EXTENDED ABSTRACT (Please adhere if possible to the following scheme)

(1.000 to 2.500 words)

Presenting Author:

Tiina Salminen

Co-Authors:

Tilo Strobach

Torsten Schubert

Affiliations:

Ludwig Maximilians University, Graduate School of Systemic Neurosciences

Contact:

Tiina Salminen

Ludwig Maximilians University

Department of Psychology

Leopoldstr. 13

80802 München

Phone: +49 (0) 89 2180 72532

E-Mail: tiina.salminen@psy.lmu.de

Title:

Working memory training: Transfer effects on executive control processes

Theoretical Background:

Working memory (WM) is a cognitive process which enables us to store and manipulate information for short periods of time (Baddeley & Hitch, 1974). Extending the capacities of WM by practice has been the interest of researches for decades but many of these attempts were restricted in the way that they improved the participants' performance only in the task at hand with particular stimuli (Butterfield, 1973; Ericsson, Chase, & Faloon, 1980). As there was no transfer observed to other tasks with new stimuli, these experiments did not succeed in improving WM processes as such. However, modern training paradigms which include extensive, adaptive WM training have not only managed to show training effects which generalize to new tasks with new stimuli (Klingberg et al., 2005) but a recent study has also shown that performance in measures of fluid intelligence can be improved by such WM training (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008).

As exciting as these results are, it is still unclear to which alternative cognitive functions WM training effects transfer. Potentially, these effects may transfer to executive control processes which are recruited in complex task situations. Such transfer is plausible because converging evidence from different research areas suggests that executive control and WM processes rely on related mechanisms. For example, Braver et al. (1997) assume that task representations are maintained in WM during ongoing interference task processing; as executive control is usually operating on these task representations (e.g. Dreisbach & Haider, 2009), the availability of a sufficient amount of WM resources must be considered as an important precondition for an efficient operation of executive control. The present study aimed to investigate the relation between executive control processes and WM functions and set out to investigate the transfer effects from adaptive WM training to executive control processes in another WM task as well as in task-switching and dual-task situations.

Methods

Altogether 33 participants took part in the experiment for monetary compensation. They were divided into two groups: a training group (15 participants: four male, mean age 24 years) and a control group (18 participants: four male, mean age 24 years). Both groups attended pre- and post-testing on the three transfer tasks as well as on the training task. Between pre- and post-tests there was a 14-session period (approximately three weeks) during which the training group trained on the training task whereas the control group underwent no training.

The training task was a dual *n*-back task described by Jaeggi and colleagues (Buschkuehl, Jaeggi, Kobel, & Perrig, 2007; Jaeggi, et al., 2008). This task consisted of simultaneously presented sequences of visuospatial and auditory stimuli (Figure 1). The task was to attend to both sequences and to decide for both individually whether the current stimulus matched an item that was presented *n* steps back. Participants received feedback during the training sessions and the level of difficulty (i.e.

the level of *n*) was adjusted in every trial for each participant according to their individual performance. The dependent variable (DV) was the mean level of *n*-back achieved by the participants.

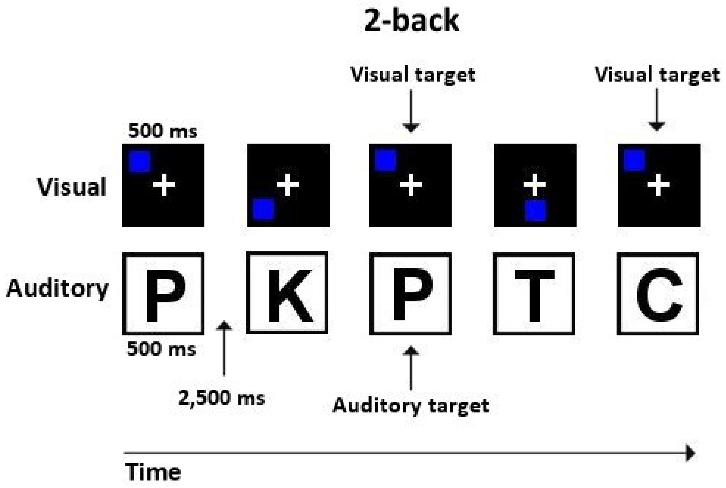

Figure 1. Example of a 2-back run in the dual *n*-back task that was used as the training task. The visual and auditory stimuli are presented simultaneously at identical rates.

The WM transfer task required constant updating of WM contents and it comprised three different types of blocks. All blocks involved lists of different lengths consisting of sequentially presented stimuli. The first block contained an auditory task, in which participants were presented with spoken digits through headphones and they were asked after each list to report the four last digits of that list in the correct order. In the second block the participants completed a visuospatial task, in which the four last locations of a black bar presented on a computer screen were to be reproduced in the correct order after each list. In the last block the auditory and visuospatial material was presented simultaneously and participants were randomly required to report either the last four digits or the last four bar positions in the correct order after each list. The DVs were the amount of correctly reported 4-stimulus sequences in each block.

The second transfer test was task switching. In this test, stimulus pairs consisting of a letter and a digit were presented and participants classified the presented letter as a consonant or a vowel or classified the digit as odd or even (Rogers & Monsell, 1995). The stimulus pairs were presented in single-task blocks in which participants exclusively classified letters or digits. In mixed blocks, participants were instructed to switch between the two tasks after every second trial. Thus, these blocks included trials with task switches and trials with task repeats in subsequent trials. The DVs in the task switching experiment were the RTs in each trial type.

In the third transfer task, the dual task, we administered an auditory-manual task (Task 1) and a visual-manual task (Task 2). In Task 1, we presented low, middle, or high pitched sine-wave tones and participants responded according to the pitches of the auditory stimuli. In Task 2, a small, middle, or large triangle was presented and participants responded according to the size of the visual stimuli. Task 1 and Task 2 were presented in single-task blocks and in dual-task blocks of the Psychological Refractory Period (PRP) type (Pashler, 1994). In single-task blocks, only one task was presented while in dual-task blocks both tasks were presented within one trial and the interval between the onset of the auditory stimuli in Task 1 and the visual stimuli in Task 2 varied (stimulus onset asynchrony, SOA, of 50, 100, and 400 ms). In dual-task blocks, participants were asked to put priority on Task 1. In this task, the DVs were the reaction times (RTs) for the first stimulus [reaction 1 (R1)] and for the second stimulus [reaction 2 (R2)], for each SOA separately.

Results:

Due to technical problems the pre-test data of two participants in the control group was lost in the *n*-back task and therefore the analyses for this task included only 16 control participants. A session (pre-test vs. post-test) × group (training vs. control) mixed-measures analysis of variance (ANOVA) on the achieved mean *n*-back level revealed significant main effects of session [$F(1, 29)=69.08$, $p<.001$] and group [$F(1, 29)=33.97$, $p<.001$] and also a significant session × group interaction [$F(1, 29)=63.14$, $p<.001$], indicating that training affected the performance differently compared to no training (Figure 2). Separate analyses for the training and control groups demonstrated a significant difference between pre- and post-test *n*-back levels for the training group but not for the control group ($p<.001$ and $p=.46$, respectively).

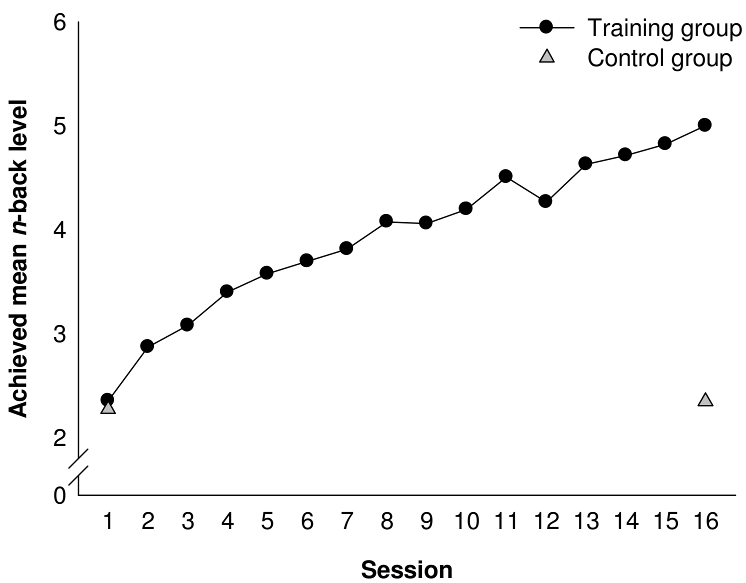

Figure 2. Improvement in the performance of the training group (session 1 – 16) and the performance of the control group in the pre- and post-tests (sessions 1 and 16, respectively) in the dual n-back task. For each session the achieved mean *n*-back level is presented.

In the transfer WM updating task, a session × modality (auditory vs. visual vs. dual modality) × group ANOVA on the amount of correctly reported stimulus sequences revealed main effects of session [$F(1, 31)=13.18$, $p<.01$] and modality [$F(2, 62)=52.45$, $p<.001$]. Additionally, the session × modality × group interaction was significant [$F(2, 62)=3.55$, $p<.05$]. Further analyses revealed a significant difference between the post-test performances of the training group and the control group in the visual updating task ($p<.05$) as well as a trend towards differences between groups in the post-test of the auditory updating task (p=.065). The pre-test performances between the two groups did not differ in either of the tasks (both p's >.2), therefore indicating a significant improvement of the training group in the visual task and a tendency towards improvement in the auditory task, whereas the improvement from pre- to post-test in the dual modality task was equal for both groups (Figure 3).

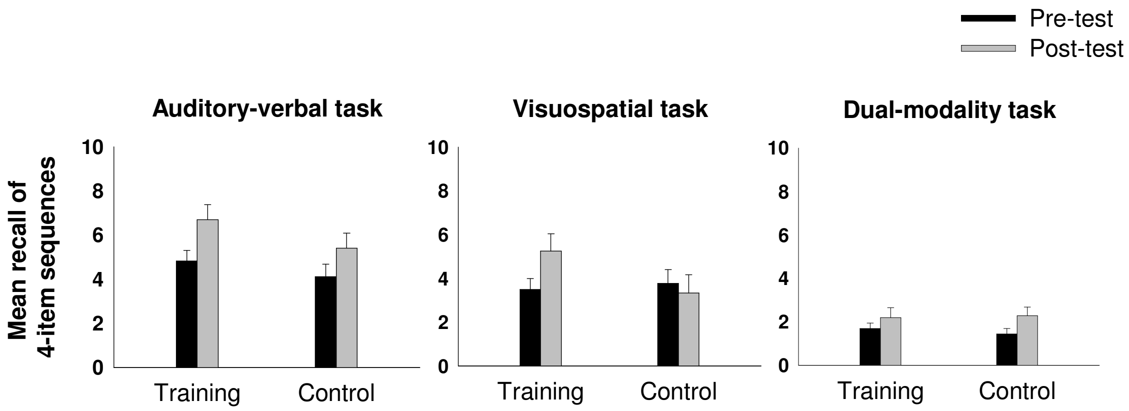

Figure 3. The number of correctly reported four-item sequences in each task: auditory, visual, and dual-modality. Performance for both groups is illustrated separately for pre- and post-tests. Error bars indicate standard errors of the mean.

Before the analysis of the task switching data, for every subject the mean correct RTs for each condition (switch trials, repeat trials, and single-task trials) were calculated and every RT that was more than two standard deviations from the mean of the trial in question was considered as an outlier and excluded from the analysis. A session × condition × group ANOVA revealed significant main effects of session and condition [$F(1, 31)=35.82$, $p<.001$ and $F(2, 62)=225.92$, $p<.001$, respectively] and also a session × condition interaction [$F(2, 62)=10.75$, $p<.001$] which indicated that the gain in RTs from pre-test to post-test was largest for switch trials and smallest for single-task trials. The main effect of group was not significant (p=.30) and neither were the other interactions (all p's >.07). However, a condition × group ANOVA for the post-test RTs revealed not only a main effect of condition [$F(2, 62)=184.85$, $p<.001$] but also a significant condition × group interaction [$F(2, 62)=3.59$, $p<.05$]. Further comparisons revealed a tendency towards differences between the two groups in the post-test RTs in switch trials (p=.06) while differences between the post-test RTs in repeat and single-task trials as well as differences between pre-test RTs in all trials types were not significant (all p's >.2). This indicates a tendency towards improvement of the control group in the switch trials whereas in the repeat and single-task trials there were no differences between the groups (Figure 4).

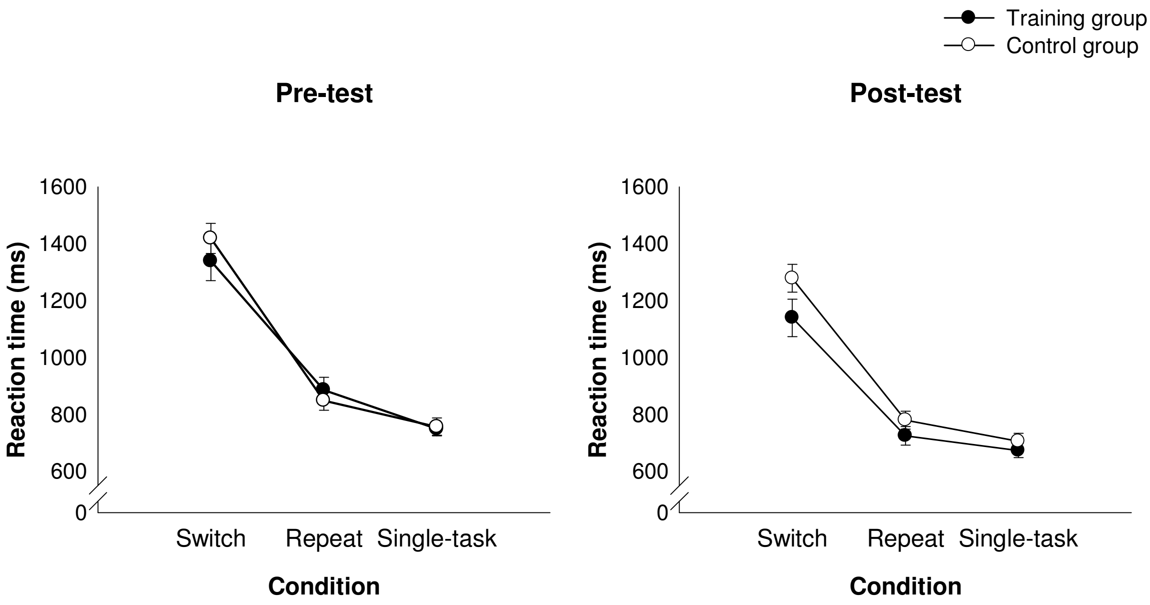

Figure 4. Reaction times in task switching experiment for training group (black dots) and control group (white dots), in pre-test (left) and post-test (right), depicted separately for switch, repeat, and single-task trials. Error bars indicate standard errors of the mean.

For the dual task, a session × SOA (50 ms vs. 100 ms vs. 400 ms) × group ANOVA revealed significant main effects of session for both R1 and R2 [$F(1, 31)=10.13$, $p<.01$, and $F(1, 31)=30.50$, $p<.001$, respectively], confirming a general improvement of both groups from pre-test to post-test (R1: pre-test M=955 ms, post-test M=893 ms; R2: pre-test M=1115 ms, post-test M=1009 ms). For R2 there was also a main effect of SOA revealed, $F(2, 62)=538.47$, $p<.001$, which shows that the RTs became shorter as the SOA increased (1196 ms, 1137 ms, and 852 ms for SOAs of 50 ms, 100 ms, and 400 ms, respectively). This manifested the typical PRP effect as longer R2 for shorter SOAs. There were no significant interactions found (all p's >.4).

Conclusions including Potential Links and Cooperation:

This study set out to investigate the effects of extensive WM training to executive control processes. We focused on transfer effects from training on a dual *n*-back task, which requires simultaneous performance of an auditory and a visuospatial WM task, to a WM updating task as well as to task switching and dual-task situations. Compared to a non-trained control group it was shown that training on the dual *n*-back task led to improvements in the trained task as well as in the visuospatial part of the transfer WM updating task. Moreover, a tendency towards improvement was found in the auditory part of the WM updating task. The finding that WM training led to an improved WM performance in the training task support the results of previous studies showing the effects of extensive WM training on WM capacity (e.g. Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008; Klingberg, et al., 2005). As this effect was transferred to another WM task that was not trained, the training effect was not purely stimulus- or task-specific. The tendency towards an improvement after training in task switching implies transfer of improvement in switching between two task streams, which is an integral component of the training task. For the dual-task, there was no transfer from WM training. Both the WM updating task as well as task-switching require constant updating of WM components: for WM updating task it concerns the updating of stimulus representations, while in task-switching it concerns the updating of task-set representations. Therefore, the results of the present study show that WM can be trained and that training can transfer to tasks that are not part of the training.

Due to the potential transfer effects of the dual *n*-back training on functions of fluid intelligence (Jaeggi, et al., 2008) and executive control processes as shown in the present study, this training regime may be of great interest for a wide community; in particular, because the related functions are responsible for many changes in cognitive aging or for disease-related changes. WM training may therefore prove to provide a marked optimization of intelligence and executive control functions to individuals with a decline in them. This potential practical application of WM training offers links to other areas of research and cooperation with researchers in these areas.

Grant:

DFG

Literature:

Baddeley, A., & Hitch, G. J. (1974). Working memory. In G. A. Bower (Ed.), *Recent Advances in Learning and Motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. *NeuroImage, 5*, 49-62.

Buschkuehl, M., Jaeggi, S. M., Kobel, A., & Perrig, W. J. (2007). BrainTwister - Aufgabensammlung für kognitives Training, Version 1.0.1. Manual und CD: Institut für Psychologie, Universität Bern.

Butterfield, E. C. (1973). On the theory and practice of improving short-term memory. *American Journal of Mental Deficiency, 77*, 654-669.

Dahlin, E., Nyberg, L., Bäckman, L., & Stigsdotter Neely, A. (2008). Plasticity of executive functioning in young and older adults: Immediate training gains, transfer, and long-term maintenance. *Psychology and Aging, 23*(4), 720-730.

Dreisbach, G., & Haider, H. (2009). How task representations guide attention: Further evidence for the shielding function of task sets. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(2), 477-486.

Ericsson, K. A., Chase, W. G., & Faloon, S. (1980). Acquisition of a memory skill. *Science, 208*, 1181-1182.

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*(19), 6829-6833.

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., . . . Westerberg, H. (2005). Computerized training of working memory in children with ADHD - a randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177-186.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychological Bulletin, 116*(2), 220-244.

Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*(2), 207-231.