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Impact of Working Memory Training on Memory Performance in Old–Old Adults

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Memory impairments constitute an increasing objective and subjective problem with advancing age. The aim of the present study was to investigate the impact of working memory training on memory performance. The authors trained a sample of 80-year-old adults twice weekly over a time period of 3 months. Participants were tested on 4 different memory measures before, immediately after, and 1 year after training completion. The authors found overall increased memory performance in the experimental group compared to an active control group immediately after training completion. This increase was especially pronounced in visual working memory performance and, to a smaller degree, also in visual episodic memory. No group differences were found 1 year after training completion. The results indicate that even in old–old adults, brain plasticity is strong enough to result in transfer effects, that is, performance increases in tasks that were not trained during the intervention.

Keywords: process-specific training, transfer, episodic memory, long-term effects

Working memory (WM) can be defined as a dynamic processing system that is capable of temporarily storing and manipulating information that is essential for higher order processes such as language comprehension, planning, or problem solving (Cowan et al., 2005; Shah & Miyake, 1999). Aging research has shown that WM is one of several cognitive functions that declines with advancing age (Craik & Bialystok, 2006; Park et al., 2002). Recently, several studies were able to show that training on WM not only leads to improvements on the trained task but also to improvements on tasks that were not part of the training (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Olesen, Westerberg, & Klingberg, 2004; Persson & Reuter-Lorenz, 2008). WM training studies have been conducted with children (Klingberg et al., 2002, 2005; Posner & Rothbart, 2005), young adults (Dahlin et al., 2008; Jaeggi, Buschkuehl, et al., 2008; Persson & Reuter-Lorenz, 2008), and also schizophrenic patients (for reviews see, e.g., Krabbendam & Aleman, 2003; Medalia, Revheim, & Casey, 2000; Pilling et al., 2002), but WM training research with healthy older adults remains very scarce (Dahlin et al., 2008) or is nonexistent with old–old adults at an age of 80 years and above.

In the present study, we report the impact of a WM training intervention in a sample of 80-year-old participants. Results are compared to a physical intervention group that served as a control group. Both groups trained twice a week for 45 min over a time period of 3 months. Our focus of research was on memory functions since memory deficits represent large objective problems (Nyberg, Backman, Erngrund, Olofsson, & Nilsson, 1996; Park et al., 2002; Rabbitt & Lowe, 2000; Salthouse, 2004) but also severe subjective concerns (Jeon, Dunkle, & Roberts, 2006; Jonker, Geerlings, & Schmand, 2000; Perrig-Chiello, Perrig, & Staehelin, 2000) for older adults. We report the immediate training success on memory as well as the long-term effects assessed 1 year after training completion.

Most existing cognitive training interventions for old adults aim to improve memory functions by teaching memory strategies (e.g., Bissig & Lustig, 2007; Carretti, Borella, & De Beni, 2007; Craik et al., 2007; Lustig & Flegal, 2008; Singer, Lindenberger, & Baltes, 2003; Verhaeghen & Marcoen, 1996). Mnemonic strategies can boost memory performance for a given type of stimuli to a very impressive extent (Ericsson, 1988; Ericsson & Chase, 1982; Verhaeghen & Marcoen, 1996). However, the effects remain very task specific and are usually not applicable to a wide variety of situations or stimuli (Chase & Ericsson, 1981; Saczynski, Willis, & Schaie, 2002). Besides this task specificity, there is substantial evidence that with increasing age, adults are less likely to effi-

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ciently use newly acquired memory strategies (Baltes & Kliegl, 1992; Nyberg et al., 2003; Verhaeghen & Marcoen, 1996).

A promising alternative to strategy-based training interventions is a process-specific approach (cf. Park, Gutchess, Meade, & Stine-Morrow, 2007) such as WM training. With WM training, the aim is not to train additional processes in the sense of strategies, like the well-known method of loci (Yates, 1966), but instead to train the WM processing system per se. Since WM forms the basis of many cognitive processes (e.g., Kane et al., 2004; Kyllonen & Christal, 1990; Oberauer, Süss, Schulze, Wilhelm, & Wittmann, 2000), a general improvement in WM performance should thus also lead to improvements on functions and tasks that rely on WM processes. That is, the performance gain in the specific training task should ideally transfer to nontrained tasks. It has been assumed that such a transfer can occur if the training task and the transfer task share some common principles (cf. Jonides, 2004); for example, a shared capacity limit as has been proposed between WM and fluid intelligence (Halford, Cowan, & Andrews, 2007). Another way to look at common features is by means of underlying neural circuitries. For example, both WM and fluid intelligence seem to rely on similar neural networks, most consistently located in lateral prefrontal and parietal cortices (Gray, Chabris, & Braver, 2003; Kane & Engle, 2002), thus providing neural evidence for the shared variance between the two domains. It seems therefore plausible that the training of a certain neural circuit might lead to transfer to other tasks that engage similar or at least overlapping neural circuitries (Jonides, 2004; Persson & Reuter-Lorenz, 2008). Indeed, recent evidence shows that transfer occurs if the training and the transfer task engage overlapping brain regions but not if they engage different regions. Dahlin et al. (2008) demonstrated that training young adults with an updating task resulted in transfer to another updating task that recruited similar striatal brain regions like the training task. No transfer was found to a task that did not engage updating processes and did not activate striatal brain regions.

However, we (Jaeggi, Buschkuehl, et al., 2008) proposed that such common features might not be the only prerequisites for transfer. We suggested that a successful training task also must minimize the possibility to develop strategies that are specific to the task because the object of training must be changes in the information processing system, not changes in the way a particular task is performed. In addition to this proposal, we also argued that it is necessary to stress the information processing system (in our case WM) during training, for example, by keeping a constantly high level of training demand while also considering interindividual performance differences. This can be achieved by using an adaptive training method that continuously adjusts the current training difficulty to each participant (Jaeggi, Buschkuehl, et al., 2008; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Olesen et al., 2004; Tallal et al., 1996). Based on these assumptions, we (Jaeggi, Buschkuehl, et al., 2008) showed that WM training with a dual *n*-back task leads to transfer effects to nontrained measures of fluid intelligence but also to a digit-span task in a population of healthy young adults.

Despite the promising data on WM training in children and young adults, it has been difficult to show transfer effects after WM training in old adults. Dahlin and colleagues (2008) trained older adults within an age range of 65–71 years, but in contrast to the young adults they trained, they did not find transfer effects in old adults, although they used the very same training paradigm. Dahlin and colleagues argued that the reason for the lack of transfer could lie in the general differential activation patterns between young and old adults in the training and transfer tasks. Additionally, Dahlin et al. pointed out that besides the neural differences, there are behavioral differences between age groups, especially in the training task where older adults train on an overall lower level than younger adults. Although this study shows that a training program that yields transfer in young adults does not necessarily yield similar effects in old adults, there are several studies that demonstrate a remarkable plasticity in old adults (e.g., Baltes, Sowarka, & Kliegl, 1989; Erickson et al., 2005, 2007a, 2007b; Mahncke, Bronstone, & Merzenich, 2006) and even in old–old adults (Yang, Krampe, & Baltes, 2006). Thus, although it seems difficult to achieve, there is still some evidence for transfer in old adults. For example, Behrer and colleagues (Bherer et al., 2006, 2008) were able to show that a dual-task training in old adults led to improvements in task combinations with stimuli that were not part of the training.

In this project, we investigated whether WM training has a beneficial effect on WM and episodic memory performance in octogenarians. Previous work with older adults (Jaeggi, Schmid, Buschkuehl, & Perrig, 2008) suggested that a dual *n*-back training task like the one we used with young adults (Jaeggi, Buschkuehl, et al., 2008) might be too demanding and initially too frustrating for old–old adults. Therefore, for this study, we developed three computerized WM training task variants that seemed to be more age appropriate. All of our WM task variants continuously adjusted to the individual's WM capacity in an adaptive way: If participants perform successfully at a given task-level, the task gets more difficult, but if performance falls below a specified level, the task gets easier. Due to this adaptivity, participants always train at the peak of their performance ability but also repeatedly experience successful task accomplishments, which should aid to the motivation to stay with the training. In order to further motivate participants, but also in order to increase the chances for transfer by task diversification (Schmidt & Bjork, 1992), we included two short forced-choice reaction time (RT) tasks that aimed to induce training variability and also aimed to train basic speed of processing (cf. Ball et al., 2002; Park et al., 2002; Salthouse, 1996).

In order to assess training-related performance changes, we tested participants on four different memory measures before and after the intervention. In addition, we conducted a follow-up assessment 1 year after training completion. In these pre-, post-, and follow-up sessions, participants performed two WM tasks (a digit-span task and a block-span task) and two episodic memory tasks (a verbal and a visual free-recall task). Results were compared to an active control group that performed a physical training intervention. We hypothesized that the experimental group would show an overall improvement in memory, with a pronounced effect in the WM tasks, since the training intervention was based on training of WM. Although it has never been shown before that WM training transfers to episodic memory, we were still interested in whether our training would show any effects on long-term memory. The reason for us to hypothesize any effects on long-term memory was because there is evidence that WM and long-term memory interact with each other in various ways. Concerning encoding, Burgess and Hitch (2005), for example, argued that high-WM capacity can help to better encode items due to a better phonological loop capability. In regard to retrieval, it has been argued (Bunting, Conway, & Heitz, 2004; Cantor & Engle, 1993; Radvansky & Copeland, 2006) that a better WM capacity is beneficial for retrieval from long-term memory. Finally, very recent evidence (Nee & Jonides, 2008) suggests that retrieval from WM and retrieval from episodic memory is based on common mechanisms as revealed by functional magnetic resonance imaging. Considering this evidence, we expected to see transfer on the episodic memory tasks as well, but only if the transfer effect on WM was strong enough, since a general improvement in WM processes would mediate transfer on episodic memory. Therefore, we hypothesized to find a much smaller transfer effect on episodic memory performance compared to the transfer on WM measures.

Method

Participants

Thirty-nine participants (23 women) with a mean age of 80.0 years ($SD = 3.3$) volunteered to take part in the study and were pseudorandomly assigned to either the experimental or the control group. Both groups were matched as closely as possible according to gender, age, body weight, and selected physical performance measures. Participants were recruited mainly in university and gymnastics courses for senior citizens. Participants were included in the study if they had no acute heart, psychiatric, or severe arthrosis problems. All participants lived independently at the beginning of the study. Thus, regarding their average age, our sample was very selective as it consisted of high-functioning participants. Participants gave informed consent and were paid CHF 200 (about $200) for their participation. The study was approved by the local ethics committee. Seven participants were excluded from data analysis for not being able to follow the required training schedule (mostly due to health issues; 3 in the experimental group and 4 in the control group). Therefore, for the pre- to posttest comparison, 32 participants (16 women) with a mean age of 80.1 years ($SD = 3.6$) were included in the data analyses (experimental group: $n = 13$, control group: $n = 19$). For the follow-up testing 1 year later, 22 of the participants could be recruited again (experimental group: $n = 11$, control group: $n = 11$). Due to a technical problem, the verbal free-recall data of 1 participant was lost in the follow-up test session.

Apparatus

The visual free-recall task was programmed in Pascal (Release 7.0) and conducted on a Microsoft DOS-based computer. All other computer-based tasks were programmed with E-Prime (Release 1.1). For the cognitive training, we used Microsoft Windows-based personal computers with 15-in. (38.1-cm) thin-film transistor monitors set at a resolution of 1,024 × 764 pixels, standard keyboards, and standard two-button mice. The control group trained on an electric bicycle ergometer that was especially designed for eccentric muscle training (Meyer et al., 2003).

General Training Procedure

Approximately 6 weeks before the start of the training, we extensively tested participants on several physiological and medical variables, in order to make sure that they could participate in the study without any health risks. Participants were then assigned to one of the two groups, based on the criteria outlined above. Approximately 1 week before the start of the training, all participants were tested on a series of psychological and physiological measures. Each participant was tested individually on 2 days. On the 1st day, they were tested psychologically and physiologically for 2.5 hr in total. On the 2nd day, they were tested for another hour on various psychological tasks. The procedure was the same for the pre-, post-, and follow-up sessions. The posttest took place in the week after training completion, and the follow-up test took place 1 year after training completion. In this article, we focus on the collected psychological (memory) data. A part of the physical data is already published (Lotscher et al., 2007), and further data are in preparation for publication elsewhere.

The training interventions took place over a time period of 12 weeks. There were two training sessions per week, lasting approximately 45 min each. The schedule was identical for both the experimental and the control group. Twenty-three training sessions were held in total. The cognitive training intervention was performed with two groups consisting of 8 participants. The physical training was conducted in smaller groups where participants met each other for warm-up and cool-down tasks, as well as in the locker room. Each training session was supervised by at least one trained experimenter. More detailed information about the training is given in the next section.

Specific Training Material and Procedures

Experimental Group

In the following section, we first give a detailed description of the WM training tasks and the RT tasks before we turn to the training procedure.

WM Task Variant 1. In this first variant, we addressed the issue that many participants had never used a computer before; thus, we first had to familiarize them with the use of a computer and the handling of the computer mouse. Participants were shown four colored squares presented in a row, centered on the screen as shown in Figure 1a. The squares were 200 × 200 pixels in size and colored red, green, yellow, and blue (in that order). One of the squares disappeared for 1,500 ms and reappeared again after 1,000 ms in a randomly defined sequence (see Figure 1b–1c). The task was to repeat the shown sequence by clicking on the appropriate squares with the computer mouse. If participants were able to reproduce the sequence correctly, the next sequence length was increased by one item; otherwise, it was reduced by one item. After reproducing the sequence, participants were notified whether the actual trial was correct. The dependent variable for the assessment of the training gain was the averaged trial length per run.

WM Task Variant 2. This task consisted of two parts. In the first part, participants had to decide whether a presented animal (either a cat or a dog; see Figure 2) was presented the right way around or upside down by pressing the right or the left mouse button. Each picture was 300 × 300 pixels in size and was presented in the middle of the screen. Participants were given 3,000 ms to answer; otherwise, a message appeared on the upper part of the screen, saying that they should respond quickly and accurately (see Figure 2b). The same message also appeared if they

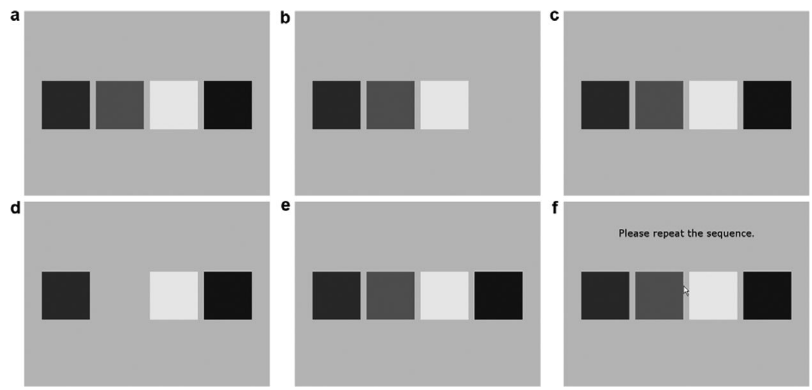

Figure 1. Example trial with a sequence length of two items from the working memory Task Variant 1 (a–e). Also shown is the prompt to repeat the presented sequence (f). Although shown in grayscale, the squares were colored red, green, yellow, and blue (in that order).

pressed the wrong button. In the second part, participants had to reproduce the previously shown sequence of cats and dogs. They could do this by clicking on the pictures (300 × 300 pixels) as depicted in Figure 2c. As a confirmation for their mouse click, a small picture (100 × 100 pixels) of the chosen animal appeared on the bottom of the screen (see Figure 2d). A performed mouse click could not be corrected. If participants were able to correctly reproduce the previously shown sequence and did not make a mistake in the first part of the task (i.e., clicked the wrong mouse button and/or took too long to perform a correct mouse click), the length of the next sequence was increased by one item. If the sequence was correctly reproduced but participants made a mistake in the first part of the task, the sequence length of the next trial was unchanged. The next sequence length was reduced by one item, if the participants were not able to reproduce the previously shown sequence correctly. After reproducing the sequence, participants received feedback on whether the actual trial was correct. The averaged trial length per run served as the dependent variable.

WM Task Variant 3. This task was identical to WM Task Variant 2 with the exception that the number of presented animals was increased from two to eight items. The following animals were shown: cat, iguana, dog, rabbit, mouse, toad, butterfly, and bee. For the second part of the task, we used 200 × 200 pixels as the dimensions of the pictures in order to fit the increased number of

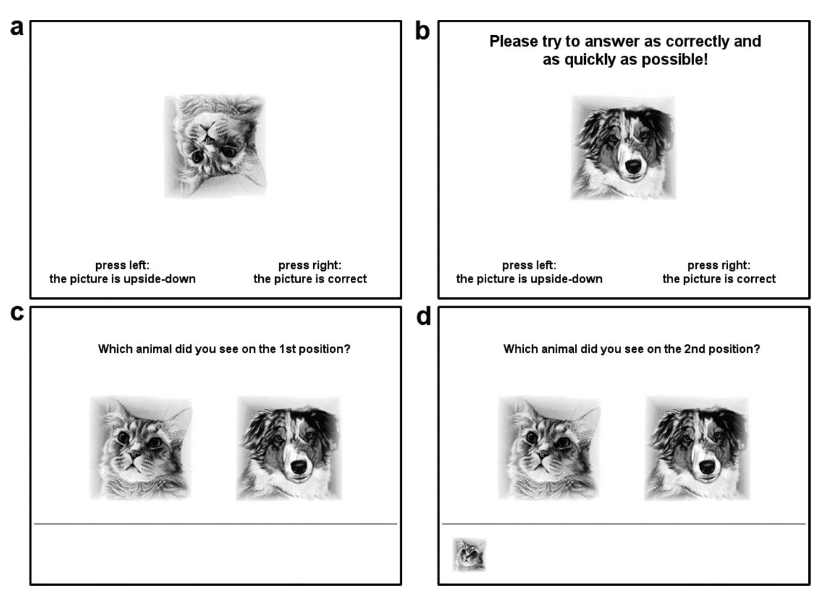

Figure 2. Partial example of a single trial from the working memory Task Variant 2. In the first part, participants had to decide whether each animal in a series is presented upside down or normally by pressing either the left or the right mouse button (a). At the same time, they had to memorize the sequence. If participants pressed the wrong mouse button or if they took too much time to answer, a screen with a reminder appeared (b). In the second part of the task, participants had to reproduce the previously presented sequence (c, d). In (a) and (b), a prompt is visible on the bottom of the screen saying which mouse button has to be pressed for the upside-down and normally presented picture.

pictures onto the screen. Again, the averaged trial length per run constituted the dependent variable.

RT Task Variant 1. A trial started with a fixation cross, presented for a randomly selected time period between 2,000 ms and 7,000 ms (in steps of 500 ms). After the presentation of the fixation cross, a word or a nonword appeared until the participant pressed a prespecified key. Participants were instructed to decide as fast as possible whether they saw a word or a nonword by pressing the appropriate key (*M* for word and *Y* for nonword). The task consisted of 30 trials with 14 words (positive aging stereotypes; cf. Levy, 1996) and 14 nonwords. The dependent variable was the RT for correct responses.

RT Task Variant 2. A trial started with a fixation cross, presented for a randomly selected time period between 2,000 ms and 7,000 ms (in steps of 500 ms). After the presentation of the fixation cross, a word appeared either above or below the cross for 115 ms. The word was followed by the stimulus mask *KGFLRTPSQZXVB*, which remained on the screen at the same position as the previously shown word until a keypress occurred. Participants were instructed to focus on the fixation cross and to press the key *Y* if the word and mask appeared above the fixation cross and the key *M* if the word and mask appeared below. The same words as in RT Task Variant 1 were used. The dependent variable was the RT for correct responses.

Each training session started and ended with a passive-activation task that served as a warm-up or cool-down task, respectively. In this task, a selection of words was visually presented on the computer screen. Participants were given instructions to attentively read the presented words. At the end of each training session, a brief and general presentation about a selected topic like attention or memory systems was given.

A typical training session was performed using the following schedule: (a) passive activation, (b) WM training, (c) RT task, (d) WM training, (e) RT task, (f) passive activation. The tasks (b) and (d) were always identical in the same session; the same was true for the tasks (c) and (e). Therefore, each training task was given twice (i.e., two runs) in the same training session. In each session, participants trained for about 8 min with the WM training tasks and for about 4 min with the RT tasks. The passive activation lasted approximately 4 min. The WM training was changed after a training block that lasted approximately 4 training weeks. Each new WM training task was more complex than its predecessor. The RT tasks were alternated every 2 weeks.

Control Group

For a control group, we included a physical intervention group that trained with an eccentric bicycle ergometer for the same amount of time as the cognitive training group. An important characteristic of eccentric muscle training is the fact that the metabolic load is comparatively low (Meyer et al., 2003). There is evidence (cf. Dustman et al., 1984; Kramer et al., 2002, 2003; Moul, Goldman, & Warren, 1995) that it is especially the cardiovascular component of physical training that leads to cognitive improvements. Thus, we assumed that a physical training with a small cardiovascular component should only minimally affect cognition.

Training sessions started with a 10-min warm-up period that included using a conventional bicycle ergometer and doing gymnastics. After the warm-up period, training on the eccentric bicycle ergometer started. The ergometer is designed like a recumbent bicycle, and the motor-driven foot pedals are constantly turning in backwards direction. Participants were instructed to slow down this movement according to a computer screen on which they had to monitor their actual load and adjust it to the target load (Vogt et al., 2003). Thus, besides the muscular component, participants were also required to constantly pay attention, monitor their actual workload, and perform adjustments as required. From a face-validity perspective, one might think that this monitoring task could also have the potential to improve cognitive functioning. However, in contrast to the experimental group in which the cognitive load in the WM training was adapted to the actual performance of the participants, the difficulty of the monitoring task was held constant in the control group and became presumably more automatic over the course of the training.

We started training with a comparably low training time (5 min) and a low load (30 W for women and 50 W for men) in order to prevent muscle sores induced by unaccustomed eccentric muscle training. Over the 23 training sessions, training time was gradually increased up to 20 min and load went up to 560 W. This ramping-up process was based upon the individual performance progress. The training sessions ended with a 10-min cool-down period with stretching. To conclude, the control group matched the experimental group very well on several aspects such as training time, social interaction with experimenter and peers, as well as basic cognitive monitoring requirements.

Transfer Tasks

Digit-span task. This test was taken from the Nuremberg Inventory of Old Age (Oswald & Fleischmann, 1995) and is comparable with the digit-span test from the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981). Participants were requested to repeat an orally given sequence of numbers either forward or backwards. The forward version was conducted first and started with a sequence length of two. If the trial was answered correctly, the sequence of the next trial was increased by one. If an error was made, a second trial with the same sequence length was given. If the second trial could not be repeated correctly either, the test was aborted. The dependent variable consisted of the sum of the longest sequence length that could be correctly repeated in the forward condition plus the longest sequence length that could be correctly repeated in the backward condition. With this summation, we followed the tradition in the psychometric literature (e.g., Wechsler, 1981) that adds scores for forward and backward spans to obtain a single span for short-term memory. In addition, there is emerging evidence from the literature that the forward and backward span share a considerable amount of variance (Colom, Flores-Mendoza, Quiroga, & Privado, 2005), which is also supported by neuroimaging literature (Colom, Jung, & Haier, 2007; Gerton et al., 2004). Finally, summing up the two scores also keeps the number of variables that go into the data analysis smaller and therefore strengthens statistical power.

Block-span task. A white 4 × 4 grid was presented on an otherwise black computer screen. A blue dot appeared sequentially in a random sequence in different locations of the grid. Participants were asked to repeat the shown sequence by pointing on the computer screen with their index finger. The experimenter used the computer mouse in order to submit the responses to the computer. Similar to the digit-span task, the next sequence length was increased by one item if the answer was correct. If not, the same sequence length was repeated once. After two consecutive trial errors, the test was aborted. This procedure was conducted in a forward and a backward manner. The forward version was always conducted first, and the start sequence length for both conditions consisted of two items. The length of the last correctly reproduced sequence in both the forward and backward condition was summed up and represented the dependent variable. The reason for this summation was the same as with the digit-span task.

Verbal free recall. This task was taken from the German version of the Wechsler Memory Scale—Revised (Härting, Markowitsch, Neufeld, Calabrese, & Deisinger, 2000). A short prose text, adapted to our needs (such as replacing German cities with Swiss cities etc.), was read to the participants. They were instructed to listen carefully and to memorize the text as best they could. Approximately 30 min later, participants were asked to reproduce as many details of the text as possible. The dependent variable was the number of correctly remembered idea units.

Visual free recall. This task was taken from the Computerized Memory Function Test (Perrig et al., 2006). Participants had to look for differences between two almost identical pictures. The pictures consisted of several objects (Snodgrass & Vanderwart, 1981), as well as several numbers, words, and patterns. One picture was presented on the right side, and the other one was presented on the left side on the computer screen. The left picture contained 18 differences compared to the right one. Participants were given the instructions to look for as many differences as possible as fast as they could. Participants were also encouraged to look at the picture in a way that they would be able to give information about it later on. The time allowed for detecting the differences was 3 min. Approximately 20 min after the difference search task, participants were asked to report as many items as possible that were included in the picture in which they were looking for differences. We encouraged participants to mention all details that came to mind. The dependent variable was the number of correctly recalled items.

For all transfer tasks, except for the block-span task where the sequences were generated randomly, we used parallel versions for the posttest session. For the follow-up test session 1 year later, the version used in the posttest was administered again.

Data Analysis

For data analyses, we used SPSS for Windows (Release 15.0.1). All statistic tests are based on a significance level of $\alpha = .05$.

Training Data

For the experimental group, we report the specific training improvement for the three WM training tasks, as well as the two RT training tasks separately. We used paired *t* tests to test for significant performance differences between the first and the last training run in all these analyses.

Transfer Data

First, we tested whether the data from the pretest differed between both groups using independent *t* tests. In order to analyze the immediate transfer effect, we calculated a multivariate analysis of variance (MANOVA), with group (experimental, control) as the between-subjects factor and the differences between post- and pretest scores (from this point on termed *gain scores*) as dependent variables. Following the suggestions by Olson and Stevens (Olson, 1974, 1979; Stevens, 1979), we report Pillai's *V* as *F* statistics, assuming that it yields the most robust outcome. In the case of a significant MANOVA, we further analyzed each memory measure separately and calculated independent *t* tests, with the gain scores as dependent measures.

For the analyses of the follow-up data, we performed the same analysis with the exception that we now looked at the difference between the follow-up and pretest scores, as well as at the difference between the follow-up and the posttest scores.

Results

Specific Training Effects

The training curves for the three different WM task variants are plotted in Figure 3. A significant improvement of 44% resulted from the first to the last run[1] in the WM Task Variant 1, $t(9) = -4.67$, $p < .01$, $r = .84$. Participants recalled a mean sequence length of 3.4 items in the first run and 4.9 items in the last run.

For the WM Task Variant 2, a significant improvement of 62% from the first to the last run was observed, $t(8) = -4.39$, $p < .01$, $r = .83$. Participants recalled 2.8 items on average in the first run and 4.5 items in the last run. In WM Task Variant 3, participants started with an average of 3.1 items in the first run and ended the training with 3.5 items. This 15% performance increase was also statistically significant, $t(9) = -4.59$, $p < .01$, $r = .84$.

The RT Task Variant 1 was conducted in three blocks[2] with 6, 7, and 9 runs, respectively. For these three blocks, there was a performance increase of 32%, 7%, and 14%, respectively. Comparing the first with the last run in each block, we observed a trend for the first block, $t(11) = 1.86$, $p = .09$, $r = .49$, as well as the second block, $t(8) = 1.91$, $p = .09$, $r = .56$. The RT Task Variant 2 was conducted in two blocks with 7 runs. Statistically significant improvements were observed in both blocks: first block, $t(9) = 4.66$, $p < .01$; second block, $t(9) = 4.93$, $p < .001$, $r = .85$, corresponding to a gain of 32% and 15%, respectively.

Transfer Effects

Descriptive data for all four memory measures and for both groups separately are given in Table 1. Significant pretest differences were found only in the digit-span task, $t(30) = 2.81$, $p < .01$, $r = .46$, but not the other three memory measures. Standardized gain scores for the immediate transfer effect right after training completion are depicted in Figure 4.

Immediate Transfer Effects (Pre- vs. Posttest)

The MANOVA with all the memory measures as dependent variables was significant, $F(4, 27) = 5.62$, $p < .01$, $\eta_p^2 = .46$,

[1] As pointed out earlier, two runs of the same task are given in each session.

[2] A block is a period of time, where the same training task was used consecutively.

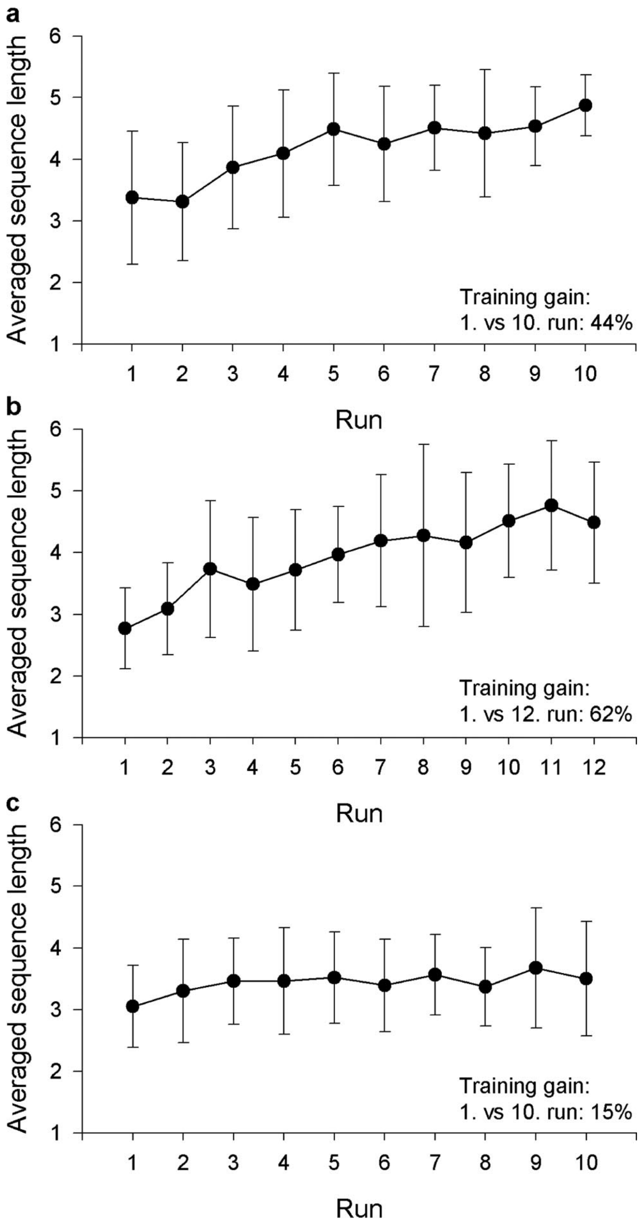

Figure 3. Training curves for the three working memory (WM) task variants. Depicted is the averaged sequence length participants were working with in a given run. Plotted are results of WM Task Variant 1 (a), results of WM Task Variant 2 (b), and results of WM Task Variant 3 (c). Error bars represent standard deviations from the averaged sequence length per participant.

showing a better overall performance for the experimental group. Independent *t* tests yielded a significant group difference for the block-span task, $t(30) = 3.94$, $p < .01$, $r = .58$, but not for the other measures: digit-span task, $t(24.35) = 0.71$, $p = .49$, $r = .14$; verbal free recall, $t(30) = -0.18$, $p = .86$, $r = .03$; visual free recall, $t(30) = 0.97$, $p = .34$, $r = .17$.

In order to test for more subtle changes, we conducted paired *t* tests between the pre- and posttest measures within each group. The analysis revealed significant performance improvements in

Table 1
Descriptive Data for the Pre-, Post-, and Follow-Up Data

Group and task	Pretest (n = 32) *M*	Pretest (n = 32) *SD*	Posttest (n = 32) *M*	Posttest (n = 32) *SD*	Follow-up (n = 22) *M*	Follow-up (n = 22) *SD*
Experimental						
Digit-span task	9.62	1.33	9.46	1.27	9.73	1.01
Block-span task	7.23	1.88	8.77	1.59	8.10	1.22
Verbal free recall	9.69	3.45	9.08	4.31	10.18[a]	3.74[a]
Visual free recall	6.15	2.73	7.69	3.75	9.27	2.90
Control						
Digit-span task	10.95	1.31	10.42	1.07	10.45	1.13
Block-span task	8.16	0.90	7.84	0.77	8.18	1.33
Verbal free recall	11.74	4.18	11.37	2.93	10.70	2.83
Visual free recall	6.37	3.64	7.00	3.57	8.82	3.25

[a] $n = 21$.

the block-span task, $t(12) = 3.68$, $p < .01$, $r = .73$, and the visual free-recall task, $t(12) = 2.38$, $p < .05$, $r = .57$, in the experimental group only (see Figure 4). The other comparisons were not significant for the experimental group (digit-span task: $t[12] = -0.37$, $p = .72$, $r = .11$; verbal free recall: $t[12] = -0.64$, $p = .54$, $r = .18$) or the control group (digit-span task: $t[18] = -1.65$, $p = .12$, $r = .36$; block-span task: $t[18] = -1.19$, $p = .25$, $r = .27$; verbal free recall: $t[18] = -0.39$, $p < .71$, $r = .09$; visual free recall: $t[18] = 0.99$, $p = .33$, $r = .23$).

Long-Term Transfer Effects (Follow-Up)

We compared the outcome 1 year after training completion to the pretest performance. The corresponding MANOVA was not significant, $F(4, 16) = 0.61$, $p = .66$, $\eta_p^2 = .13$. Independent *t* tests yielded no significant group differences either: digit-span task, $t(20) = 1.01$, $p = .32$, $r = .22$; block-span task, $t(20) = 1.33$, $p = .20$, $r = .29$; verbal free recall, $t(19) = 0.49$, $p = .63$, $r = .11$; visual free recall, $t(20) = -0.49$, $p = .63$, $r = .11$. The MANOVA comparing the gain scores from the follow-up to the posttest

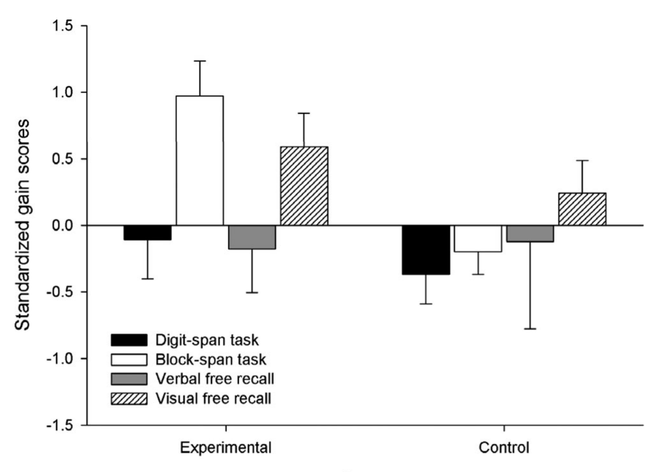

Figure 4. The gain scores for the immediate transfer effect visualized in units of standard deviation. Error bars represent standard errors.

session as dependent measures missed significance only by a margin, $F(4, 16) = 2.92$, $p = .054$, $\eta_p^2 = .42$. The independent *t* tests showed a reliable group difference for the verbal free recall, $t(19) = 2.22$, $p < .05$, $r = .45$, in which the experimental group outperformed the control group. There were no significant group differences in the other measures: digit-span task, $t(20) = 0.76$, $p = .46$, $r = .17$; block-span task, $t(20) = -1.91$, $p = .07$, $r = .39$; visual free recall, $t(20) = -1.26$, $p = .22$, $r = .27$.

Discussion

Our aim in the present study was to look at the impact of WM training on nontrained WM and episodic memory tasks in a sample of old–old participants with an average age of 80 years. The results of the experimental group were compared to an active control group. Our analyses showed that our participants considerably increased their performance in the trained task. In terms of transfer, we observed reliable group differences immediately after training completion, which were mainly driven by the improvement in visual WM. In addition, there was some evidence for a performance increase in the visual free-recall task that was exclusively observed in the experimental group. No reliable group differences were observed 1 year after training completion.

The analyses of the specific training effects revealed significant training gains in all three WM task variants. The percentage gain differed considerably between the three tasks with the largest increase in the WM Task Variant 2 and the smallest increase in WM Task Variant 3. We assume that these differences emerged because of the different task properties. For example, participants reported that it was relatively easy to generate task-specific strategies to solve WM Task Variant 2, but no participant reported to have used a similar successful strategy for WM Task Variant 3. Alternatively, it might also be possible that participants reached their capacity limit in WM Task Variant 3, especially since this task was performed during the last 4 weeks of the training. Therefore, no more improvement might have been possible. Concerning the RT tasks, we found a significant improvement in the more complex RT Task Variant 2 but not in the RT Task Variant 1. We assume that the RT Task Variant 1 was too easy to show a significant improvement. It seems that RT Task Variant 2 was more complex compared to the first task and consequently had more potential for a training improvement.

Although the analyses of the specific training effects are without doubt interesting in themselves, we now focus on the criterion tasks performed in the pre-, post-, and follow-up test sessions, since these tasks were of major interest in our study. Our results show that the overall group effect favoring the experimental group was primarily driven by the block-span task (see Figure 4). This transfer effect has to be classified as near transfer according to the informal definitions given by the transfer literature (e.g., Salomon & Perkins, 1989; Singley & Anderson, 1989; Willis, 2001): The WM training (especially WM Task Variant 1) and the block-span task seem to involve similar short-term storage processes and, in addition, both tasks were performed in the visual domain. Nevertheless, both tasks differed considerably in the used material as well as in the general task design.

Thus, we were able to show that transfer is possible even with old–old participants, providing further evidence that the human brain stays remarkably plastic even with advanced age (e.g., Baltes et al., 1989; Erickson et al., 2005, 2007a, 2007b; Mahncke et al., 2006). Although these effects are remarkable, the results also indicate that the effects of our training do not go far beyond an improvement in visual WM. Thus, we did not find a significant transfer to the digit-span task, although we had expected to see an increase in this task. This lack of transfer can be attributed to many causes; for example, it could be that processes involved in the performance of a digit-span task, such as rehearsal, are well-learned and thus rely on mainly automatic processes. Because such automatic processes might be very difficult to alter (Perrig & Perrig, 1993), the transfer from the training tasks to the digit-span task has been prevented. Another reason for the limited transfer might also lie in the fact that our participants were able to develop task-specific strategies especially for the WM Task Variants 1 and 2. Since we argued that strategy use might prevent transfer (Jaeggi, Buschkuehl, et al., 2008), our WM training intervention might not have been as effective as planned. Since it seems that strategies were used less used in WM Task Variant 3, prolonged training with this task may have led to better results.

Although we did not expect to find large improvements in the episodic memory tasks, we still hoped to find transfer to episodic memory because previous research (Bunting et al., 2004; Burgess & Hitch, 2005; Cantor & Engle, 1993; Nee & Jonides, 2008; Radvansky & Copeland, 2006) suggested an interaction between WM and long-term memory. But in contrast to our hypothesis, we did not find a significant improvement in episodic memory performance as revealed by a statistical between-groups analysis. However, we found a more subtle improvement in visual episodic memory as revealed by a significant pre- to posttest comparison that was observed exclusively in the experimental group. Our expectation to find transfer in episodic memory was mainly based on the assumption that we would find near transfer to the WM transfer tasks, which would reflect a more general improvement of processes associated with WM. But since the transfer to WM was limited to the visual domain, we assume that the overall transfer to WM was not strong enough to also result in reliable transfer effects in episodic memory or in transfer effects that go beyond the visual domain. As pointed out above, it might be that more efficient WM training would be able to yield stronger performance increases in episodic memory.

The follow-up data 1 year after training revealed that the advantage of the experimental group no longer existed. Therefore, the transfer effects observed immediately after intervention completion did not persist 1 year later compared to the initial performance in the pretest, but they were not (although not clearly) statistically different from the posttest either. Taken together, our data suggest that in order to maintain cognitive plasticity, it seems crucial that the cognitive system gets a certain amount of training over time (e.g., Mahncke et al., 2006). However, since we only had 22 participants who completed the follow-up tests, this result has to be treated with particular caution due to the low statistical power that is associated with this nonresult.

Also in the posttest session, our sample size of 32 participants was comparatively small. Nevertheless, although the effects obtained with such a small simple size need to be interpreted with caution, the effect sizes were appropriate (cf. Results section). Another caveat in our study that might reduce the generalization of our findings is the fact that our sample constituted of highly functioning old–old adults; therefore, it is not clear whether the effects could also be obtained with participants who already experience deficits in the trained function.

These limitations notwithstanding, the results of our study are of importance in showing that it is possible to improve memory in old–old adults with a WM training intervention, indicating that induced plasticity seems to be possible even in advanced old age.

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