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

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Recent studies suggest that working memory training may benefit older adults; however, findings regarding 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 explored possible moderators of training and transfer effects. For that purpose, 80 older adults (65–95 years) were assigned either to a training group that worked on visuospatial, verbal, and executive working memory tasks for 9 sessions over 3 weeks or to a control group. Performance on trained and transfer tasks was assessed in all participants before and after the training period, as well as at a 9-month follow-up. Analyses revealed significant training effects in all 3 training tasks in trained participants relative to controls, as well as near transfer to a verbal working memory task and far transfer to a fluid intelligence task. Encouragingly, all training effects and the transfer effect to verbal working memory were stable at the 9-month follow-up session. Further analyses revealed that training gains were predicted by baseline performance in training tasks and (to a lesser degree) by age. Gains in transfer tasks 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 regime can lead to (partly specific) training and transfer effects. However, baseline performance, age, and training gains moderate the amount of plasticity.

Keywords: executive functions, plasticity, third age, fourth age, training

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; see also Baddeley & Hitch, 1974), it comprises a verbal, a visuospatial, and an executive system (central executive) that is thought to coordinate the other two subsystems, for example, by distributing and switching attention (Baddeley, 1996). 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; see Shipstead, Redick, & Engle, 2012, for an alternative view). Earlier studies have investigated enhancing WM with the help of strategies, for example, rehearsal (Butterfield & Wambold, 1973) or chunking strategies (Ericcson, Chase, & Faloon, 1980), which led

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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 using a strategy may not efficiently improve performance. These training studies usually involved repeated performance of tasks focusing on WM capacity (Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005), 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 have suggested 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; Brehmer, Westerberg, & Bäckman, 2012) may also be effective in enhancing performance on trained tasks in young-old adults, as well as old-old adults (Buschkuehl et al., 2008; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012). However, so far no study has included participants across the full age-range of older 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 (65–95 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 task; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Olesen, Westerberg, & Klingberg, 2004) or measures of nonverbal reasoning (Jaeggi et al., 2008; Klingberg et al., 2005). Although the neural mechanisms for these effects are still not well understood (see, e.g., Buschkuehl, Jaeggi, & Jonides, 2012), studies have shown WM training to be associated with changes in brain activity in frontal and parietal cortex and basal ganglia and 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 older compared with younger participants. Whereas some studies did not find any significant transfer effects after training in 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 et al. (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 et al. (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 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 have been generally limited and, if found, restricted to WM tasks that were rather similar with regard to format and processing requirements to the trained tasks (i.e., near transfer tasks). In other studies, evidence for improvements in tasks that assess different cognitive constructs (i.e., far transfer tasks) has been found. A recent meta-analysis suggests near transfer is a reliable finding, but findings regarding far transfer are rather inconsistent (Melby-Lervåg & Hulme, 2013). Following up on this issue and Klingberg's suggestion (2010) to investigate transfer on different levels, 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 addressing verbal, visuospatial, and executive components in the same sample.

In addition to immediate training and transfer effects, it is conceptually important to explore whether benefits that are obtained immediately after training remain stable over time. So far, findings on the stability of training or transfer effects have been mixed. Whereas Buschkuehl et al. (2008) found no maintenance of either training or transfer effects after 1 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 (young and young-old ones). However, stability of the reported transfer effect was only found for the young participants, not for the young-old participants. Other studies were able to show maintenance of training and (some of the) transfer gains in young-old adults 3 months (Li et al., 2008) or 8 months (Borella et al., 2010) after training. Thus, the findings on maintenance of training and transfer effects are mixed, and evidence is particularly lacking with regards to old-old adults. Therefore, the current study assessed the stability of training and transfer effects in a broad age range of older adults 9 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 (60–70 years; Brehmer et al., 2011; 65–75 years; Borella et al., 2010); studies with older participants reported no or limited transfer (mean age of 80 years, Buschkuehl et al., 2008; 77–96 years, Zinke et al., 2012).

A second possible variable that may influence the efficiency of cognitive training may be the general cognitive ability of the participants. It may be that only participants who have maintained a high cognitive status profit from a rather complex and demanding intervention such as WM training, perhaps because a relatively high level of functioning is required to actively engage in and benefit from extensive practice on WM 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 participants with lower cognitive status would profit more from such an intervention. According to the disuse hypothesis (Hultsch, Hertzog, Small, & Dixon, 1999; Kliegel, Zimprich, & Rott, 2004), cognitive decline in old age may be associated with a reliance on automatic modes of cognitive processing as opposed to frequent engagement in cognitively demanding activities. An adaptive training regime may force the lower ability participants to engage in demanding activities and (re)learn to use more controlled, strategic cognitive processes. Thus, the current study aimed at investigating the possible influence of individual differences in crystallized cognitive ability on training and transfer effects.

Additionally, baseline performance on the specific WM tasks to be trained may moderate the training and transfer effects. For example, in a recent training study focusing on old-old adults, those individuals starting with low levels of WM capacity were the ones who profited most (Zinke et al., 2012). This finding suggests 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 nontrained fluid intelligence task was observed only in the subgroup of participants who improved considerably on the trained WM tasks. On the basis of these findings, we predicted that baseline scores would impact the amount of training gains and that the amount of training gains would 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 age. For that purpose, an experimental approach was used to compare a training group with 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.

Method

Participants

The participants of the study were volunteers from the community recruited with brochures, posters, and oral information sessions held in clubs and associations that target senior citizens. They received extensive oral and written information about the study, were given the opportunity to ask questions about the procedure, and gave written informed consent to participate afterward. The 80 participants of the study were between 65 and 95 years old (mean age = 77.2 years, SD = 8.1) and did not receive monetary compensation. Half of the participants were randomly assigned to a WM training program of nine sessions distributed over 3 weeks (training group, $n = 40$); the other half were assigned to a control group ($n = 40$) and performed the same tasks as the training group on pre- and posttest sessions spaced 3 weeks apart. Training and control groups did not differ significantly from each other regarding age, gender, years of education, and cognitive status (all $p > .10$; see Table 1). Exclusion criteria were noncorrected visual or auditory impairments and neurological or psychiatric disorders, in particular mild cognitive impairment or Alzheimer's disease. We screened for such disorders via self-report and with the Mini Mental Status Test (MMST)–German Short Form for old-old adults (maximum score of 21; cutoff 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, which have been shown to influence cognitive performance, using the Hospital Anxiety and Depression Scale (HADS–D, German version, Herrmann, Buss, & Snaith, 1995). Crystallized ability was assessed with a German vocabulary test (MWT–B; Lehrl, 2005).

Training Tasks

Training material was chosen based on Baddeley's conceptualization of WM (2003; Baddeley & Hitch, 1974) and was designed to target multiple aspects of WM with tasks requiring verbal WM, visuospatial WM, and executive control processes. The training tasks required both storage and processing of information in WM. 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).

Visuospatial WM was trained with a *picture grid task*: the spatial memory subtest of the Kaufmann Assessment Battery for Children (K–ABC; Melchers & Preuss, 1991). The (modified) K–ABC spatial memory task[1] was an adaptive visuospatial WM task in which participants had to process and maintain the spatial arrangement of multiple stimuli. Each participant was presented with an increasing number of icons (pictures of common objects, e.g., a saw) that were placed either in a 3 × 3 grid or, at higher difficulty levels, in a 3 × 4 grid. The participant had 5 s to memorize each arrangement of pictures. Afterward, an empty grid was presented, and the participant was asked to name all pictures he or she had seen and point out each individual location on the empty grid. The set size (total number of pictures to be recalled) ranged from two to nine. Each trial was scored as correct only if the participant recalled all pictures and their locations correctly. The main dependent variable was the total number of correctly recalled trials.

Verbal WM was trained with the *subtract-2-span task* (Salthouse, 1988). The experimenter read out loud number sequences of increasing length (at a rate of one number per second). The participant was asked to subtract 2 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).[2] 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 were

[1] To use the K–ABC spatial memory task as an adaptive training task for adults, we constructed several additional trials: parallel versions of original trials (same amount of objects in different places) and more difficult trials following the structure of the original trials (a 3 × 4 grid with more objects to remember).

[2] Although the Tower of London task draws upon several cognitive processes including holding several configurations in WM, mentally manipulating them to find the solution, or inhibiting prepotent responses, following Baddeley's (1996) conceptualization of the central executive, we refer to this task as the *executive control task* of our WM training henceforth.

Table 1
*Participant Characteristics of the Training and Control Groups (*N = *40)*

Variable	Training group *M* (*SD*)	Control group *M* (*SD*)
Age	76.7 (8.4)	77.7 (7.9)
Education in years	14.4 (3.4)	13.5 (3.5)
Cognitive functioning (MMST score)	20.2 (1.1)	20.0 (1.2)
Crystallized abilities (MWT–B score)	31.4 (3.1)	31.3 (3.2)
Depression and anxiety (HADS–D score)	10.2 (5.2)	9.6 (4.1)

Note. Gender ratios (female: male): in training group 32:8 and in control group 27:13. MMST = Mini Mental Status Test (abbreviated version by Kliegel, Rott, d'Heureuse, Becker, & Schönemann, 2001; maximum points = 21, cutoff = 16); MWT–B = Mehrfach-Wortschatz-Intelligenztest, Version B (Lehrl, 2005); HADS–D = Hospitality Anxiety and Depression Scale–German Version (Herrmann, Buss, & Snaith, 1995).

shown on a picture that was present during the whole trial. Difficulty was adapted by increasing the number of moves necessary to solve the problems (from three to 11). As for the other training tasks, there was no time limit for solving each problem. 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 verbal and visuospatial WM was adapted by increasing the set size (number of items to be recalled) on the next trial by one item whenever the participant had two consecutive correct trials at the same difficulty level. If he or 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, the 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 the number of moves necessary to solve the problem by one, whenever the participant solved four out of five trials (problems) of the same difficulty level correctly. If the participant solved two or three out of the five problems correctly, the difficulty level remained the same. If he or she solved less than two problems correctly, the difficulty level was decreased by one move. We used this adaptive procedure to attempt 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 the pre- and posttest sessions resembled those of the training sessions. Different (parallel) versions of trials for each difficulty level were used for each session. That is, the exact same trial was never presented twice.

Transfer Tasks

To assess the first level of transfer within the same domain but to other stimuli (i.e., near transfer), we used three different tasks that corresponded to each of the trained domains. The *Corsi block span* task, taken from the Wechsler Memory Scale–Revised (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 read out loud 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* (Simon, 1975) was used to assess executive control. The participants had to move an increasing number of disks of different sizes from a starting pole to an end pole while adhering to certain rules: only one disk can be moved at a time, disks may be moved only to another peg, and a small disk can only be placed on a larger one. The problem was counted as correctly solved if the participant solved the problem in the least possible moves. The difficulty of problems (number of disks) was increased by one disk 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 (i.e., far transfer), we used two tasks: the *Raven Standard Progressive Matrices* (Raven SPM; Raven, Raven, & Court, 1979) and the *Stroop interference task* (German version of the color–word Stroop test taken from the Nürnberger Altersinventar; NAI; Oswald & Fleischmann, 1995).

In keeping with the literature, we used the Raven SPM 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, the original Raven SPM was shortened by 24 items due to time constraints; two parallel versions with 18 items each were constructed out of the remaining items for the pretest and posttest sessions.

We used the Stroop interference task to measure inhibitory control. Here, the participant first had to read aloud color names (printed in black on a sheet) as fast as possible; in the second test, the participant had to name color patches; and in the last test, he or she had 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 tests.

Procedure

Two to 3 days before and after training, the training group completed a pretraining and a posttraining assessment, respectively, consisting of two sessions each. One session measured pre- and posttraining performance on the trained tasks that served as baseline and outcome measure for the trained tasks. The other session included the nontrained transfer tasks to assess both near and far transfer. Parallel versions of each transfer task were used at pre- and posttraining assessments: Versions A for pretraining and Versions B for posttraining. The order of the tasks was the same in pre- and posttraining sessions and for all participants. Training was administered in nine sessions over 3 weeks. Each training session lasted 30 min in total, with about equal time (10 min) for each of the three training tasks. Within these 10-min time windows, participants worked on a mean of nine trials of the visuospatial WM task, six trials of the verbal WM task, and five trials of the executive control task. Difficulty levels were adapted individually within each session as described previously. 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 ($n = 33$) participated in a follow-up session including trained tasks, the verbal and visuospatial WM, and fluid intelligence transfer tasks, using Versions B of the parallel tests.

The control group was also tested in pre- and posttest assessments with the same time interval between assessments as the training group. Similar to the training group, these assessments included two sessions: one for assessing performance on the training tasks and one for assessing performance on the transfer tasks; all tasks were performed in the same order as the training group. Due to resource limitations, 20 control participants were randomly selected for a follow-up testing session 9 months later, and 18 agreed to participate (45% of the original control group).[3]

Results

First, we tested for comparability of the training and control group in baseline performance using *t* tests. Analyses indicated no significant differences at the pretraining assessment in any of the training or transfer tasks (all $p > .2$), suggesting that randomization had been successful. The first set of analyses focused on training and transfer effects on the group level, followed by a second set of analyses focusing on possible moderators of training and transfer gains.

WM Training Effects

To compare changes in performance on trained tasks from pre- to posttraining between groups, we conducted a two-factorial analysis of variance (ANOVA) with group (training vs. control) as a between-subjects factor and time of measurement (pretraining vs. posttraining) as a within-subject factor. Most important, there was an interaction for all three trained tasks between the time of measurement and the group (as can be seen in Figure 1): for the number of correctly repeated sequences in the picture grid task, $F(1, 78) = 20.1$, $p < .001$, 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 $\eta^2 = .14$. That is, there were larger changes from pre- to posttraining assessments in the training group than in the control group for the picture grid task, $d' = 0.62$ vs. $d' = -0.17$, subtract-2 span, $d' = 1.10$ vs. $d' = 0.08$, and the Tower of London, $d' = 1.04$ vs. $d' = -0.01$. Analyses also revealed a main effect of time, indicating gains from pre- to posttraining assessments for all trained tasks: for the picture grid task, $F(1, 78) = 7.4$, $p = .008$, 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 toward significance for the picture grid task, $F(1, 78) = 3.7$, $p = .06$, partial $\eta^2 = .05$.[4]

To explore the stability of the training effects (following Buschkuehl et al., 2008; Dahlin et al., 2008), we conducted repeated-measures ANOVAs with group as the between-subjects factor and time of measurement (pretraining vs. follow-up) as the within-subject factor to compare differences between groups before training and at follow-up. For all trained tasks, the interaction term between time of measurement and group was still significant (see Figure 1): for the picture grid task, $F(1, 49) = 14.5$, $p < .001$, 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 $\eta^2 = .14$. That is, there were larger changes between pretraining and follow up assessments in the training group than in the control group for the picture grid task, $d' = 0.77$ vs. $d' = -0.12$; subtract-2 span, $d' = 0.88$ vs. $d' = 0.17$; and the Tower of London, $d' = 0.73$ vs. $d' = 0.16$.

To summarize the analyses on WM training effects, larger gains for the trained participants than for the control participants were revealed for all training tasks posttraining. Furthermore, the effects of training on performance on the trained tasks were still evident at the 9-month follow-up.

[3] In the reduced sample at follow-up (33 trained participants and 18 control participants), there were no significant differences between the training and control groups in regard to either the pretraining performance on training and transfer tasks or the demographic variables of age, gender distribution, years of education, and cognitive status (all $p > .13$). It is important to note that the basic pattern of results (significant training and transfer effects) was not different between the whole and the reduced samples. Because of higher statistical power, analyses including the whole sample will be reported wherever possible (pre- and posttraining comparisons); analyses including follow-up assessments will be reported with the reduced sample.

[4] We conducted the analyses on training effects again as a multivariate analysis of variance (MANOVA) to control for multiple comparisons, and the same pattern was found. Analyses revealed a significant overall effect of time (pretraining vs. posttraining), $F(3, 76) = 18.8$, $p < .001$, partial $\eta^2 = .43$; of group (training vs. control), $F(3, 76) = 4.7$, $p = .004$, partial $\eta^2 = .16$; and, more important, of the interaction Time $\times$ Group, $F(3, 76) = 19.1$, $p < .001$, partial $\eta^2 = .43$. Follow-up univariate ANOVAs for the relevant interaction effect revealed significant training effects for all training tasks: verbal WM, $p < .001$; visuospatial WM, $p < .001$; and executive control, $p = .001$ (all significant at Bonferroni-corrected α level of $.05/3 = .017$).

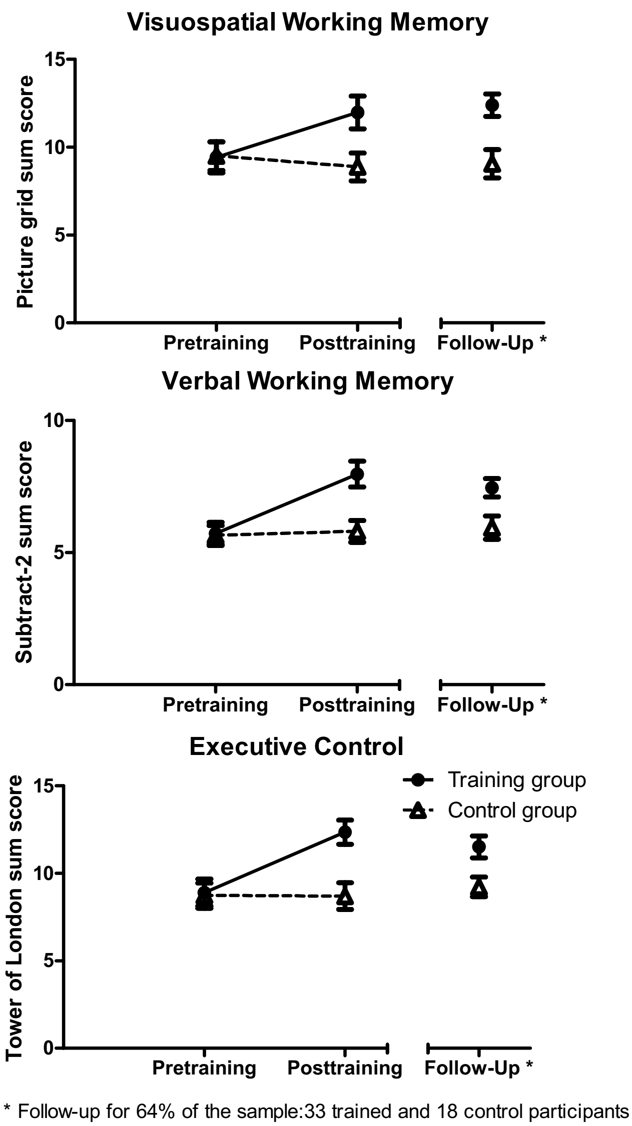

Figure 1. Training effects for all trained tasks (mean performance scores ± *SE* at pretraining, posttraining, and follow-up) in the training and the control group: (a) visuospatial working memory (picture grid task), (b) verbal working memory (subtract-2-span), and (c) executive control (Tower of London).

Transfer Effects

To explore possible group-level transfer effects of training, we conducted analyses analogous to the analyses of the training effects. A two-factorial ANOVA was used with group (training vs. control group) as the between-subjects factor and time of measurement as the within-subject factor. Means and standard deviations for pretraining, posttraining, and follow-up performance for the respective transfer tasks as well as effect sizes (d') 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 posttraining assessment. Neither the main effect of group nor the two-way interaction between time and group was significant, indicating that groups did not differ overall or 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 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). There was a main effect of time indicating gains from pre- to posttraining assessment, $F(1, 78) = 33.8$, $p < .001$, partial $\eta^2 = .30$, and 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 $\eta^2 = .11$. 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 did not differ overall or 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.[5]

We again analyzed the stability of the transfer effects using repeated-measures ANOVAs with group as the between-subjects factor and time of measurement (pretraining vs. follow-up) as the within-subject factor. In these analyses, 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 than in the control group. For the Raven SPM, the crucial Time × Group interaction term was not significant, $p > .1$, indicating no significant differences in changes from pretraining to follow-up between the training and control groups.

To summarize the analyses on transfer effects, near transfer (as indicated by larger pre- to posttest gains in the training group than in 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 evident after 9 months for the verbal WM task, but not for the fluid intelligence task.

[5] We conducted the analyses on transfer effects again as a MANOVA to control for multiple comparisons. Analyses revealed a significant overall effect of time (pretraining vs. posttraining), $F(5, 74) = 9.8$, $p < .001$, partial $\eta^2 = .40$, and, more important, of the interaction Time × Group, $F(4, 74) = 4.4$, $p < .001$, partial $\eta^2 = .23$. Follow-up univariate ANOVAs for the relevant interaction effect revealed significant transfer effects for verbal WM, $p < .001$, and a clear trend for fluid intelligence, $p < .03$ (at Bonferroni-corrected α level of $.05/5 = .01$).

Table 2
Performance in Transfer Tasks in the Training and Control Groups and Effect Sizes for Pre- to Posttraining and for Pretraining to Follow-Up Comparisons

Measure	Training group								Control group							
	Pretraining		Posttraining		Follow-up[a]		Pre vs. post d'	Pre vs. follow-up d'	Pretraining		Posttraining		Follow-up[a]		Pre vs. post d'	Pre vs. follow-up d'
	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	0.51	0.31	6.40	2.02	6.75	1.81	6.56	1.92	0.18	0.08
Letter-span-plus	3.53	1.71	5.23	2.45	4.91	1.93	0.80	0.75	3.08	1.47	3.40	1.55	3.44	1.76	0.21	0.23
Tower of Hanoi	1.83	1.22	2.52	1.41			0.52		1.65	1.00	2.25	1.32			0.51	
Far transfer																
Stroop task	0.25	0.16	0.22	0.12			−0.21		0.28	0.14	0.27	0.14			−0.07	
Raven SPM	11.02	4.32	12.08	2.75	10.85	4.03	0.29	0.04	10.50	3.79	9.98	2.50	10.17	3.42	−0.16	−0.09

Note. Due to time restrictions, only three transfer tasks were assessed in the follow-up. SPM = Standard Progressive Matrices (Raven, Raven, & Court, 1979).
[a] Follow-up for 64% of the sample: 33 from the training group and 18 from the control group.

Moderators of Training and Transfer Gains

To explore possible moderating factors of individual differences in training and transfer gains, we conducted a set of hierarchical linear regression analyses with only the trained individuals. The possible moderating factors we considered were age, crystallized ability, and baseline performance on trained tasks as well as gains 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. For each training gain, age was included as a predictor into the regression analyses in a first step, followed by crystallized ability in a second step. After controlling for the general influence of age and crystallized ability, we entered baseline performance in the respective training task in a third step to explore whether it had an additional predictive value for the respective training gains (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 ability 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 each 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 in the hierarchical linear regressions in the first step, followed by crystallized ability in the second step. Again, after controlling for these general influences, we entered the gains in each of the trained tasks in a third step to explore whether they had an additional predictive value for the transfer gains (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 toward significance for verbal WM and executive control. When considering the bivariate correlations, older age was related to smaller transfer gains, with the exception of transfer gains in the

Table 3
Correlation Matrix for Age, Crystallized Abilities, Baseline Performance Levels in Trained Tasks, and Training and Transfer Gains

Variable	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 (Picture grid)	−.27†	.28†	—										
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 (Picture grid)	**−.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†	−.10	−.07	—				
10. Transfer gain verbal WM (Letter span plus)	−.27†	−.09	.03	.10	−.28†	**.32***	**.36***	**.39***	.24	—			
11. Transfer gain executive control (Tower of Hanoi)	−.29†	.19	.26	.18	−.30†	.11	−.09	**.43***	.26†	**.38***	—		
12. Transfer gain interference control (Stroop tasks)	−.31†	.26†	.11	.20	**.39***	.00	−.15	−.14	.24	−.15	.18	—	
13. Transfer gain fluid intelligence (Raven SPM)	**.42***	−.17	−.11	−.09	−.27†	−.03	−.16	.11	−.03	.16	.15	−.13	—

Note. Boldface type indicates significant correlations. MWT = Mehrfach-Wortschatz-Intelligenztest Version B (Lehrl, 2005); WM = working memory; SPM = Standard Progressive Matrices (Raven, Raven, & Court, 1979).
† $p < .10$. * $p < .05$.

Table 4
Summary of Hierarchical Linear Regression Analysis for Variables Predicting Gains in Trained Tasks

	Training gain in visuospatial WM task (Picture grid task)		Training gain in verbal WM task (Subtract-2 task)		Training gain in 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†
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. WM = working memory; MWT = Mehrfach-Wortschatz-Intelligenztest Version B (Lehrl, 2005).
† $p < .10$. * $p < .05$. ** $p < .01$.

fluid intelligence task, where the opposite pattern emerged and older age was found to be correlated with larger gains. Crystallized ability did not add to the prediction of transfer gains (except for a trend toward significance in the interference control task). Finally, even after controlling for age and crystallized ability, 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 regime of nine 30-min 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 show that training effects (in comparison to nontrained controls) are still evident in participants well into the old-old range of adulthood after as long as 9 months. Encouragingly, transfer to verbal WM was also still evident 9 months after training. Moreover, the current study provides evidence that different factors seem to moderate the amount of training and transfer effects. These findings shed some light onto factors that might explain the mixed results on WM training and transfer effects in different studies. This is the first study to show that age and baseline performance in WM and executive control tasks uniquely impact the extent to which individuals may benefit from WM training. Specifically, training gains within each domain were larger for individuals with lower baseline scores on WM and executive control in the respective domains, suggesting both that lower-ability older adults benefited most from the WM training program and that those effects may be relatively domain-specific. Moreover, training gains in visuospatial WM and transfer gains in all tasks were smaller as a function of age, and the amount of training gains impacted the amount of transfer.

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 9 months at the long-term follow-up assessment. These findings are in line with those by Dahlin et al. (2008), who showed maintenance of training gains in young-old adults. The current results extend the finding of stable training effects to a considerably larger age range including old-old participants in whom such long-term training effects have not been found until now (e.g., Buschkuehl et al., 2008). These findings suggest that significant training effects in WM and executive control may even be possible with a shorter training regime than previously employed—note that the total training time was only about 4.5 hr spread over 3 weeks in the current study.

Furthermore, the current study systematically explored near transfer (i.e., transfer within the same domain but with different stimuli and response modes) and 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 are activated by both WM and fluid intelligence tasks (Gray, Chabris, & Braver, 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).

On the level of near transfer, transfer effects were found for the verbal WM task, and this effect was stable at the 9-month follow-up with substantial differences still present between the training and control groups. For the visuospatial WM task and the executive control task, no transfer effects were found. 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, possibly, because the Stroop difference score was not a very sensitive transfer measure. Note,

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)		Transfer gain in verbal WM (Letter span plus)		Transfer gain in executive control (Tower of Hanoi)		Transfer gain in interference control (Stroop task)		Transfer gain in fluid intelligence (Raven SPM)	
	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1	.16*		.07†		.09†		.10*		.18*	
Age (in years)		−.35*		−.16		−.29†		−.36*		.44**
Step 2	.02		.01		.04		.07†		.03	
Crystallized abilities (MWT)		.16		−.06		.17		.26†		−.17
Step 3	.08		.25*		.24*		.05		.05	
Training gains visuospatial WM		.25		.22		.11		−.04		.13
Training gains verbal WM		−.20		.20		−.27†		−.16		−.17
Training gains executive control		−.03		.35*		.48**		−.13		.17
	$F(3, 34) = 2.3^{\dagger}$		$F(3, 34) = 3.3^{*}$		$F(3, 34) = 3.9^{**}$		$F(3, 34) = 2.0$		$F(3, 34) = 2.4^{\dagger}$	
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. WM = working memory; SPM = Standard Progressive Matrices (Raven, Raven, & Court, 1979); MWT = Mehrfach-Wortschatz-Intelligenztest Version B (Lehrl, 2005).
† $p < .10$. * $p < .05$. ** $p < .01$.

however, that findings regarding stability need to be interpreted cautiously because of the reduced sample size at follow-up. Although there was no evidence that the reduced sample differed substantially from the whole sample, having a reduced sample may still have influenced the findings due to reduced statistical power or selective attrition. Overall, the transfer effects of the current training seemed to have been most reliable in the traditional verbal WM span (i.e., near transfer) domain. One might speculate that those findings suggest training-induced plasticity in regions in the brain for verbal WM processing and differential pathways of plasticity for visuospatial WM and executive control. These hypotheses will have to be tested in future neuroimaging studies. Alternatively, that the particular training employed had its strongest impact on verbal span abilities may have been due to the emergence and effective use of verbal mnemonic strategies. With regards to transfer, the impetus of WM training programs is to generally improve one's WM ability—not to simply teach strategies for efficient performance on a particular task—but, in reality, training participants are likely generating strategies and testing them out during training. The extent to which training gains transfer to performance on other tasks may largely depend on the utility of the processes (e.g., strategies) learned during training for performance on the transfer tasks. This could reflect why WM training consistently produces near transfer, but demonstrations of far transfer are more limited. Note, however, that an alternative explanation for the current findings is that verbal training and transfer tasks were more similar than the respective tasks in the other domains. In the future, researchers should try to disentangle these issues—possibly by employing more than one training and transfer task per domain (see e.g., Schmiedek, Lövdén, & Lindenberger, 2010).

The current findings suggest that the WM training transferred 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 provide evidence for far transfer to a fluid intelligence task in adults ranging well into old-old age, thereby extending results obtained with young adults (Jaeggi et al., 2008) and young-old adults (Borella et al., 2010). However, 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 (perhaps due to the reduced sample size) and gain in the fluid intelligence task was not predicted by training gain.

One limitation of the current study is that we did not employ an active control group. However, other WM training studies also employed no-contact control groups (e.g., Dahlin et al., 2008; Li et al., 2008; Schmiedek et al., 2010) and found similar patterns of training and transfer results as those that used some kind of active control group (Brehmer et al., 2011, 2012; Buschkuehl et al., 2008; Richmond et al., 2011). Encouragingly, a recent meta-analysis of WM training studies showed that the effect size of WM training was similar whether the training group was compared with either a treated or untreated control group (Melby-Lervåg & Hulme, 2013). Nevertheless, in future research, investigators would do well to include at least some control participants who perform similarly demanding tasks (ideally the same tasks, but without adaptive difficulty) and assess whether these active control participants differ from either training or no-contact control participants.

This design would better allow excluding possible alternative explanations for the observed effects, for example the influence of social interaction with the experimenter, expectations of the participants about the usefulness of the intervention, or motivational issues.

Individual Differences in Training and Transfer Effects

A major strength of the current study is that we were able to delineate factors that influenced the amount of training-induced plasticity. The regression analyses revealed that 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 of plasticity induced by cognitive training with increasing age. Perhaps visuospatial WM training was not as beneficial as verbal WM training because the underlying networks for these tasks are already experiencing neurodegeneration (Hale et al., 2011). Note, however, that for the fluid intelligence task, older age was related to larger transfer gains. As mentioned earlier, findings regarding this task need to be interpreted cautiously because it was not stable. Furthermore, relatively high performance in the younger part of the sample (already at the pretraining assessment) may in part be associated with this counterintuitive finding.

It is interesting that 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 individuals with initially low WM capacity (Zinke et al., 2012) and additionally suggests domain-specific training effects. These findings may suggest that initially low performers may have had latent potential that was being underutilized and that the WM training program forced them to engage and realize their latent potential, thereby providing evidence for "flexibility" of WM processing resources (Lövdén, Bäckman, Lindenberger, Schäfer, & Schmiedek, 2010). Lövdén and colleagues have proposed that there needs to be a mismatch between what they termed the *supply* (one's capacity for plasticity) and *demand* (the demands required by the environment and one's capacity for flexibility) in order for training to be effective. Individuals with lower baseline WM capacity may have shown larger gains from training than those with higher capacity, perhaps because there was more of a mismatch between the demands of the training and their latent potential (Lövdén et al., 2010). Similarly, the disuse hypothesis (Hultsch et al., 1999; Kliegel et al., 2004) 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 controlled, strategic cognitive processes 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 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 who profited most from the training.[6]

Another important finding was that 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 et al., 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 investigate these issues in further detail, investigators in future studies should employ training tasks that allow a more fine-grained analysis of training progress than a mere difference between pre- and posttraining performance.

To summarize our findings, a rather short-term dose of WM training led to training and transfer effects in an age-diverse sample of older adults. This result 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 (Reichman, Fiocco, & Rose, 2010), although the extent to which transfer effects may be obtained and upheld over time may be limited to some specific transfer tasks (Craik & Rose, 2012). The current study also highlights the importance of taking into account variables 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 to differentiating between specific circumstances under which beneficial effects arise from cognitive training. Especially important in this regard seems 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 the young-old adults. In future studies, these factors should be considered in more detail so that researchers can further delineate the optimal conditions under which WM training can produce robust and meaningful 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 specific tailoring of the programs

[6] It may seem peculiar that while those with lower baseline scores showed greater training gains—and as a group, the old-old adults had lower scores—age was associated with smaller benefits from training. However, in predicting individual training gains, these two effects appear to operate independently from one another.

to the needs of different subgroups, for example, old-old participants or those with low baseline scores.

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