Working Memory Training and Transfer in Older Adults: Effects of Age, Baseline performance, and Training Gains.

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Abstract

Recent studies suggest that executive control and working memory training can benefit older adults, however, findings regarding the amounts of training and transfer effects are mixed. The current study aimed to investigate the effects of a process-based training intervention in a diverse sample of older adults and explore possible moderators of the amount of training and transfer effects. For that purpose, 80 older adults (65-95 years) were enrolled in the study, half of them were trained for three weeks on visuospatial, verbal, as well as executive working memory tasks; the other half did not receive training. Performance on trained and transfer tasks was assessed before and after training, as well as at a nine-month follow-up. Analyses revealed significant training effects in all three tasks, as well as near transfer to a verbal working memory and far transfer to a fluid intelligence task. Remarkably, all training effects and the transfer effect to verbal working memory were stable at the nine-month follow-up. Further analyses revealed that training gains were predicted by baseline performance in training tasks and (to a lesser degree) by age. Transfer gains on the other hand, were predicted by age and by the amount of improvement in the trained tasks. These findings suggest that cognitive plasticity is preserved over a large range of old age and that even a rather short training regimen can lead to (partly specific) training and transfer effects. However, there are a range of factors that may moderate the amount of plasticity.

Keywords: Executive functions, Plasticity, Third age, Fourth age, Training

Working Memory Training and Transfer in Older Adults: Effects of Age, Baseline performance, and Training Gains.

Working memory (WM) is a central neurocognitive processing resource that is involved in most conscious everyday mental activities. The term WM describes the ability to maintain (store) and manipulate (process) information over short periods of time. According to the WM model by Baddeley (2003, Baddeley & Hitch, 1974) it comprises a verbal, a visuospatial, and an executive subsystem. The verbal subsystem (phonological loop) stores and processes verbal and other acoustic information. The visuospatial subsystem (visuospatial sketchpad) is involved in storing and processing visual and spatial information as well as mental images. The executive system (central executive) is thought to coordinate the other two subsystems. With these basic components, WM has been shown to support a wide range of complex cognitive functions, including logical reasoning and problem solving, and to be strongly related to measures of fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999). From an aging perspective it is crucial to note that WM functions are among those cognitive processes that are prone to age-related decline: Research has revealed substantial mean level decreases in WM in old age (in both verbal and spatial WM tasks, Bopp & Verhaeghen, 2005; Hale et al., 2011; Park et al., 2002). This decline is already evident in young-old adults (60-80 years), but is particularly pronounced in old-old adults (over 80 years, Craik, 2000; Gilinsky & Judd, 1994; Hale et al., 2011). Considering the importance of WM for cognitive functioning in general, the question of possibly modifying this decline has been raised in aging research.

Although WM capacity has been viewed as a relatively constant trait, recent studies suggest that it can be improved by adaptive and extended training (see Klingberg, 2010, for a review). Earlier studies have investigated enhancing WM with the help of strategies, e.g., rehearsal (Butterfield & Wambold, 1973) or chunking strategies (Ericsson, Chase, & Faloon, 1980), which led to substantial improvements in performance on the targeted tasks but hardly any transfer to other tasks. Recent studies involve a more implicit, process-based approach where improvement in performance is based on repetition, feedback and often gradual adjustment of difficulty (Klingberg, 2010) with tasks where strategy use is rather unlikely.

These training studies usually involved repeated performance of tasks focusing on WM capacity (Klingberg et al., 2005; Holmes, Gathercole, & Dunning, 2009), updating (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008), or task switching (Karbach & Kray, 2009). These studies targeted different age groups with most of the studies involving children or young adults. Some recent studies suggest that updating (Dahlin, Nyberg, Bäckman, & Stigsdotter Neely, 2008; Li et al., 2008) and WM training (Borella, Carretti, Riboldi, & de Beni, 2010; Brehmer et al., 2011) may also be effective in enhancing performance on trained tasks in young-old adults and old-old adults (Buschkuehl et al., 2008; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012). However, no study has so far included participants across the full age-range of old adulthood. Thus, the first aim of the current study was to verify the potential for training-induced plasticity of WM in older adults ranging from young-old to old-old age (65 to 95 years old).

In addition to improvements in trained tasks, transfer to non-trained tasks has been observed after process-based WM training for tasks within the WM memory domain (e.g., complex span tasks, Holmes et al., 2009) as well as to executive control tasks (e.g., Stroop; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Olesen, Westerberg, & Klingberg, 2004) or measures of non-verbal reasoning (Klingberg et al., 2005; Jaeggi et al., 2008). On a neural level, WM training has even been shown to be associated with changes in brain activity in frontal and parietal cortex and basal ganglia pointing to increased neural efficiency, as well as changes in dopamine receptor density (Brehmer et al., 2011; McNab et al., 2009; Olesen et al., 2004). Taken together these recent findings suggest that WM training can be used as an intervention to improve WM and associated cognitive functions and that this may be especially helpful for individuals who experience difficulties in everyday life, perhaps as a result of decreased WM capacity (Klingberg, 2010). Although these findings have mostly been acquired with young participants, some recent studies have also targeted older adults. However, the findings regarding transfer effects in old age are more mixed and generally suggest that transfer may be more restricted in old as compared to younger participants Findings regarding transfer, however, are mixed. Whereas some studies did not find any significant transfer effects after training in their older participants (Dahlin et al., 2008;

Zinke et al., 2012), other studies provide evidence for transfer effects to similar tasks. For example, in the study by Li and colleagues (2008), visuospatial n-back WM training transferred to visuospatial as well as numerical n-back tasks in both young and young-old participants but not to more complex WM span tasks. Buschkuehl and colleagues (2008) found a clear transfer effect directly after training for a very similar visuospatial WM task, and some evidence for a performance increase in a visual free-recall task in the experimental group. Recently, some studies have even suggested transfer of WM training to tasks very different from the ones trained, for example sustained attention and episodic memory (Brehmer et al., 2011; Richmond, Morrison, Chein, & Olson, 2011) or fluid intelligence, speed and inhibition (Borella et al., 2010). That is, in some studies transfer effects seem to be generally limited and, if they are found, restricted to WM tasks that were rather similar with regard to format and processing requirements to the trained tasks (near transfer tasks). In other studies evidence for improvements in tasks that assess different cognitive constructs (far transfer tasks) has been found. According to models of neural plasticity, one would expect transfer if training induces plasticity in a common neural network that is shared between the training and transfer tasks (Olesen et al., 2004). For example, studies have shown that WM and fluid intelligence tasks both activate particular lateral prefrontal and parietal regions (Gray, Chabris, & Braver, 2003; Olesen et al., 2004). Thus, if the current training program is able to induce changes in this common neural network we would expect transfer to other WM tasks (near transfer) or fluid intelligence tasks (far transfer). Following up on this issue, the second aim of the current study was to systematically test the emergence and magnitude of near and far transfer effects after WM training in older adults.

In addition to immediate training and transfer effects, it is conceptually important to explore whether benefits that are obtained immediately after training will remain stable over time. So far, findings on the stability of training and/or transfer effects have been mixed. Whereas Buschkuehl et al. (2008) found no maintenance of either training or transfer effects after one year in their study with 80-year old participants, (Dahlin et al., 2008) were able to show maintenance of training gains 18 months after training for all trained participants. However, stability of the reported transfer effect was only found for the young participants, not for the young-old ones. Borella et al. (2010) showed maintenance of training and some of the transfer gains in young-old adults eight months after training. Thus, the findings on maintenance of training and transfer effects are mixed, particularly with regards to old-old adults. Therefore, the current study assessed stability of training and transfer effects in both young-old and old-old adults nine months after the immediate posttest for the training and control groups.

Given the heterogeneous picture on the emergence of training and transfer effects, the third and key aim of the present study was to explore possible moderators of training and transfer effects that may underlie these inconsistencies. Many factors have been proposed to impact the degree of benefit obtained from WM training. Age is one prominent factor that may moderate training and transfer effects (as has been pointed out by Borella et al., 2010, for example). Previous studies that reported far transfer effects were those with young-old participants (60 to 70 years, Brehmer et al., 2011; 65 to 75 years, Borella et al., 2010), studies with older participants reported no or limited transfer (mean age of 80 years, Buschkuehl et al., 2008; 77 to 96 years, Zinke et al., 2012). Up until now, no study has directly investigated whether the effects of process-based WM training interventions on training and transfer effects may differ with the age of the participants. Considering findings from episodic memory strategy trainings, one would expect reduced training efficiency in old-old as compared to young-old adults (Singer, Lindenberger, & Baltes, 2003). Therefore, current study for the first time included a large age range of participants covering both young-old and old-old age.

A second possible variable that may influence the efficiency of cognitive training may be the general cognitive ability of the participants. This is especially important in old age, as it may be that only participants who have maintained a high cognitive status profit from a rather complex and demanding intervention such as a WM training. This may be because a relatively high level of functioning could be required to actively engage in the extensive practice of abstract working memory problems (see, e.g., Bissig & Lustig, 2007; Yesavage, Sheikh, Friedman, & Tanke, 1990, for similar effects in memory training). On the other hand, one may predict that especially participants with a low cognitive status profit from such an intervention. This may be because participants' low starting level may be low due to decline in the use of their cognitive resources and engaging in a working memory intervention may help them to reactivate some of their potential as is suggested by the disuse hypothesis (e.g., Hultsch, Hertzog, Small, & Dixon, 1999; Kliegel, Zimprich, & Rott, 2004). Therefore, the current study aimed at investigating the possible influence of individual differences in general ability on training and transfer effects.

Further possible moderating factor are more specifically tied to the WM training, e.g., the baseline level of performance on the WM tasks. For example, in a recent training study focusing on old-old adults, those individuals starting with low levels of WM capacity were the ones that profited most (Zinke et al., 2012). This could indicate that those individuals who start at a relatively low level may show more, or at least equal, training gains. Concerning transfer, a recent study by Jaeggi, Buschkuehl, Jonides, and Shah (2011) on WM training in children suggests that the individual amount of training gains may impact the amount of transfer found. In this study, transfer to a non-trained fluid intelligence task was only observed in the subgroup of participants that improved considerably on the trained WM tasks. Based on these findings, we predict that baseline scores will impact the amount of training gains. Furthermore, we predict that the amount of training gain will impact the amount of transfer.

Taken together, the current study explored the limits and potential of WM plasticity in a sample of older adults ranging from young-old to old-old adults. For that purpose, an experimental approach was used comparing a training group to a control group on measures of training and transfer performance. With an individual difference approach, possible moderating factors of training-related plasticity were investigated for training and transfer gains.

Methods

Participants

The 80 participants of the study were between 65 and 95 years old (mean age: 77.2 years, $SD = 8.1$). Half of the participants participated in a WM training program for three weeks (training group, $n = 40$); the other half did not receive training (control group, $n = 40$). Training and control groups did not differ significantly from each other regarding age, gender, years of education, and cognitive status (see Table 1). Exclusion criteria were non-corrected visual or auditory impairments and neurological or psychiatric disorders, in particular Mild

Cognitive Impairment or Alzheimer's disease. This was screened for via self-report and with the Mini Mental Status Test (MMST), German short form for old-old adults (maximum score of 21; cut-off for risk of dementia = 16; see Kliegel, Rott, d'Heureuse, Becker, & Schönemann, 2001; Rott, d'Heureuse, Kliegel, Schönemann, & Becker, 2001). Participants were also screened for depression and anxiety disorders with the Hospital Anxiety and Depression Scale (HADS-D, German version, Herrmann, Buss, & Snaith, 1995). Crystallized intelligence was assessed with a German vocabulary test (MWT, Lehrl, Merz, Burkhard, & Fischer, 1991).

Training tasks

Training material was chosen based on Baddeley's WM conceptualization (2003; 1974) target multiple aspects of WM (as has been done in studies by Klingberg and colleagues) with tasks requiring both verbal and visuospatial WM, as well as executive control processes. The training included tasks that each required both storage and processing of information in WM.

Visuospatial WM span was trained with a picture grid task: *K-ABC Icons* (Kaufmann Assessment Battery for Children, Melchers & Preuss, 1991). The (modified) K-ABC-Icons task was an adaptive visuospatial WM task where participants had to process and maintain the spatial arrangement of multiple stimuli. An increasing number of icons (pictures of objects), that were either placed in a 3x3 grid or, at higher difficulty levels, in a 3x4 grid, was presented to the participant. The participant had five seconds to memorize each arrangement of icons. Afterwards, an empty grid was presented and the participant was asked to name all icons he/she had seen and show their individual location on the empty grid. The set size (total number of icons to be recalled) ranged from two to nine. Each trial was scored as correct only if the participant recalled all icons and their locations correctly. The main dependent variable was the total number of correctly recalled trials.

Verbal WM span was trained with the *Subtract-2-Span* task (Salthouse, 1988). The experimenter presented number sequences of increasing length. The participant was asked to subtract two from each number that was presented and repeat the (manipulated) sequence of numbers. Set size (total number of numbers to be recalled) ranged from two to eight numbers. The dependent variable was the overall number of sequences correctly recalled.

Executive control was trained with the *Tower of London* task (Ward & Allport, 1997). Participants were asked to move five differently colored balls on a board with three equally long pegs from a start position to a defined end position. The end position and the number of moves required to solve the problem was shown on a picture. Difficulty was adapted by increasing the number of moves necessary to solve the problems (from 3 to 11). Only trials solved in the fewest possible number of moves were scored as correct. The main dependent variable was the total number of correctly solved problems.

The difficulty level for all tasks was constantly adapted for each participant over the course of the training program, because increasing the level of difficulty adaptively has been shown to be an important feature for effective training tasks (Klingberg et al., 2005). The difficulty level for verbal and visuospatial WM was adapted by increasing set size (number of items to be recalled) of the next trials by one item whenever the participant had two consecutive correct trials at the same difficulty level. If he/she only had one out of two trials of the same difficulty level correct, set size remained the same for the next two trials. If none of the trials were solved correctly, set size was decreased by one item on the next two trials. Similarly, the difficulty level for the Tower of London task was adapted by increasing set size (number of moves necessary to solve the problems) by one, whenever the participant solved four out of five trials (problems) of the same difficulty level correctly in the minimum number of moves. If the participant solved two or three out of the five problems correctly, the difficulty level remained the same. If he/she solved less than two problems correctly, the difficulty level was decreased by one move. This adaptive procedure attempted to keep all participants motivated by allowing them to experience periodic success while ensuring that participants regularly practiced at a level of difficulty that was at the limit of their current performance level. All tasks were administered in individual, face-to-face sessions. The tasks that were used in pre- and posttest sessions resembled those of the training sessions. To ensure that the exact same trials were not presented repeatedly, different (parallel) versions for trials on each difficulty level were constructed for all sessions.

Transfer tasks

To assess the first level of transfer (near transfer: within the same domain but to other stimuli) three different tasks were used that corresponded to each of the trained domains. The *Corsi Block Span* task, taken from the Wechsler Memory Scale (WMS-R, Wechsler, 2000), was used to assess visuospatial WM. The experimenter tapped a number of blocks on a board in sequences of increasing length. The participant had to reproduce the sequences by tapping immediately after the experimenter had finished. The sequence length (number of blocks tapped) was increased by one block if the participant was successful in completing at least one out of the two sequences of the same length. The dependent variable was the overall number of correctly reproduced sequences.

The *Letter-Span Plus* task (Verhaeghen & Marcoen, 1996) was used to measure verbal WM capacity. The experimenter presented letter sequences of increasing length containing the letters A to I. The participant was asked to increase each presented letter in alphabetic order by one and repeat the (manipulated) sequence of letters. The sequence length (number of letters presented) was increased by one letter if the participant was successful in completing at least one out of the two sequences of the same length. The dependent variable was the overall number of correctly recalled sequences.

A computerized version of the *Tower of Hanoi* was used to assess executive control. The participants had to move an increasing number of discs of different sizes from a starting pole to an end pole while adhering to certain rules, e.g., only one disc can be moved at a time, a small disc can only be placed on a larger one, etc. The problem was counted as correctly solved if the participant solved the problem in the least possible moves. The difficulty of problems (number of discs) was increased by one disc if the participant solved at least one out of the two problems of equal difficulty. The main dependent variable was the sum of correctly solved problems.

To assess the second level of transfer to other cognitive constructs associated with WM capacity (far transfer), two tasks were used. In keeping with the literature, the *Raven Standard Progressive Matrices* (Raven, Court, & Raven, 1979) was used to assess nonverbal complex reasoning ability/fluid intelligence. The participant had to find logical patterns in an array of figures or patterns and choose the item that best fit in the blank space to complete the pattern. In the current study two parallel versions with 18 items each were constructed for the pretest and posttest sessions. The *Stroop interference* task (German version of the color-word-Stroop test taken from the Nürnberger Altersinventar, NAI, Oswald & Fleischmann, 1995) was used to measure inhibitory control. Here, the participant first had to read out loud color names (printed in black on a sheet) as fast as possible; in the second run the participant was to name color patches; in the last run he/she was to name the print color of color words printed in different colors. The main dependent variable was the difference in overall naming time between the third and the second run.

Procedure

Two to three days before and after training, the training group completed a pretraining and a posttraining assessment, respectively, with two sessions each. One session measured pre- and posttraining performance on the trained tasks to serve as baseline and outcome measure for the trained tasks. The other session included the non-trained transfer tasks to assess transfer on all three levels. The order of the tasks was the same in pre- and posttraining sessions and for all participants. Training was administered in nine sessions over three weeks. Each training sessions lasted 30 minutes in total, with about equal time (about 10 minutes) for each of the three training tasks. Difficulty levels were adapted individually within each session as described above. Participants started each session at the final difficulty level of the preceding session. The sequence of training tasks was counterbalanced over the sessions. Nine months after the posttraining assessment, 83 % of the training group (n = 33: 15 young-old and 18 old-old adults) participated in a follow-up session including trained tasks, and (due to time restrictions) a reduced set of transfer tasks (i.e., verbal and visuospatial WM and fluid intelligence).

The control group received no treatment, but was also tested in pre- and posttest assessments with the same time interval in between assessments as the training group. Similar to the training group, these assessments included two sessions: one for assessing performance on the transfer tasks and one for assessing performance on the training tasks. Twenty control participants were randomly selected for a follow-up testing session nine months later, and eighteen participated (45 % of the original control group): nine young-old and nine old-old adults.

Results

First, we tested for comparability in baseline performance between training and control group. Importantly, analyses indicated no significant differences at pretraining in any of the training or transfer tasks between training and control group suggesting that randomization had been successful.

WM training effects

To compare changes in performance on trained tasks from pre- to posttraining between groups, a two-factorial ANOVA was conducted with group (training vs. control) as a between-subjects factor and time of measurement (pretraining vs. posttraining) as a within-subject factor. Most importantly, there was an interaction for all three trained tasks between the time of measurement and the group indicating larger changes between the pre- and posttraining assessments for the trained group than for the control group (as can be seen in Figure **??**): for the number of correctly repeated sequences in K-ABC Icons, $F(1, 78) = 20.1$, $p < .001$, partial $\eta^2 = .21$, for the number of correctly repeated sequences in Subtract-2 Span, $F(1, 78) = 32.7$, $p < .001$, partial $\eta^2 = .30$, and for the number of correctly solved problems in the Tower of London, $F(1, 78) = 13.0$, $p = .001$, partial $\eta^2 = .14$. Analyses also revealed a main effect of time, indicating gains from pre- to posttraining assessments for all trained tasks: for K-ABC Icons, $F(1, 78) = 7.4$, $p = .008$, partial $\eta^2 = .09$, for Subtract-2 Span, $F(1, 78) = 42.7$, $p < .001$, partial $\eta^2 = .35$, and for the Tower of London, $F(1, 78) = 12.6$, $p < .001$, partial $\eta^2 = .14$. There was also a main effect of group with the trained group performing significantly better than the control group for Subtract-2 Span, $F(1, 78) = 8.6$, $p = .004$, partial $\eta^2 = .10$, and for Tower of London, $F(1, 78) = 11.6$, $p = .001$, partial $\eta^2 = .13$, and a trend towards significance for K-ABC Icons, $F(1, 78) = 3.7$, $p = .06$, partial $\eta^2 = .05$.

To explore the *stability* of the training effects, repeated measures ANOVAs with group as between-subjects factor and time of measurement (pretraining vs. follow-up) as a within-subject factor were conducted to compare differences between groups before training and at follow-up. Importantly, for all trained tasks the interaction term between time of measurement and group was still significant, indicating larger differences between pretraining and follow-up assessment for the trained group than for the control group (see Figure **??**): for K-ABC Icons, $F(1, 49) = 14.5$, $p < .001$, partial $\eta^2 = .23$, for Subtract-2 Span, $F(1, 49) = 16.9$, $p < .001$, partial $\eta^2 = .26$, and for Tower of London, $F(1, 49) = 8.0$, $p = .007$, partial $\eta^2 = .14$.

To summarize the analyses on WM training effects, larger gains for the trained participants as compared to the control participants were revealed for all training tasks. Furthermore, the effects of training on performance on the trained tasks were still evident at the nine month follow-up.

Transfer effects

To explore possible group-level transfer effects of training, analyses were conducted analogous to the analyses of the training effects. A two-factorial ANOVA was used with group (training vs. control group) as a between-subjects factor and time of measurement as a within-subject factor. Means and SDs for pretraining, posttraining, and follow-up performance for the respective transfer tasks can be found in Table 2.

In the domain of near transfer, for the visuospatial WM transfer task (number of correctly repeated sequences in the Block Span task) there was a main effect of time, $F(1, 78) = 16.9$, $p = .003$, partial $\eta^2 = .11$, indicating general performance gains from pre- to post-training assessment. Neither main effect of group nor the two-way interaction between time and group was significant, indicating that groups neither differed overall nor in the pre- to posttraining gains on this task. For the verbal WM task (number of correctly repeated sequences in the Letter-Span Plus Task), there was a main effect of time indicating gains from pre- to posttraining assessment, $F(1, 78) = 33.8$, $p < .001$, partial $\eta^2 =.30$. There was also a significant main effect of group with the trained group performing significantly better than the control group, $F(1, 78) = 9.3$, $p = .003$, partial $\eta^2 =.11$. There was a significant effect for the crucial interaction between the time of measurement and the group, $F(1, 78) = 15.6$, $p < .001$, partial $\eta^2 =.17$, indicating transfer effects in the verbal WM task (see Table 2). For the executive transfer task (number of correctly solved problems in the Tower of Hanoi) there was a main effect of time indicating gains from pre- to posttraining assessments, $F(1, 78) = 16.9$,

$p < .001$, partial $\eta^2 = .18$. Neither main effect of group nor the interaction between time and group was significant, indicating that groups neither differed overall nor in the pre- to posttest gains on this task.

In the domain of far transfer, for the inhibition task (interference score in the Stroop task) analyses revealed no significant main or interaction effects, indicating neither group differences nor changes from pre- to posttest. For the fluid intelligence task (Raven SPM), there was a significant effect for the crucial interaction between the time of measurement and the group, $F(1, 78) = 5.0$, $p = .03$, partial $\eta^2 = .06$, indicating larger changes in the trained group pre- vs. posttraining than in the control group.

Stability of the transfer effects was again analysed using repeated measures ANOVAs with group as between-subjects factor and time of measurement (pretraining vs. follow-up) as a within-subject factor were conducted to compare differences between groups before training and at follow-up. At follow-up, the crucial interaction between the time of measurement and the group was still significant for the verbal near transfer task (Letter-Span Plus), $F(1, 49) = 16.7$, $p < .001$, partial $\eta^2 = .25$, indicating larger changes from pretraining to follow-up in the trained compared to the control group. For the Raven SPM, the crucial Time x Group interaction term was not significant, $p > .1$, indicating no significant differences in changes from pretraining to follow-up between training and control group.

To summarize the analyses on transfer effects, near transfer (as indicated by larger pre- to posttest gains in the training group compared to the control group) was found for the verbal WM task, but not for the visuospatial WM task and the executive transfer task. Far transfer was found for the fluid intelligence task, but not for the inhibition task. Effects on transfer tasks were stable for the verbal WM task, but not for the fluid intelligence task.

Moderators of training and transfer gains

To explore possible moderating factors of individual differences in training and transfer gains, a set of analyses was conducted with only the trained individuals. The possible moderating factors we considered were age, crystallized ability, and baseline performance on trained tasks. Correlations between these factors and the training and transfer gains (differences between posttraining and pretraining performance) are presented in Table 3.

Moderators of training gains. To examine the unique contribution of factors that may moderate training and transfer effects, a series of hierarchical linear regression analyses were conducted. For each training gain age was included as a predictor in a first step, followed by crystallized abilities in a second step, and baseline performance in the respective training task in a third step (see Table 4 for a summary). Regression analyses revealed age to be a significant predictor for training gains in the visuospatial WM task, but not for training gains in the other training tasks. Older age was related to smaller training gains in the visuospatial WM task (negative bivariate correlation, Table 3). Crystallized abilities did not significantly add to the prediction of training gains when included in the second step. On the contrary, baseline performance on the respective trained tasks contributed significantly and substantially to the prediction of gains in all three training tasks. The bivariate correlations indicate that lower baseline levels in one specific training task were related to higher gains in this respective task.

Moderators of transfer gains. For gains in near and far transfer tasks age was included as a predictor into the hierarchical linear regressions in a first step, followed by the inclusion of crystallized abilities in a second step and the gains in each of the trained tasks in a third step (see Table 5 for a summary). The analyses revealed that age explained a substantial amount of variance in the gains of all transfer tasks, which was significant for visuospatial WM, interference control, and fluid intelligence, and a trend towards significance for verbal WM and executive control. When considering the bivariate correlations, older age was related to lower transfer gains, with the exception of transfer gains in fluid intelligence where the opposite pattern emerged and older age was found to be correlated with higher gains. Crystallized abilities did not add to the prediction of transfer gains (except for a trend towards significance in the interference control task). Finally, even after controlling for age and crystallized abilities, the gains in the trained tasks contributed significantly and substantially to the prediction of transfer gains in verbal WM and executive control tasks when added to the regression in a third step. Bivariate correlations revealed higher training gains in the executive control task to be related to higher transfer gains in verbal WM and executive control tasks.

Discussion

The results of the current study provide the first evidence that, even with a relatively short training regimen of nine 30-minute sessions, training gains in three domains of WM (verbal, visuospatial and executive control) are possible in old age and transfer can be observed to near and far transfer tasks in older adults. Moreover, the current study is the first to provide evidence for stability of training effects (in comparison to non-trained controls) in participants well into the old-old range of adulthood for at least nine months. Remarkably, transfer to verbal WM was also stable nine months after training. Additionally, the current study provides evidence that different factors seem to moderate the amount of training and transfer effects. These findings may shed some light onto factors that might explain the mixed results on WM training and transfer effects in different studies as this is the first study to show that age and performance in WM and executive control tasks uniquely impact the extent to which individuals might benefit from WM training. Specifically, training gains were larger for individuals with lower baseline scores on WM and executive control, suggesting that lower ability older adults benefited most from the WM training program. Moreover, training gains in visuospatial WM and transfer gains in all tasks were smaller for old-old adults, and the amount of training gains impacted the amount of transfer, to some extent.

Group-level WM training and transfer effects

Overall, the short-term, adaptive WM training program applied in this study proved to be effective in increasing older adults? performance on each of the three trained tasks relative to the control group. This was also true after nine months at the long-term follow-up assessment. These findings are in line with those of Dahlin et al. (2008) who showed maintenance of training gains in young-old adults up to 18 months. The current results extend the finding of stable training effects to a considerably larger age range including old-old participants where such long-term training effects have not been found until now (see, e.g., Buschkuehl et al., 2008). These findings suggest that substantial and relatively stable training effects can be obtained for WM and executive control even with a total training time of only about four and a half hours spread over three weeks.

Furthermore, the current study aimed at exploring two levels of transfer from the WM training: (a) near transfer, i.e., transfer within the same domain but with different stimuli and response modes, and (b) far transfer, i.e., transfer to other cognitive constructs. According to models of neural plasticity one would expect transfer if training induces plasticity in a common neural network that is shared between the training and transfer tasks (Olesen et al., 2004), for example, in lateral prefrontal and parietal regions that is activated by both WM and fluid intelligence tasks (Gray et al., 2003; Olesen et al., 2004). If the current training program was able to induce such changes in common networks, one would expect transfer especially to other WM tasks (near transfer) and fluid intelligence task performance (far transfer).

For near transfer, transfer effects were found for the verbal WM task for the whole group (there were no differences between age groups). Moreover, this transfer effect seemed to be robust as it was stable at the nine month follow-up with substantial differences still present between the training and control group. This could suggest substantial training-induced plasticity in verbal WM processing regions in the brain. Future neuroimaging studies will have to directly test this hypothesis. For the visuospatial WM task and the executive control task, no transfer effects were found. This may suggest differential pathways of plasticity between WM domains and could constitute an important avenue for future research in this area. Far transfer was found for the fluid intelligence task. However, this benefit was not maintained at follow-up. Transfer to the interference control (Stroop) task was not significant. Thus, our WM training program produced transfer to a fluid intelligence task, which is methodologically quite different from the trained abilities, but may share similar underlying cognitive processes with WM performance. This is the first study to show far transfer to a fluid intelligence task in old-old adults, thereby extending results obtained with young adults (Jaeggi et al., 2008) and young-old adults (Borella et al., 2010).

Individual differences in training and transfer effects

The current study set out to delineate possible factors that may influence the amount of training-induced plasticity. The regression analyses revealed age was an important predictor of training and transfer gains in both the near and far transfer tasks. Specifically, older age was associated with smaller training gains in the visuospatial training task and smaller transfer gains in all three near transfer tasks and the interference control far transfer task. These findings suggest a reduction in the amount plasticity induced by cognitive training in old-old age, especially on the level of of training and transfer gains in old-old age. However, age was positively associated with the amount of transfer gained on the fluid intelligence task. One possibility is that older participants simply had more room for improvement on the Raven's task (young-old participants started out relatively high). Findings of transfer in the fluid intelligence task should be treated cautiously until further replication is provided, particularly given that the transfer effect was not maintained at follow-up.

Interestingly, baseline performance in trained tasks turned out to be the strongest predictor of training gains with lower baseline levels in a particular domain predicting higher training gains in this domain. This is in line with previous findings that revealed the largest training gains for those individuals with initial low WM capacity (Zinke et al., 2012). These findings could be explained by the disuse hypothesis (Hultsch et al., 1999; Kliegel et al., 2004) which assumes that cognitive decline in old age may be associated with a reliance on automatic or habitual modes of cognitive processing as opposed to frequent engagement in cognitively demanding activities in daily life. The adaptive training regime used in the current study forced participants to continually adapt to increasing demands by engaging their cognitive resources ever more efficiently. Participants with higher baseline WM capacity who were already performing closer to optimal levels prior to training may not have profited as much from the type of WM training that we employed. This finding is important as it suggests that WM training does not simply result in the ”rich getting richer.” Rather, lower capacity participants were those that profited most from the training.

Additionally, the amount of training gains predicted the amount of gains in (some of) the near transfer tasks. Those individuals who showed higher increases in performance in the executive control training task showed higher increases in verbal WM and executive control transfer tasks. Our findings parallel similar findings from recent studies showing specific correlations between training gains and transfer gains (Chein & Morrison, 2010; Schmiedek, Lövdén, & Lindenberger, 2010) and a study that found transfer only in those who improved considerably in the trained task (Jaeggi et al., 2011). This is in line with the hypothesis that process-based training approaches lead to improvements in the trained processes that directly mediate improvements in (at least near) transfer tasks.

To summarize our findings, a rather short-term dose of WM training led to training and transfer effects in an age-diverse sample of old adults. This provides further evidence for cognitive plasticity through WM training interventions in old age and suggests that the capacity to modify cognition and brain health through the biological process of neuroplasticity is preserved, although the extent to which transfer effects may be obtained and upheld over time may be limited to some specific transfer tasks. The current study also highlights the importance of taking variables into account that may moderate the amount of training and transfer gains. Future research has to go beyond simply asking whether cognitive training can produce training and transfer effects or not, but rather differentiate between specific circumstances under which beneficial effects arise from cognitive training. Especially important in this regard seem to be baseline performance on the tasks that are trained and the amount of improvement in the trained tasks over the course of the intervention, with larger profits obtained by individuals with lower pretraining scores and by those who achieved greater training related gains. Additionally, age was revealed to be an important moderator of some of the training gains and all transfer gains, with old-old adults partly profiting less from the training than young-old adults. Future studies should consider these factors in more detail to further delineate the optimal conditions under which WM training can produce the largest training and transfer benefits. Another important aspect in this regard could be to systematically vary the duration and intensity of training. Further delineating all of these conditions would allow differentiating between training programs and specifically tailoring them to the needs of different subgroups, e.g., old-old participants or those with low baseline scores.

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Table 1

Participant characteristics of the training and control group (all n = 40)

	Training group $M(SD)$	**Control group** $M(SD)$
Gender Ratio (female : male)	32 : 8	27 : 13
Age	76.7 (8.4)	77.7 (7.9)
Education in years	14.4 (3.4)	13.5 (3.5)
Cognitive functioning (MMST)	20.2 (1.1)	20.0 (1.2)
Crystallized abilities (MWT)	31.4 (3.1)	31.3 (3.2)
Depression and Anxiety (HADS-D)	10.2 (5.2)	9.6 (4.1)

Note. MMST = Mini Mental Status Test (abbreviated version by Kliegel et al., 2001; maximum points = 21, cut-off = 16); MWT = Mehrfach-Wortschatz-Intelligenztest version B; HADS-D = Hospitality Anxiety and Depression Scale - German Version.

Table 2

Performance in transfer tasks in the training group and the control group

	Training group						Control group					
	Pretraining		Posttraining		Follow-up [a]		Pretraining		Posttraining		Follow-up [a]	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Near Transfer												
Block Span	6.62	1.68	7.58	2.00	7.09	1.31	6.40	2.02	6.75	1.81	6.56	1.92
Letter-Span	3.53	1.71	5.23	2.45	4.91	1.93	3.08	1.47	3.40	1.55	3.44	1.76
Tower of Hanoi	1.83	1.22	2.52	1.41	/		1.65	1.00	2.25	1.32	/	
Far Transfer												
Stroop	0.25	0.16	0.22	0.12	/		0.28	0.14	0.27	0.14	/	
Raven	11.02	4.32	12.08	2.75	10.85	4.03	10.50	3.79	9.98	2.50	10.17	3.42

[a] Follow-up for 64% of the sample: 33 from the training group and 18 from the control group. Note that due to time restrictions only three transfer tasks were assessed in the follow-up.

Table 3

Correlation Matrix for Age, Crystallized Abilities, Baseline Performance Levels in Trained Tasks, Training and Transfer Gains.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1 Age	–												
2 Crystallized abilities (MWT)	.02	–											
3 Baseline level visuospatial WM training (K-ABC)	-.27^t	.28^t	–										
4 Baseline level verbal WM training (Subtract-2)	**-.37***	.24	**.54***	–									
5 Baseline level executive control (Tower of London)	-.18	.23	.20	**.32***	–								
6 Training gain visuospatial WM (K-ABC)	**-.33***	-.18	**-.46***	-.19	-.10	–							
7 Training gain verbal WM (Subtract-2)	-.16	-.06	.13	**-.32***	-.21	.21	–						
8 Training gain executive control (Tower of London)	-.02	.06	.24	-.01	**-.64***	-.02	.24	–					
9 Transfer gain visuospatial WM (Block Span)	**-.40***	.11	-.17	.04	.07	.30^t	-.10	-.07	–				
10 Transfer gain verbal WM (Letter Span plus)	-.27^t	-.09	.03	.10	-.28^t	**.32***	**.36***	**.39***	.24	–			
11 Transfer gain executive control (Tower of Hanoi)	-.29^t	.19	.26	.18	-.30^t	.11	-.09	**.43***	.26^t	**.38***	–		
12 Transfer gain interference control (Stroop)	-.31^t	.26^t	.11	.20	**.39***	.00	-.15	-.14	.24	-.15	.18	–	
13 Transfer gain fluid intelligence (Raven)	**.42***	-.17	-.11	-.09	-.27^t	-.03	-.16	.11	-.03	.16	.15	-.13	–

$^* p < .05$, $^t p < .10$.

Table 4

Summary of Hierarchical Linear Regression Analysis for Variables Predicting Gains in Trained Tasks.

Training gain in	**Visuospatial WM task** (K-ABC Icons)		**Verbal WM task** (Subtract-2)		**Executive control task** (Tower of London)	
	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1	**.11***		**.03**		$<$**.01**	
Age (in years)		-.49**		-.33*		-.15
Step 2	**.03**		$<$**.01**		$<$**.01**	
Crystallized abilities (MWT)		-.003		.06		.23^{t}
Step 3	**.30****		**.16***		**.47****	
Baseline performance in respective training task		-.59**		-.45**		-.72**
	$F(3, 36) = 9.1^{**}$		$F(3, 36) = 2.9^{*}$		$F(3, 36) = 10.9^{**}$	
Total R^2	.43		.19		.48	
Total corrected R^2	**.38**		**.13**		**.43**	

Note. β is based on the final regression model with all predictors. $^{**}p < .01$, $^{*}p < .05$, $^{t}p < .10$.

Table 5

Summary of Hierarchical Linear Regression Analysis for Variables Predicting Gains in Near and Far Transfer Tasks.

Transfer gain in	**Visuospatial WM** (Block span)		**Verbal WM** (Letter Span Plus)		**Executive control** (Tower of Hanoi)		**Interference control** (Stroop)		**Fluid intelligence** (Raven)	
	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1	**.16***		**.07**^{t}		**.09**^{t}		**.10***		**.18***	
Age (in years)		-.35*		-.16		-.29^t		-.36*		.44**
Step 2	**.02**		**.01**		**.04**		**.07**^{t}		**.03**	
Crystallized abilities (MWT)		.16		-.06		.17		.26^t		-.17
Step 3	**.08**		**.25***		**.24***		**.05**		**.05**	
Training gains visuospatial WM		.25		.22		.11		-.04		.13
Training gains verbal WM		-.20		.20		-.27^t		-.16		-.17
Training gains executive control		-.03		.35*		.48**		-.13		.17
	$F(3, 34) = 2.3^t$		$F(3, 34) = 3.3^*$		$F(3, 34) = 3.9^{**}$		$F(3, 34) = 2.0$		$F(3, 34) = 2.4^t$	
Total R^2	.25		.32		.36		.22		.26	
Total corrected R^2	**.14**		**.22**		**.27**		**.11**		**.15**	

Note. β is based on the final regression model with all predictors. $^{**}p < .01$, $^{*}p < .05$, $^{t}p < .10$.

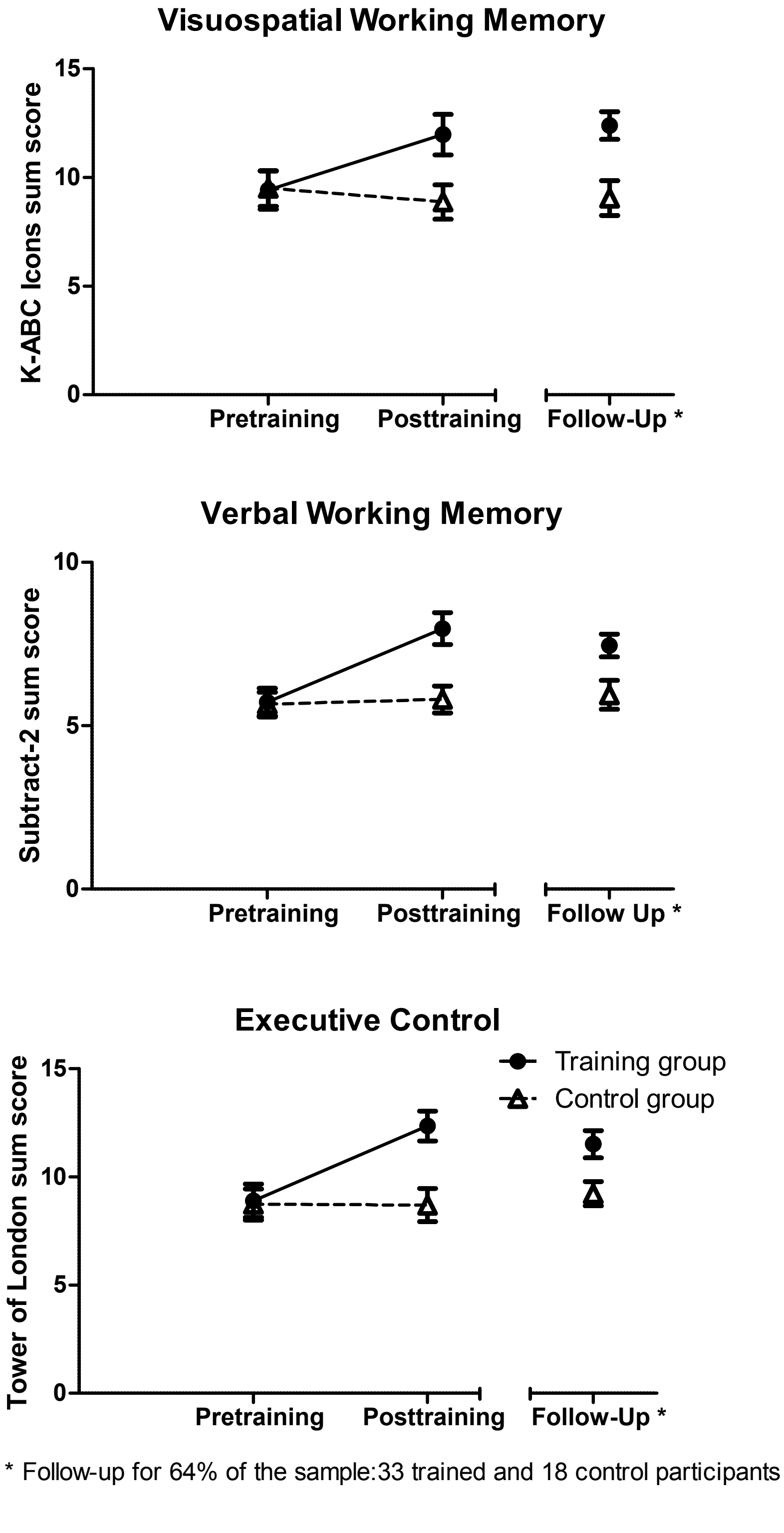

Figure 1: Training effects for all trained tasks (mean performance scores ± SE pretraining, posttraining and at follow-up) in the training and the control group: Visuospatial Working Memory (K-ABC Icons), Verbal Working Memory (Subtract-2-Span), Executive Control (Tower of London).