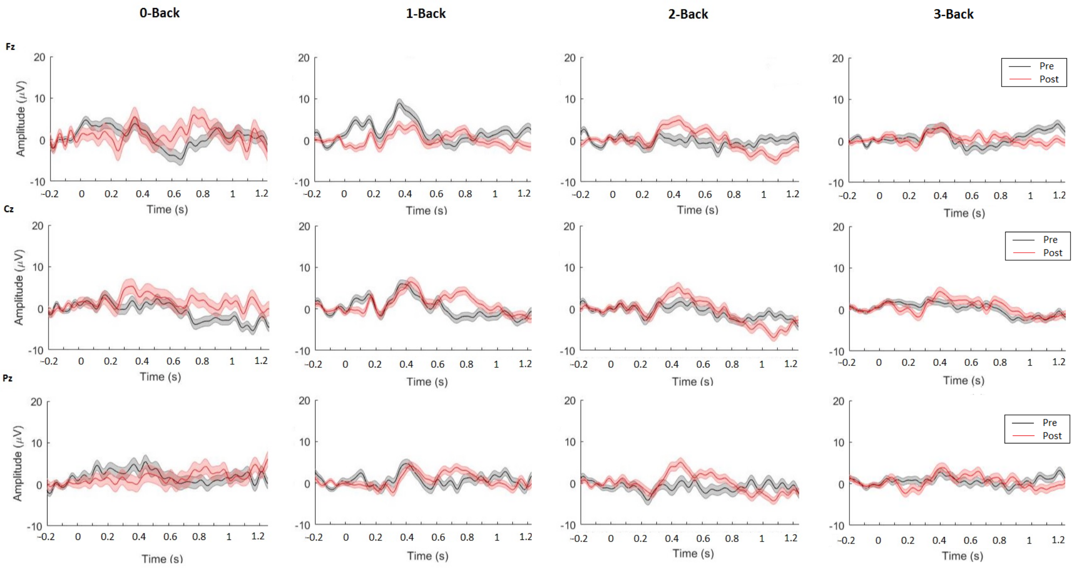

Figure 3. ERPs (P300, target – no-target) of healthy older subjects during N-Back training. Significant differences are indicated by horizontal lines and measured using two-way ANOVA (N-Back x sessions). Error bars indicate SEM.

C. *Pre-post tests- transfer effects*

To test whether we could find any transfer effects, we administered pre-post training tests and performed a paired t-test analysis, intra- and inter-group (Table 2). We found significant effects for N-Back (p = 0.000157) and CORSI (p = 0.01), thus evidence for a near-transfer effect. In the passive control group, we did not find any significant effects. Furthermore, the comparison between the two groups showed significant differences only for the trained task (N-Back) with p = 2.78 x 10 $^{(-05)}$ (p<0.001).

TABLE II. ACCURACY PRE-POST COGNITIVE TESTS IN HEALTHY OLDER SUBJECTS BETWEEN TRAINING GROUP AND PASSIVE CONTROL GROUP (PCG).

Cognitive tests	**Training Group Pre-Test**		**Training Group Post-test**		**Passive control group Pre-Test**		**Passive Control Group Post-Test**		**T-TEST***
	Mean	***SEM***	***Mean***	***SEM***	***Mean***	***SEM***	***Mean***	***SEM***	***p-values***
CORSI	77.50*	3.42	76.25*	3.03	87.5	7.40	90	5	0.01*
TOVA	95.31	0.83	97.19	0.66	44.17	0.93	44.38	0.62	0.80
N-Back	18.81*	8.18	76.34*	4.46	44.4	13.19	51.6	14.87	0.000157*
RAVEN	65.42	7.58	79.17	3.19	82.92	3.45	85	2.5	0.09

a.*Significance using t-tests (p<0.001).

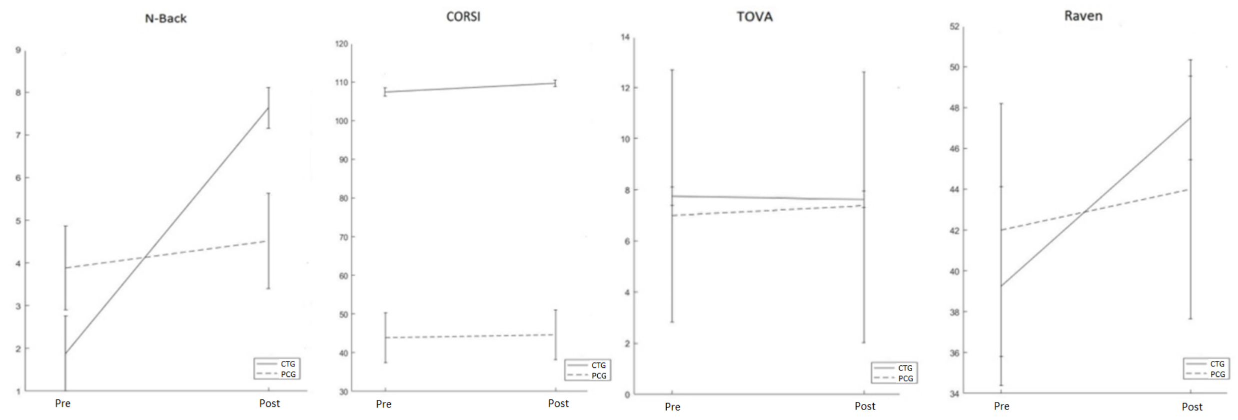

Figure 4. Accuracy of pre-post cognitive tests in healthy older subjects between training group and passive control group (PCG). Error bars indicate SEM.

We also run a two-way ANOVA analysis (N-Back x sessions) for pre-post training tests, see Figure 4, and found significant differences between groups in the trained task (N-Back task) per session ($F(1) = 12.73$, $p<0.05$) and more interestingly for the interaction between N-Back x sessions ($F(1) = 0.0078$, $p<0.05$).

IV. Discussion and Conclusion

The aim of our study was to determine whether N-Back training of healthy older adults improves not only the trained task, compared to a passive control group, but also yield near- and far-transfer effects to untrained cognitive functions (spatial memory task, attention and reasoning and intelligence). We had two groups of healthy older subjects: one group performed 10 sessions of N-Back training and another group was not trained (passive control group). Both groups were administered a battery of cognitive tests (CORSI, TOVA, RAVEN). The first group pre- and post-training for which case we expected to find significant differences [28][29]. We found significant evidence for near-transfer effects to spatial memory (CORSI), based on accuracy level, but no evidence for far-transfer effects. This could be due to our small sample size. The results are in line with those of Dahlin et al. [9] who observed that working memory training improves performance in related cognitive tasks, such as spatial memory, but not in other cognitive functions. Furthermore, the N-Back task (trained task) improved significantly in accuracy and RT in the trained group compared to the passive control group. Besides the behavioral findings, the P300 ERP results also showed a significant effect pre-post training, especially for 2-Back in the central and parietal channels. As expected [23], we could observe clear differences in P300 amplitudes for different N-Back levels, thus, supporting the results of Colom et al. [24] and Salminen et al. [25] who reported improvements after an N-Back training in healthy adults.

The novelty of our study was to add the P300 ERP component, by looking at pre-post differences after N-Back training. As mentioned before, we found significant differences for the 2-Back task, showing that this task level could be important to improve WM in older subjects. Future research could look more into detail at differences in pre-post training in the 2-Back task of healthy older subjects and repeat the experiment in patients with mild cognitive impairment (MCI) and Alzheimer’s disease (AD) as it is known that these patients have significant difficulties in WM [26]. Reducing cognitive decline in MCI patients could delay the diagnosis of AD, as we know that MCI patients have a high risk to convert to clinically-probable AD in a few years’ time [27]. In light of our results, N-Back training could be an effective tool for improving WM and related cognitive functions and for delaying cognitive decline. Furthermore, another point that we would like to suggest for future research is to test whether by using a specific strategy during an N-Back training could achieve significant transfer effects in untrained cognitive tasks, as there is a gap in the literature about what WM training strategies to use. What we do know is that the strategy of mental rehearsal has been proven to be effective in enhancing performance [28].

Acknowledgment

Valentina Pergher is supported by research grant No. G088314N, sponsored by the Belgian Fund for Scientific Research-Flanders, Marc M. Van Hulle by research grants No. PFV/10/008 from the Program Financing program, No. IDO/12/007 from the Interdisciplinary research project of KU Leuven, No. IOF/HB/12/021 sponsored by the Industrial research fund project of KU Leuven, No. G088314N and No. G0A0914N sponsored by the Belgian Fund for Scientific Research-Flanders, No. IUAP P7/11 from the Interuniversity Attraction Poles Programme – Belgian Science Policy, No. GOA 10/019 from the Flemish Regional Ministry of Education (Belgium) and No. AKUL 043 sponsored by the Hercules Foundation. Benjamin Wittevrongel is supported by the Flemish Agency for Innovation and Entrepreneurship (VLAIO).

REFERENCES

[1] A. Baddeley, "Working memory", Science, vol. 255, no. 5044, pp. 556-559, 1992.

[2] R. De Beni and P. Palladino, "Decline in working memory updating through ageing: Intrusion error analyses," Memory, vol. 12, no. 1, pp. 75-89, 2004.

[3] T. Klingberg, "Training and plasticity of working memory," Trends in cognitive sciences, vol. 14, no. 7, pp. 317-324, 2010.

[4] K. Ball et al., "Effects of cognitive training interventions with older adults: a randomized controlled trial," Jama, vol. 288, no. 18, pp. 2271-2281, 2002.

[5] T. Klingberg et al., "Computerized training of working memory in children with ADHD-a randomized, controlled trial," Journal of the American Academy of Child & Adolescent Psychiatry, vol. 44, no. 2, pp. 177-186, 2005.

[6] 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, vol. 25, no. 1, pp. 46-59, 2005.

[7] S. M. Jaeggi, M. Buschkuehl, J. Jonides, and W. J. Perrig, "Improving fluid intelligence with training on working memory," Proceedings of the National Academy of Sciences, vol. 105, no. 19, pp. 6829-6833, 2008.

[8] S. M. Jaeggi et al., "The relationship between n-back performance and matrix reasoning implications for training and transfer," Intelligence, vol.38, no. 6, pp. 625–635, 2010.

[9] E. Dahlin, A. S. Neely, A. Larsson, L. Backman, and L. Nyberg, "Transfer of learning after updating training mediated by the striatum," Science, vol. 320, no. 5882, pp. 1510–1512, 2008.

[10] P. Verhaeghen and C. Basak, "Ageing and switching of the focus of attention in working memory: Results from a modified N-Back task," The Quarterly Journal of Experimental Psychology Section A, vol. 58, no. 1, pp. 134-154, 2005.

[11] W. Kirchner and K. Wayne, "Age differences in short-term retention of rapidly changing information," Journal of experimental psychology, vol. 55, no. 4, pp. 352, 1958.

[12] 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, vol. 9, no. 4, pp.637-671, 2002.

[13] 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, vol. 9, no. 4, pp. 045008, 2012.

[14] J. H. Smith-Spark and J. E. Fisk, "Working memory functioning in developmental dyslexia," Memory, vol. 15, no. 1, pp. 34-56, 2007.

[15] T. P. Zanto, B. Toy, and A. Gazzaley, "Delays in neural processing during working memory encoding in normal aging," Neuropsychologia, vol. 48, no. 1, pp. 13-25, 2010.

[16] H. M. Morgan, C. Klein, S. G. Boehm, K. L. Shapiro, and D. E. Linden, "Working memory load for faces modulates P300, N170, and N250r," Journal of cognitive neuroscience, vol. 20, no. 6, pp. 989-1002, 2008.

[17] E. Dahlin et al., "Plasticity of executive functioning in young and older adults: immediate training gains, transfer, and long-term maintenance," Psychology and aging, vol. 23, no. 4, pp. 720, 2008.

[18] S. C. Li et al., "Working memory plasticity in old age: practice gain, transfer, and maintenance," Psychology and aging, vol. 23, no. 4, pp. 731, 2008.

[19] G. B. Forbes, "Clinical utility of the test of variables of attention (TOVA) in the diagnosis of attention-deficit/hyperactivity disorder," Journal of clinical psychology, vol. 54, no. 4, pp. 461-476, 1998.

[20] R. PC. Kessels, M. J. Van Zandvoort, A. Postma, L. J. Kapelle, and E. H. De Haan, "The Corsi block-tapping task: standardization and normative data," Applied neuropsychology, vol. 7, no. 4, pp. 252-258, 2000.

[21] J. C. Raven et al., "Raven's progressive matrices," Western Psychological Services, 1938.

[22] R. J. Croft and R. J. Barry, "Removal of ocular artifact from the EEG: a review," Neurophysiologie Clinique/Clinical Neurophysiology, vol. 30, no. 1, pp. 5-19, 2000.

[23] R. J. Croft and R. J. Barry, "EOG correction: a new aligned-artifact average solution," Clinical Neurophysiology, vol. 107, no. 6, pp. 395-401, 1998.

[24] R. Colom et al., "Adaptive n-back training does not improve fluid intelligence at the construct level: Gains on individual tests suggest that training may enhance visuospatial processing," Intelligence, vol. 41, no. 5, pp. 712-727, 2013.

[25] T. Salminen, T. Strobach, and T. Schubert, "On the impacts of working memory training on executive functioning," Frontiers in human neuroscience, vol. 6, pp. 166, 2012.

[26] S. Belleville, H. Chertkow, and S. Gauthier, "Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment," Neuropsychology, vol. 21, no. 4, pp. 458, 2007.

[27] Levey, J. Lah, F. Goldstein, K. Steenland, and D. Bliwise, "Mild cognitive impairment: an opportunity to identify patients at high risk for progression to Alzheimer's disease," Clinical therapeutics, vol. 28, no. 7, pp. 991-1001, 2006.

[28] J. E. Driskell, C. Copper, and A. Moran, "Does mental practice enhance performance?" Journal of applied psychology, vol. 79, no. 4, pp. 481, 1994.