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Transfer after Process-Based Object-Location Memory Training in Healthy Older Adults

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Abstract

A substantial part of age-related episodic memory decline has been attributed to the decreasing ability of older adults to encode and retrieve associations among simultaneously processed information units from long-term memory. In addition, this ability seems to share unique variance with reasoning. In this study, we therefore examined whether process-based training of the ability to learn and remember associations has the potential to induce transfer effects to untrained episodic memory and reasoning tasks in healthy older adults (60-75 years). For this purpose, the experimental group (n = 36) completed 30 sessions of process-based object-location memory training, while the active control group (n = 31) practiced visual perception on the same material. Near (spatial episodic memory), intermediate (verbal episodic memory), and far transfer effects (reasoning) were each assessed with multiple tasks at four measurements (before, midway through, immediately after, and four months after training). Linear mixed effects models revealed transfer effects on spatial episodic memory and reasoning that were still observed four months after training. These results provide first empirical evidence that process-based training can enhance healthy older adults' associative memory performance and positively affect untrained episodic memory and reasoning abilities.

Keywords: cognitive training, memory training, episodic memory, object-location memory, aging

Transfer after Process-Based Object-Location Memory Training in Healthy Older Adults

Old age is characterized by a relatively large average episodic memory decline (e.g., Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Schaie, 2005). According to the associative deficit hypothesis (Naveh-Benjamin, 2000), a substantial part of this decline can be attributed to the decreasing ability of older adults to encode and retrieve associations between simultaneously processed information units from long-term memory (for a review see Shing et al., 2010; for meta-analyses see Old & Naveh-Benjamin, 2008; Spencer & Raz, 2005). The most frequent memory complaints of older adults, that is, forgetting names of acquaintances or locations of objects (Bolla, Lindgren, Bonaccorsy, & Bleecker, 1991; Ossher, Flegal, & Lustig, 2013), imply that their deficient ability to learn and remember associations between information units directly affects their quality of life. Furthermore, the ability to create stable associations between simultaneously processed information units facilitates the construction and manipulation of new structural representations required for reasoning (Oberauer, Süss, Wilhelm, & Sander, 2007). Latent variable studies indeed demonstrated that this ability predicts variance in reasoning above and beyond working memory and speed in young adults (Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009) and in samples covering most of the adult lifespan (Tamez, Myerson, & Hale, 2012). Consequently, a cognitive training intervention enhancing older adults' ability to encode and retrieve associations from long-term memory has the potential to improve their episodic memory more generally, their reasoning ability, and their quality of life.

So far, episodic memory of healthy older adults has been mainly targeted by strategy-based training. Meta-analyses summarizing this research have shown that these interventions induce small to medium performance gains in the trained tasks (Gross et al., 2012; Verhaeghen, Marcoen, & Goossens, 1992). However, often only subgroups of the trained older adults apply the practiced strategies after training (e.g., Brehmer et al., 2008; Gross et al., 2014; Nyberg et al., 2003). Strategies acquired through such interventions are also often very specific and do not yield transfer even to other untrained episodic memory tasks (for reviews, see Eschen, 2012; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009).

An alternative training approach is process-based training which aims to directly increase the efficiency of basic cognitive processes through extensive repeated practice (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010; Willis & Schaie, 2009). In general, process-based training has shown more promising transfer effects in healthy older adults than strategy-based training (Morrison & Chein, 2011) and thus may be more suitable to target episodic memory processes in healthy older adults. Nevertheless, as yet, most research has focused on interventions practicing working memory or executive functions. Recent meta-analyses indicate that these interventions induce small to medium improvements in untrained working memory and executive functioning tasks, but findings on reasoning have been inconsistent (for positive findings see Karbach & Verhaeghen, 2014; for negative findings see Melby-Lervåg & Hulme, 2013, 2016).

To our knowledge, only two process-based training interventions targeting episodic memory processes in healthy older adults have been investigated: one practicing recollection processes in word list recognition (Jennings & Jacoby, 2003; Jennings, Webster, Kleykamp, & Dagenbach, 2005; Stamenova et al., 2014) and another practicing spatial navigation (Lövdén et al., 2012). Although both interventions led to large improvements in the trained tasks, there was little evidence for transfer. For the recollection intervention, previously found transfer effects to an untrained word list recognition task and a working memory task (Jennings et al., 2005) could not be confirmed in a later study with a larger sample size (Stamenova et al., 2014). For the spatial navigation intervention, Lövdén et al. (2012) also observed no transfer effects across 14 outcome tasks measuring a wide range of cognitive abilities both at post-training and at four-month follow-up. However, both interventions did not specifically target the ability to encode and retrieve associations from long-term memory. Moreover, the training tasks in both interventions may not have been completed by episodic memory processes at all. Stamenova et al. (2014) found that training gains in their word list recognition training task were not predicted by baseline episodic memory, but by baseline working memory performance. Likewise, the spatial navigation training task employed by Lövdén et al. (2012) could be completed by simply using procedural route knowledge or mere exploration. Hence, it is unclear whether process-based training of the ability to encode and retrieve associations from long-term memory in healthy older adults improves this ability and produces transfer to untrained cognitive abilities.

The above findings on cognitive training in healthy older adults have to be regarded with caution. Prior cognitive training research has been extensively criticized on methodological grounds. Many studies included only passive control groups, thereby confounding potential expectancy or non-cognitive intervention effects with training-induced improvements (cf. Dougherty, Hamovitz, & Tidwell, 2016; von Bastian & Oberauer, 2014). Furthermore, transfer was often assessed with only one task per outcome ability. Therefore, observed transfer effects may have been solely driven by task-specific surface commonalities between training and transfer tasks (e.g., material or response modality, cf. Lövdén et al., 2010; Shipstead, Reddick, & Engle, 2012). More theoretical criticisms on previous cognitive training research include the often arbitrary selection of cognitive outcome and control training tasks which does not allow for evaluating positive and negative transfer (i.e., convergent and discriminant validity, cf. Noack, Lövden, & Schmiedek, 2014) and arbitrary classifications of cognitive outcome tasks as representing near, intermediate, or far transfer (cf. Noack, Lövdén, Schmiedek, & Lindenberger, 2009).

The Present Study

The main aim of the present study was to examine the potential of process-based training to improve the ability to encode and retrieve associations between simultaneously processed information units from long-term memory and to yield transfer to untrained episodic memory and reasoning tasks in healthy older adults. Furthermore, we wanted to overcome methodological and theoretical shortcomings of previous cognitive training studies.

For this purpose, we developed a process-based training regime in which participants repetitively practiced object-location memory (OLM) tasks. OLM critically depends on the ability to encode and retrieve associations between simultaneously processed objects and their locations (Postma, Kessels, & van Asselen, 2008). OLM performance decrements in older adults have been repeatedly demonstrated (for reviews see Kessels & Postma, 2006 and Uttl & Graf, 1993; Noack, Lövdén, Schmiedek, & Lindenberger, 2013). More importantly, memory for objects and memory for locations are relatively mildly impaired in old age, but profound memory deficits arise for object-location associations (Kessels, Hobbels, & Postma, 2007; Naveh-Benjamin, 1987; 1988; Old & Naveh-Benjamin, 2008; but see Soei & Daum, 2008). Besides, OLM is particularly suitable for a process-based training approach because it solely involves visuo-spatial material. Strategies that are often spontaneously and successfully applied for remembering associations involving verbal information (e.g., sentence generation or interactive imagery; Dunlosky, & Hertzog, 2001; Kuhlmann, & Touron, 2012; Richardson, 1998) are less helpful for forming stable associations between objects and their locations. OLM training may also be particularly successful in older adults because OLM relies heavily on the hippocampus (for a meta-analysis see Kessels, de Haan, Kappelle, & Postma, 2001; for reviews see Burgess, 2008; Postma, Kessels, & van Asselen, 2008), one of the most plastic brain regions up into old age (Goh & Park, 2009; Lövdén et al., 2010). To maximize the intervention’s effectiveness, OLM training was both variable (by using three different tasks;

Schmidt & Bjork, 1992) and adaptive (by adjusting task difficulty to individual performance; Klingberg, 2010, but see von Bastian & Eschen, 2016).

We selected our cognitive outcome abilities according to Noack et al.'s (2009) theoretical framework for classifying the scope of transfer effects. It is based on Carroll's (1993) hierarchical model of human intelligence with general intelligence on top, eight broad cognitive abilities on the second level, and 69 narrow cognitive abilities on the third level. Transfer is categorized as near, intermediate, or far according to whether training positively affects tasks measuring the trained narrow ability, a different narrow but same broad ability, or different broad abilities, respectively. We chose spatial episodic memory, verbal episodic memory, and reasoning as outcome abilities. According to Carroll's model of intelligence, OLM and spatial episodic memory belong to the same narrow ability (visual memory), verbal episodic memory to a different narrow (meaningful memory) but the same broad ability (memory and learning), and reasoning to a different broad ability (reasoning). These abilities thus represent near, intermediate, and far transfer, respectively.

The formation of object-location associations depends on simultaneous visual processing of objects and locations during encoding (Postma et al., 2008). To demonstrate that transfer of process-based OLM training to spatial and verbal episodic memory and reasoning is based on improved associative memory rather than enhanced visual perception for objects and locations (convergent validity), we included an active control group that practiced visual perception tasks with the same stimuli and duration as the OLM training tasks. The control intervention was non-adaptive, as adjusting the difficulty of the visual perception tasks by reducing stimulus discriminability would have compromised our goal to primarily control for improvements in visual perception of the *same stimuli*. We also refrained from adjusting difficulty by reducing stimulus presentation time, as it proved infeasible to define the time difference between levels of difficulty long enough to affect performance, but short enough for conscious processing at high levels of difficulty. To still achieve between-group comparability in training motivation and effort, the control group received similarly extensive performance feedback as the OLM training group. To demonstrate discriminant validity and increase the plausibility of the control intervention, we also assessed visual perception.

We administered at least three heterogeneous tasks per assessed outcome ability and analyzed transfer effects on the level of these cognitive abilities with linear mixed effect models. To evaluate the maintenance of transfer effects, the cognitive test battery was not only administered before, after the first half of the training period, and immediately after training, but also four months after training completion.

Based on prior research on process-based training in older adults, we expected that OLM performance would improve linearly across the training period and lead to large performance gains. We had no clear predictions about the scope and maintenance of transfer effects of the OLM training. The few available studies on process-based episodic memory training in healthy older adults generally failed to demonstrate any transfer immediately after training and at four-month follow-up. However, according to the associative deficit hypothesis and to findings showing that the ability to encode and retrieve associations from long-term memory contributes to reasoning performance, OLM training could potentially yield transfer to spatial episodic memory, verbal episodic memory, and reasoning, that is, induce near, intermediate, and far transfer. We did not expect OLM training to yield transfer to visual perception, and the visual perception control intervention, if at all, to induce transfer to this cognitive ability only.

Methods

General Procedure

Experimental OLM training and visual perception control training comprised two phases with 15 sessions each that participants had to complete within three weeks. A one-week break separated the phases. Participants trained at home on their personal computers. Material, structure, and duration of the experimental and control interventions were similar, but only the experimental intervention was adaptive.

Participants completed the cognitive transfer test battery and several questionnaires at four times: before training (T1), in the week after the first training phase (T2), in the week after the second training phase (T3), and four months after training completion (T4). They were tested in groups of up to four. Each session took 2.5 h (including a 15-min break). Participants also underwent an individual 1.5-h neuroimaging session (including functional and structural magnetic resonance imaging (fMRI and sMRI), fluid-attenuated inversion recovery (FLAIR), and diffusion tensor imaging) within the same week in our lab, but these data are not in the focus of the present study.

The T1 assessment was preceded by two screening phases. In the first screening phase, potential participants completed screening questionnaires at home. Eligible participants were invited to the second screening phase. In this individual 1.5-h screening session in our lab, participants completed further screening tests and questionnaires and underwent an MRI simulator training for familiarization with the scanner and practice of the fMRI paradigm. After the baseline assessment, eligible participants were finally included in the study and randomly assigned to either the experimental or the active control group. Within a week before the start of the first training phase, participants were invited to an individual 1-h training introductory session in which a practice version of their training regime was administered.

The study was conducted double-blind, so that neither participants nor experimenters assessing the outcome measures were aware of group assignment. Participants were recruited for a “cognitive training study”, but were not informed about the two training conditions. Study staff not involved in assessing the outcomes randomly assigned participants to groups, conducted the training introductory sessions, monitored training compliance, and served as contact during training.

The study was conducted in four waves to accommodate scanner access availability. Randomization was stratified by study wave and gender (Kang, Ragan, & Park, 2008) and was subject to two restrictions. First, to maintain blindness for training conditions, members of couples participating in the study (four participants) were assigned to the same group. Second, as OLM training duration could increase with advancing levels of difficulty, each control participant’s training duration was matched to that of a participant in the experimental condition (for details see paragraph on training). To ensure that the matching procedure could be implemented, this matching partner had to be chosen among those starting the first training phase at least a week before the active control participant.

Participants

Participants were recruited at lectures for senior citizens at the University of Zurich, through newspaper articles, advertisements in magazines for older adults, public talks, flyers, and word of mouth. All participants gave written informed consent and were paid after the completion of different study parts. The study was approved by the Ethics Committee of the Canton of Zurich.

Inclusion criteria were age between 60-75 years, right-handedness, native or highly proficient German speaker, basic computer and internet experience, and access to computer and internet during training. Exclusion criteria were previous or current neurological and psychiatric disorders or substance use negatively affecting brain function, sensory and motor deficiencies hindering the completion of training tasks and outcome measures, violation of MRI safety requirements, participation in another training study within the last five years, failed screening measures (see below), and pathological incidental findings in the baseline sMRI and FLAIR assessments.

Figure 1 illustrates the recruitment process alongside the specific reasons for exclusion and drop-out of participants. Out of 180 participants in the first screening phase, 56 were excluded based on eligibility criteria and 44 dropped out. After the second screening phase and the neuroimaging baseline assessment another 7 participants were excluded and 5 dropped out. Finally, 68 participants were included in the study. During the second training phase, one participant in the experimental condition dropped because of personal reasons[1]. Descriptive data of the remaining 67 participants are listed in Table 1.

[1] We can only speculate why the retention rate was as high in our study, but we suggest two reasons. First, the financial compensation scheme explicitly rewarded retention in the study, as reimbursement increased over its course (CHF 30 after screening, CHF 70 after T1, CHF 150 after T3, and another CHF 70 after T4). Second, frequent and regular contact with the study staff at the many experimental sessions (e.g., two sessions at T1-T4) and during training (e.g., weekly e-mails) probably further enhanced study commitment.

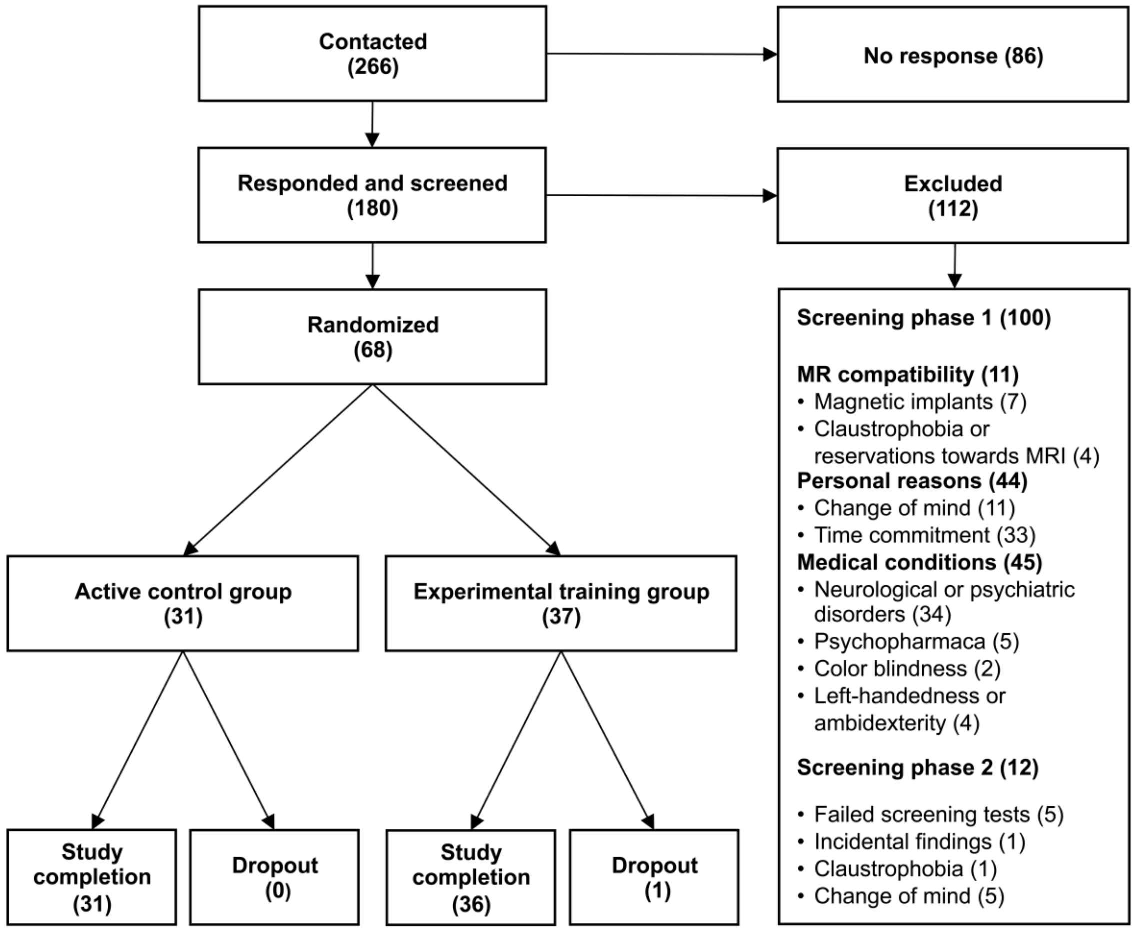

Figure 1. Recruitment process.

Screening

First screening phase. Potential participants received four questionnaires assessing the following variables: health and demographic data, computer and internet experience, MRI safety requirements, and handedness (Annett, 1970). Additionally sent questionnaires are described in the Supplemental Online Materials.

Second screening phase. In an individual lab session, participants were screened for cognitive deficits indicative of Mild Cognitive Impairment or dementia with the Consortium to Establish a Registry for Alzheimer's Disease Neuropsychological Assessment Battery (CERAD-NAB; Berres, Monsch, Bernasconi, Thalmann, & Stähelin, 2000) and for clinically relevant depressive episodes with the short version of the Geriatric Depression Scale (GDS; Sheik & Yesavage, 1986). As descriptive measure, crystallized intelligence was assessed with the Mehrfachwahlwortschatztest B (MWT-B; Lehrl, 1977).

The CERAD-NAB includes seven subtests: the Mini Mental State Examination (MMSE, Folstein, Folstein, & McHugh, 1975), a semantic fluency test, a 15-item form of the Boston Naming Test, a constructional praxia test, a figural delayed free recall test, a word list learning test, a delayed free recall test, and a delayed recognition test for this word list. For the figural and the word list delayed free recall tests, two measures are taken into account: the number of recalled items per se (recall performance) and the percentage of recalled items from correctly copied or recalled items in the last learning trial (savings). The short form of the GDS comprises 15 yes-no questions. Sum scores greater than 5 are indicative of clinically relevant depressive episodes. In the 37 items of the MWT-B, participants have to mark the real word among four nonsense words.

Participants were not included in the study if they scored lower than 28 in the MMSE, performed 1.5 *SD* below age-, gender-, and education-specific norms in more than one of the nine other measures of the CERAD-NAB, or scored greater than 5 in the GDS. Descriptive statistics for the screening and descriptive measures are reported in Table 1.

Table 1

Demographic and Descriptive Variables and Screening Measures

Variable	Group: OLM	Group: Active Control	*t*	*p*
Demographic and descriptive variables				
Sample size (*n*)	36	31		
Age (years)	66.75 (4.17)	68.23 (3.84)	1.50	.139
Gender (f/m)[a]	22/14	19/12	< 0.01	.988
Education (years)	14.97 (3.32)	14.10 (3.27)	-1.08	.282
Computer experience (years)	18.69 (7.74)	19.26 (7.59)	0.30	.764
Internet experience (years)	12.49 (5.82)	12.29 (5.53)	-0.14	.889
MWT-B (IQ)	123.61 (12.05)	122.23 (12.89)	-0.45	.651
Screening measures				
GDS (0-15, normal < 6)	0.50 (0.70)	0.81 (1.17)	1.28	.207
MMSE (0-30, normal > 28)	29.11 (0.75)	29.39 (0.72)	1.54	.129
CERAD (*z*-scores)				
Semantic fluency	-0.01 (0.76)	0.11 (0.90)	0.62	.536
Boston naming test	0.67 (0.60)	0.93 (0.47)	1.98	.052
Word list learning	0.62 (0.80)	0.58 (0.92)	-0.20	.839
Word list delayed free recall	0.44 (0.86)	0.41 (0.94)	-0.13	.899
Word list delayed free recall savings	0.14 (0.87)	0.15 (1.05)	0.04	.971
Word list delayed recognition	0.26 (0.72)	0.28 (0.70)	0.10	.921
Constructional praxia	0.39 (0.71)	0.32 (0.84)	-0.35	.728
Figural delayed free recall	0.36 (1.09)	0.20 (1.18)	-0.60	.548
Figural delayed free recall savings	0.13 (0.78)	0.01 (0.89)	-0.60	.551

Note. Means are provided alongside standard deviations in parentheses where applicable.
[a] χ^2 instead of *t* is reported.

Training

Training was self-administered at home using the open-source Java-based software Tatool (von Bastian, Locher, & Ruflin, 2013; www.tatool.ch). After each training session, data were automatically uploaded to a web server allowing for constant monitoring of participants' compliance. Automatized online analyses permitted the detection of irregularities (e.g., accuracy below chance level). The experimenters monitoring training compliance also supported the participants in case of technical difficulties. To ensure all participants were able to use the training software and to complete the training tasks, they practiced the installation of the software and completed a short version of the first training session with different material in an individual 1-h introductory training session. In addition, participants received a manual with step-by-step software installation instructions and detailed information about training operations and procedures. Participants were informed that the training software permitted the completion of only one session per day and that they would be contacted by e-mail or phone in case of no recorded training sessions on three consecutive days. To further enhance training commitment, they received weekly motivational e-mails during the training phases.

Training motivation and affect. In the training introductory session and at T2, participants completed the Questionnaire on Current Motivation (QCM; Rheinberg, Vollmeyer, & Burns, 2001), measuring four factors of achievement motivation in learning situations: interest, challenge, expected success, and performance anxiety. Its 18 items are rated on a 7-point Likert scale (1 = “does not apply”; 7 = “applies exactly”). At the beginning of each training session, participants rated their current training motivation on a 5-point Likert scale (1 = “very motivated”, 5 = “not at all motivated”) and their current arousal and emotional valence on 9-point Likert scales using self-assessment manikins (Bradley & Lang, 1994; arousal:1 = “calm, relaxed”, 9 = “excited, stimulated”; valence: 1 = “annoyed, sad”, 9 = ”happy, hopeful”).

Training tasks. Both training interventions included 30 sessions lasting about 30-45 min. In each session, participants practiced three different training tasks with 10 trials each. The order of the tasks was counterbalanced across training sessions and the same for all participants. In the beginning of each training task, participants could complete an optional practice trial. In both interventions, the object stimuli were randomly drawn from the same task-specific databases, with the restriction for the OLM training tasks that no object was repeated within one training session. Feedback on individual performance was provided at the end of each trial, task, and session.

OLM training. In all three training tasks, cued recall for object-location associations was practiced. Each trial consisted of an encoding phase in which *n* associations had to be encoded, a 20-s distractor task (to ensure that the encoded object-location associations could not be held in short-term memory), and a retrieval phase. Task difficulty was adapted to individual performance by increasing or decreasing *n* of to-be-encoded object-location associations by one. Participants started the first session on the lowest level of difficulty with two object-location associations. The highest possible level of difficulty required encoding of 21 object-location associations. Individual performance was assessed for each task separately. Task difficulty was increased in the next training session if performance was greater than 70 % and was decreased if performance was below 50 %. Feedback was given on the percentage of correctly recalled associations and the level of difficulty achieved. Level of difficulty served as performance measure.

Object-location task. Each of *n* objects was presented sequentially in a 5-x-6 grid for 4 s followed by an ISI of 0.5 s. Objects were drawn from a database of 245 colored drawings of everyday objects (Rossion & Pourtois, 2004; Snodgrass & Vanderwart, 1980). In the distractor task, simple arithmetic equations were displayed serially. Participants had to indicate by key presses whether they were correct or not. During the retrieval phase, each of the previously encoded objects was presented sequentially below the empty grid. Participants had to indicate by mouse click in which cell the object had been presented during encoding. Each object was presented until a cell in the grid was clicked on or for maximally 6 s.

Shape-location task. Twenty-nine self-created geometrical shapes in nine different colors (resulting in 261 different shapes) served as object stimuli. During encoding, *n* shapes were presented simultaneously in a 6-x-6 grid. Display duration was set to *n* x 3 s (e.g., 6 s at the lowest level of difficulty with two shapes). In the subsequent distractor task, 10 words had to be selected in alphabetical order with mouse clicks. During the retrieval phase, the previously encoded shapes were presented left and right to the empty grid. Participants had to click with the mouse on each shape and then on the cell in which they were presented during encoding. The retrieval phase ended when all shapes had been assigned to cells or after a maximum of *n* x 6 s (e.g., 12 s at the lowest level of difficulty).

Landmark-location task. This task was the same as the shape-location task with three exceptions. First, object stimuli were drawn from a database of 261 photographs of real-world buildings (retrieved from the internet, photographs of highly salient or famous buildings were excluded). Second, the 6-x-6 grid was superimposed by a different self-created city map in each training session. The 30 maps consisted of patterns of white lines on a gray background. Third, in the distractor task, 10 two-digit numbers had to be selected in the order of their magnitude.

Control training. Each of the control training tasks was matched to one of the OLM training tasks in terms of stimulus material and distractor task. Instead of an encoding phase and a retrieval phase as in an OLM training task trial, in a control training task trial the distractor task separated two phases of a visual perception task. The duration of these visual perception phases was determined by the duration of the encoding and retrieval phases of the same trial in the corresponding OLM training task in the same training session of the individually matched OLM training participant.[2] Within both visual perception phases, after participants had solved one item, the next item was presented until phase duration expired. Participants had to solve the presented items as quickly as possible. Feedback was given on the number of completed items, the number and percentage of correct responses, and the average reaction time. Proportion of correctly solved items and average reaction time served as performance measures.

Object-perception task. Two 1-x-10 grids filled with objects were presented, one below the other. Participants had to click with the mouse on the one object that differed between the two grids.

[2] Four control group participants had to be matched to other experimental training participants during the course of the training because one experimental training participant dropped out and three experimental training participants lagged behind in completed training sessions because of computer problems.

Shape-perception task. A target shape was presented on top of the 6-x-6 grid which was filled with 36 shapes. Participants had to click with the mouse on the target shape in the grid.

Landmark-perception task. The procedure was the same as for the shape-perception task, except that a target building was presented on top of city maps filled with 21 buildings.

Transfer

We administered five spatial episodic memory tasks (near transfer), three verbal episodic memory tasks (intermediate transfer), six reasoning tasks (far transfer), and three visual perception tasks (control tasks). All transfer tasks differed in stimulus material and test format from the training tasks. Task order was counterbalanced across the four abilities and the same from T1 to T4. At the end of the cognitive assessments, participants additionally completed several questionnaires (see Supplemental Online Materials).

To assess spatial and verbal episodic memory, we used the three respective subtasks of the paper-and-pencil Berlin Intelligence Structure Test Form 4 (BIS-4, Jäger, Süss, & Beauducel, 1997). For spatial episodic memory, we additionally administered two computerized tasks. Reasoning was measured with the five visuo-spatial reasoning subtasks of the BIS-4 and with a short version of the Raven’s Advanced Progressive Matrices (Arthur & Day, 1994). Visual perception skills were assessed with the three paper-and-pencil tasks representing the factor perceptual speed from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Dermen, 1976). Table 2 lists short descriptions of all administered tests.

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Table 2

Descriptions of the Transfer Tasks

Task	Description
	Spatial Episodic Memory (Near Transfer)
BIS-4 Orientation Memory	Encode the locations of 27 black geometrical shapes representing buildings on a fictitious city map within 90 s and then mark the encoded locations on an uncolored copy of the map within 90 s.
BIS-4 Remembering Routes	Encode a route with 30 segments on a fictitious city map within 30 s and then reproduce the route on a copy of the map without this route within 40 s.
BIS-4 Company Logos	Encode 20 company logos presented in differently shaped frames within 60 s and then mark the shape that had framed each logo out of 4 provided shapes within 90 s.
OLM Pairs[a]	Encode 15 object-location association pairs sequentially presented in a 5 x 6 grid. The first object will be presented alone for 1 s and then together with the second object for 3 s, followed by an ISI of 3 s. After a 30-s distractor task (adapted version of the Digit Symbol Substitution subtest of the HAWIE-R; Tewes, 1991), one object-location association of a pair will be displayed in the 5 x 6 grid. Indicate the cell in which the second object had appeared during encoding by mouse click within 4 s. Two learning trials will be conducted.
OLM Recognition[b]	Encode 6 object-location associations presented sequentially (3 s each) in a 5 x 5 grid. After a distractor task (a 1-back task with arrows pointing in 8 possible directions) with random duration between 12-18 s, indicate by pressing two buttons whether the again sequentially presented objects (3 s each) are displayed in their original grid cells (50 %) or not. After a visual fixation phase with random duration between 9-15 s, complete the next trial (two runs with 12 trials each).
	Verbal Memory (Intermediate Transfer)
BIS-4 Meaningful Text	Encode a text within 60 s and then answer questions about 22 details from the text within 120 s.
BIS-4 Remembering Words	Encode a list of 20 nouns within 40 s and then recall them in written form within 90 s.
BIS-4 Fantasy Language	Encode 20 word pairs, each consisting of one real and one nonsense word, within 60 s and then select for each presented real word the encoded out of five provided nonsense words within 75 s.
	Reasoning (Far Transfer)
BIS-4 Analogies	Determine how 2 shapes relate to one another. Select the shape which has the same relationship to a target shape out of 5 provided shapes. Solve as many out of 8 items as possible within 105 s.

BIS-4 Charkov	Complete series of patterns that are governed by a certain rule by adding 2 patterns to the first 3 provided patterns. Solve as many out of 6 items as possible within 180 s.
BIS-4 Bongard	Deduct from 2 provided groups with 6 patterns each to which group 3 additional patterns belong. Solve as many out of 5 items as possible within 130 s.
BIS-4 Shape Selection	Decide which of 5 provided large shapes can be built from 3 to 4 small pieces of a shape. Solve as many out of 6 items as possible within 150 s.
BIS-4 Transaction	Decide which out of 5 provided three-dimensional figures can be built from a folding template. Solve as many out of 5 items as possible within 110 s.
RAPM	Complete a spatial logical pattern by choosing the correct out of 8 provided figures. Solve 12 items without time constraint.
	Visual Perception (Control Measure)
KIT Finding A's	Mark as many of 200 words containing the letter „a" as possible out of a total of 820 words within 120 s (two trials).
KIT Number Comparison	Compare 48 pairs of 3- to 13-digit numbers and mark as many pairs with different digits as possible within 90 s (two trials).
KIT Identical Pictures	Mark the geometrical figure or picture out of 5 presented ones that is identical to a target figure or picture. Solve as many of 48 items as possible within 90 s (two trials).

Note. The number of correctly remembered or correctly solved items served as outcome measure, except for OLM Recognition (mean number of recognition hits across the two runs with 72 items each), Number Comparison, and Identical Pictures (difference between the number of correctly marked and incorrectly marked items). BIS-4 = Berlin Intelligence Structure Test Form 4. RAPM = Raven's Advanced Progressive Matrices. KIT = Kit of Factor-Referenced Cognitive Tests.

[a] Rasch, Büchel, Gais, & Born (2007).

[b] This task was conducted in the MRI scanner while recording task-related brain activity (fMRI). The object stimuli were drawn from the Bank of Standardized Stimuli (BOSS; Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010). The objects were comparable in object identity and familiarity ratings across the two runs.

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Analysis

We replaced outliers in the transfer data with the median of the raw scores plus or minus three times the median absolute deviation (MAD, cf. Leys, Ley, Klein, Bernard, & Licata, 2013). Next, outlier-corrected raw data were *z*-transformed separately for T1 and for T2 through T4. Training motivation ratings were recoded so that higher ratings represent higher motivation.

Due to strong floor effects and no variance at T1 or T1 and T3 respectively, we excluded the Charkov (T1: $M = 0$, $SD = 0$) and Bongard (T1 and T3: $M = 1$, $SD = 0$) reasoning tasks from further analyses. To ensure that the remaining transfer tasks loaded on the hypothesized cognitive ability factor, we ran a confirmatory factor analysis (maximum likelihood extraction with oblique rotation) with a fixed number of four factors. The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis (KMO = .67). Bartlett's test of sphericity indicated that correlations between individual tests were sufficiently large ($\chi^2(105) = 256.33$, $p < .001$) and that the four factors with eigenvalues above Kaiser's criterion of 1 explained 57.36 % of the variance. Two spatial episodic memory task loaded most strongly on other factors (OLM Pairs on verbal episodic memory, $r = .49$; Company Logos on visual perception, $r = .59$) instead of spatial episodic memory (OLM Pairs: $r = .24$; Company Logos: $r = .47$) and were therefore excluded from further analyses. Spatial episodic memory was thus finally represented by three tasks (Remembering Routes, Orientation Memory, OLM Recognition), verbal episodic memory by three tasks (Meaningful Text, Remembering Words, Fantasy Language), reasoning by four tasks (Analogies, Shape Selection, Transaction, Raven's Advanced Progressive Matrices), and visual perception by three tasks (Finding A's, Number Comparison, Identical Pictures).

Baseline group comparability regarding demographic, descriptive, and screening measures and transfer abilities, and group differences in the four subscales of the QCM across

T1 and T2 were analyzed with MANOVAs. Group differences in the trajectories of training motivation, arousal, and valence ratings, and within-group trajectories in training task performance across the 30 training sessions were analyzed with ANOVAs. Transfer effects were analyzed with linear mixed-effects (LME) models. LME models were fit in R (R Core Team, 2014) with the package “lme4” (Bates, Maechler, Bolker, & Walker, 2014). The degrees of freedom were estimated using Kenward-Roger approximation with the package “pbkrtest” (Halekoh & Højsgaard, 2014) to derive information about the significance of the predictors. MAD computations were done in MATLAB R2013b (Mathworks Inc., MA, USA). All other analyses were conducted with SPSS 20 (http://www.spss.com). The alpha level was set at .05 for all analyses.

Results

Missing Data

Five participants completed only 27 to 29 sessions (experimental group: one 29, one 27; active control group: two 29, one 28) because of technical and scheduling problems. These participants were excluded from the training measure analyses. Two participants of the experimental group completed one additional session (one in the second training phase, one in the follow-up period).

Transfer assessments were completed by all 67 participants with the exception of two participants (one of each group) who did not take part in follow-up testing because of medical reasons. The three completed cognitive assessments of these participants were included in the analyses.

Baseline Group Comparability

Demographics, descriptive, and screening measures. We conducted a MANOVA with group (OLM vs. active control) as between-subjects factor and all demographic, descriptive, and screening measures (except gender) as dependent variables. The effect of group was not significant, $F(16, 50) = 0.79$, $p = .686$, $\eta_p^2 = 0.20$. Table 1 lists the results of the planned pairwise group comparisons for each of these measures and of the chi-square test for gender, none of which were significant.

Transfer abilities. Table 3 lists the descriptive statistics for each transfer task and group from T1 to T4. To determine baseline group comparability, we conducted MANOVAs for each of the four abilities with group as between-subjects factor (OLM vs. active control) and with performance in the tasks measuring each ability at T1 as dependent variables. The effect of group was not significant for spatial episodic memory ($F(3, 63) = 0.55$, $p = .647$, $\eta_p^2 = 0.03$), reasoning ($F(4, 62) = 1.70$, $p = .162$, $\eta_p^2 = 0.10$), and visual perception, $F(3, 63) = 0.75$, $p = .527$, $\eta_p^2 = 0.03$. However, for verbal episodic memory, the effect of group was significant, $F(3, 63) = 4.36$, $p = .007$, $\eta_p^2 = 0.17$. Planned pairwise group comparisons on the level of single tasks revealed that the OLM group showed significant better baseline performance than the active control group in the Fantasy Language task, $M_{diff} = 1.89$, $p = .010$. Without this task, the effect of group on verbal episodic memory was no longer significant, $F(2, 64) = 2.00$, $p = .144$, $\eta_p^2 = 0.06$. We therefore excluded this task from further analyses. The pattern of results of the LME models on transfer effects was identical when this task was included.

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Table 3

Mean Performance in the Transfer Tasks and Mean Ratings on the Subscales of the Questionnaire on Current Motivation as a Function of Training Group and Time of Assessment

		OLM				Active Control			
Task	Max	T1	T2	T3	T4	T1	T2	T3	T4
Spatial Episodic Memory									
Orientation Memory	27	11.69 (3.50)	12.67 (3.23)	15.28 (4.23)	14.40 (3.41)	11.81 (3.61)	12.74 (3.28)	13.68 (3.40)	13.83 (3.40)
Remembering Routes	30	12.11 (4.36)	12.97 (3.85)	13.36 (5.07)	14.66 (4.96)	10.94 (4.36)	10.87 (3.86)	14.23 (4.86)	12.70 (3.79)
OLM Recognition	72	57.03 (4.71)	60.74 (4.19)	61.85 (4.05)	63.07 (3.97)	57.45 (5.21)	59.31 (6.47)	61.32 (4.23)	59.91 (4.61)
Verbal Episodic Memory									
Meaningful Text	22	6.89 (2.96)	8.44 (3.35)	10.61 (3.21)	9.89 (3.42)	7.23 (2.63)	9.29 (2.95)	10.16 (2.91)	9.73 (2.96)
Remembering Words	20	4.94 (1.67)	6.39 (1.87)	6.97 (2.05)	7.11 (1.91)	4.32 (1.87)	5.55 (1.93)	6.61 (1.93)	6.03 (1.65)
Fantasy Language	20	8.28 (3.23)	8.75 (3.95)	11.11 (3.54)	11.34 (3.90)	6.39 (2.53)	7.84 (3.43)	9.55 (4.00)	10.33 (3.09)
Reasoning									
Analogies	8	1.53 (1.30)	2.03 (1.56)	2.67 (1.55)	2.57 (1.75)	1.42 (1.29)	1.39 (1.17)	1.94 (1.36)	1.67 (1.24)
Shape Selection	6	2.17 (1.38)	2.33 (1.62)	2.39 (1.23)	2.49 (1.62)	1.55 (1.18)	2.00 (1.21)	2.32 (1.40)	2.00 (1.49)
Transaction	5	1.06 (0.92)	1.47 (1.18)	1.61 (1.15)	1.43 (0.98)	0.97 (0.80)	1.10 (0.94)	1.06 (1.15)	1.20 (1.03)
RAPM	12	5.81 (2.41)	6.25 (2.29)	6.28 (2.26)	6.77 (2.62)	4.68 (2.65)	5.35 (2.36)	5.35 (2.27)	5.60 (2.77)
Visual Perception									
Finding A's	200	56.50 (15.75)	62.08 (16.92)	62.78 (19.07)	61.51 (16.50)	55.97 (14.23)	60.90 (15.60)	64.71 (18.03)	63.47 (13.66)
Number Comparison	96	18.81 (5.26)	18.97 (5.36)	19.22 (4.94)	17.86 (6.86)	17.26 (5.92)	18.39 (6.41)	18.16 (6.07)	14.90 (10.89)
Identical Pictures	96	45.47 (12.07)	47.31 (11.55)	49.53 (12.15)	47.51 (13.78)	46.84 (8.02)	49.74 (8.49)	49.65 (9.07)	47.30 (8.15)
Questionnaire on Current Motivation									
Interest	35	32.03 (3.23)	29.89 (5.60)			31.90 (3.62)	31.00 (3.61)		
Challenge	28	25.56 (2.38)	24.56 (2.91)			24.58 (2.51)	23.03 (3.78)		
Expected Success	28	23.19 (2.96)	22.64 (4.46)			22.68 (3.28)	20.90 (4.21)		
Performance Anxiety	35	13.17 (5.25)	14.33 (7.23)			11.68 (6.27)	14.39 (6.97)		

Note. Means are provided alongside their standard deviations in parentheses. The Questionnaire on Current Motivation was administered only at T1 and T2. RAPM = Raven's Advanced Progressive Matrices.

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Training Measures

Training motivation and affect. Table 3 displays the descriptive statistics for the four QCM subscales of each group at T1 and T2. Across T1 and T2, both groups regarded their interest, challenge, and expectation to complete the training regime successfully as high and their performance anxiety as moderate. We conducted a MANOVA with group (OLM vs. active control) as between-subjects factor, time (T1, T2) as within-subject factor, and the four QCM subscales as dependent variables. The main effect of group was marginally significant, $F(4, 62) = 2.21$, $p = .078$, $\eta_p^2 = 0.13$[3]. There was a significant main effect of time ($F(4, 62) = 6.99$, $p < .001$, $\eta_p^2 = 0.31$), reflecting decreasing achievement motivation from T1 to T2, but no significant group x time interaction, $F(4, 62) = 1.60$, $p = .185$, $\eta_p^2 = 0.09$.

Figure 2 displays the trajectories of training motivation, arousal, and valence ratings in each group. Across the 30 training sessions, motivation was very high, arousal moderate, and emotional valence very positive in both groups. We conducted mixed ANOVAs with group as between-subjects factor (OLM vs. active control), time (30 sessions) as within-subject factor, and motivation, arousal, and valence ratings as separate dependent variables. Consistent across measures, the main effect of group was not significant (Fs ≤ 0.43, ps $\geq .513$). The main effect of time was significant for arousal ($F(29, 1740) = 3.04$, $p < .001$, $\eta_p^2 = 0.05$) and valence ($F(29, 1740) = 1.74$, $p = .041$, $\eta_p^2 = 0.03$), but was only marginally significant for motivation, $F(29, 1740) = 1.55$, $p = .098$, $\eta_p^2 = 0.03$. Although the group x session interaction was significant for motivation ($F(29, 1740) = 1.91$, $p = .027$, $\eta_p^2 = 0.03$) and valence ($F(29, 1740) = 2.44$, $p = .002$, $\eta_p^2 = 0.04$), it was not for arousal, $F(29, 1740) = 0.24$, $p = .625$, $\eta_p^2 < 0.01$. Figure 2 illustrates that motivation and valence ratings were relatively stable across training in the OLM training group, but followed a slight U-shaped function in the control

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[3] Follow-up ANOVAs on the four subscales revealed that the groups differed only in challenge across T1 and T2 ($F(1, 65) = 4.15$, $p = .046$, $\eta_p^2 = 0.06$; other: Fs ≤ 2.35, ps $\geq .130$), with the OLM group feeling more challenged than the active control group. However, the absolute differences in challenge ratings between the groups were only very small and, thus, hardly practical meaningful (about 1-1.5 out of maximally 24 points).

group. Trend analyses confirmed significant medium linear trends (motivation: $F(1, 27) = 9.63$, $p = .004$, $\eta_p^2 = 0.26$; valence: $F(1, 27) = 5.06$, $p = .033$, $\eta_p^2 = 0.16$) and large quadratic trends (motivation: $F(1, 27) = 10.72$, $p = .003$, $\eta_p^2 = 0.28$; valence: $F(1, 27) = 11.14$, $p = .002$, $\eta_p^2 = 0.29$) for the control group, but not for the OLM training group (Fs ≤ 2.11, ps $\geq .155$).

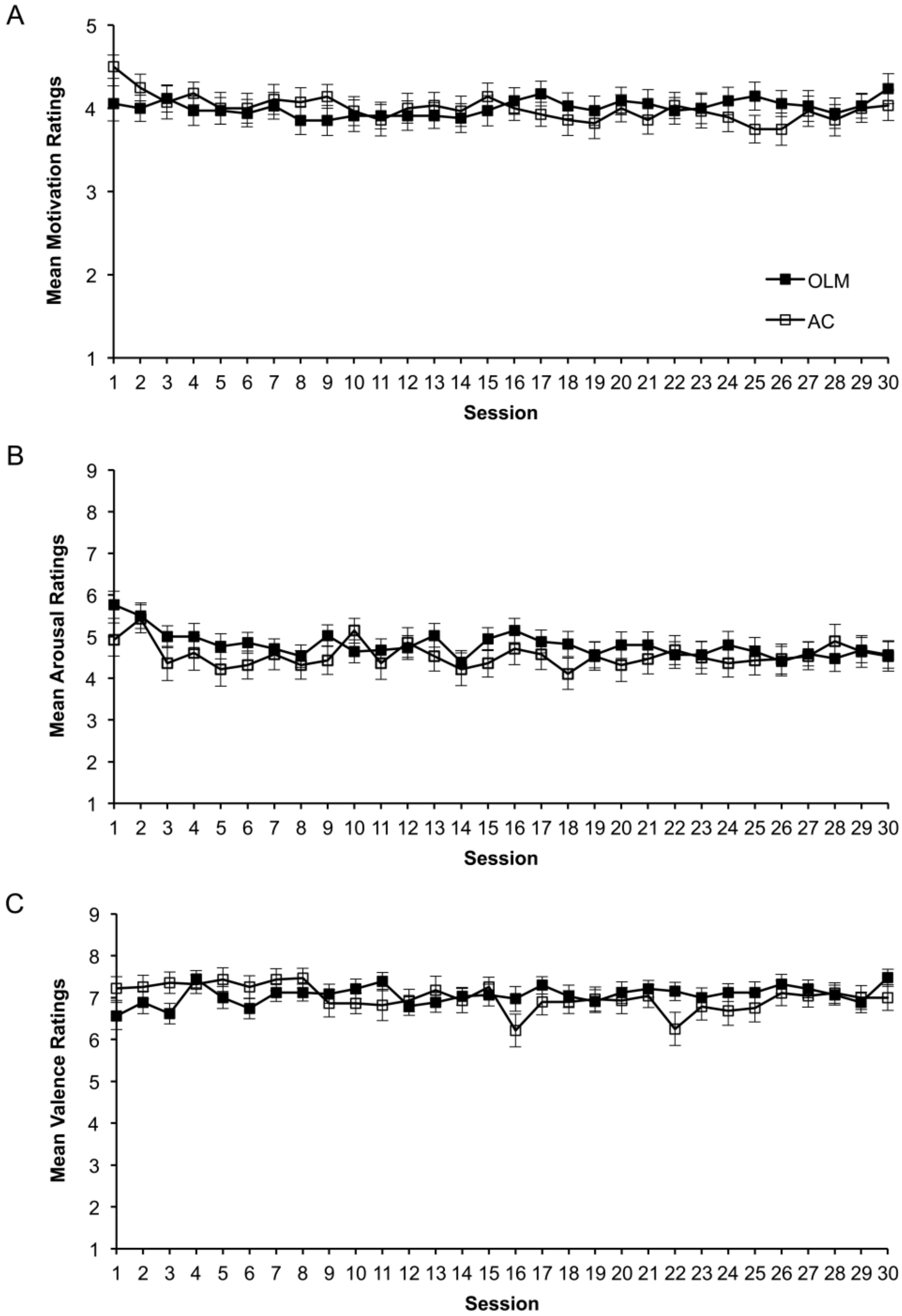

Figure 2. Mean ratings of A) motivation (scale: 1-5), B) arousal (scale: 1-9), and C) valence (scale: 1-9) of the two experimental groups in the 30 training sessions. Error bars represent standard errors of the mean (SEM).

Training performance. Figure 3 displays mean level of difficulty in the OLM training tasks and mean proportion of correctly solved items and mean reaction time in the visual perception control training tasks for each training session. We evaluated whether performance changed systematically with linear contrasts of session for each measure (see Table 4 for the descriptive statistics and results). We found significant large linear trends indicating increasing performance across sessions for all measures in both groups.

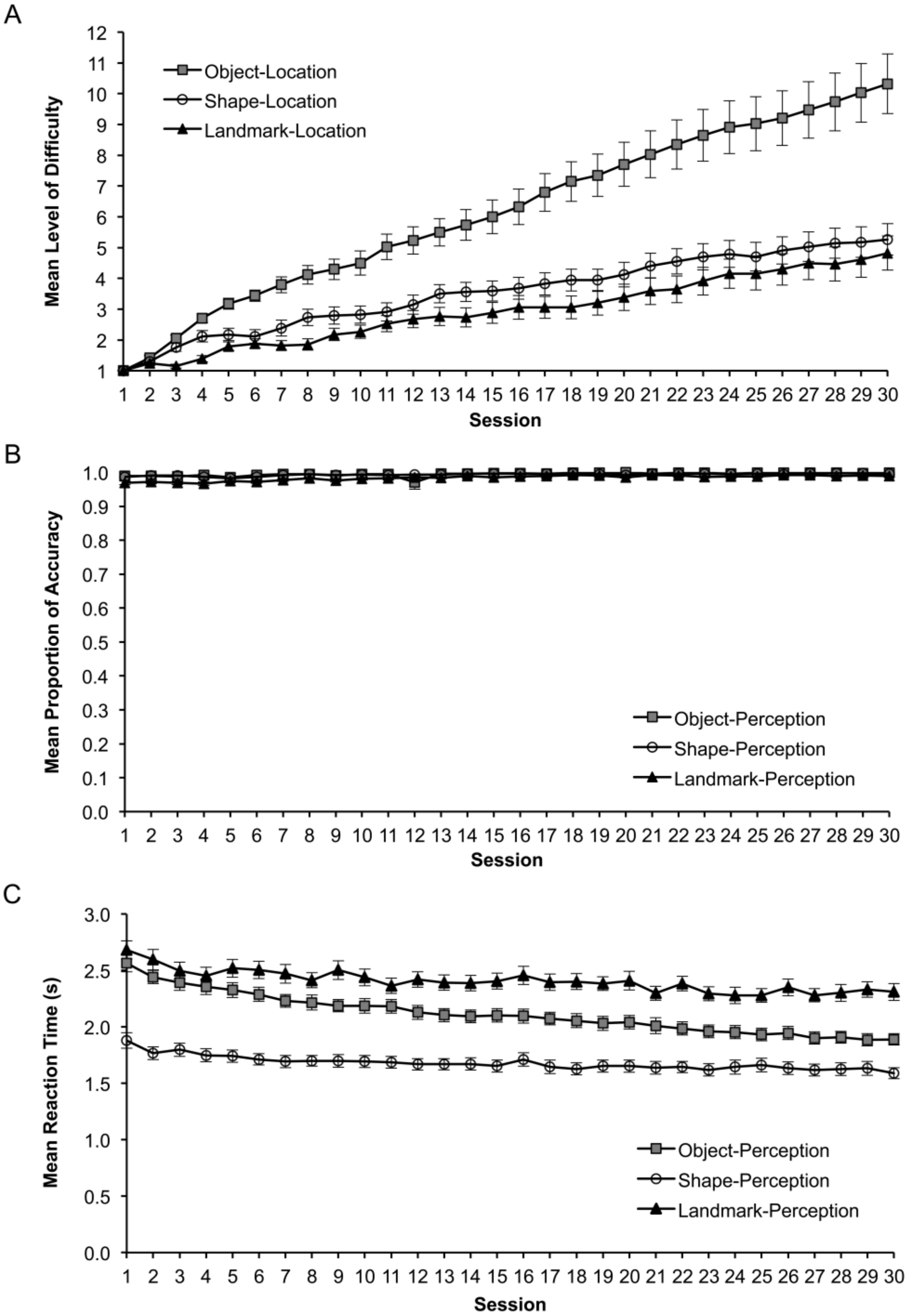

Figure 3. A) Mean level of difficulty in the three OLM training tasks in the 30 training sessions. B) Mean proportion of correctly solved items and C) mean reaction time (s) in the three active control training tasks in the 30 training sessions. Error bars represent standard errors of the mean (SEM).

Table 4

Linear Contrast Analyses for Performance Measures of the OLM and of the Control Training Tasks

Training Task	F^a	p	η_p^2	Session 1	Session 30

				M (SD)	*M (SD)*
		OLM Training Tasks: Level of Difficulty			
Object-Location	71.20	**<.001**	0.68	1 (0)	10.32 (5.66)
Shape-Location	78.02	**<.001**	0.70	1 (0)	5.26 (2.97)
Landmark-Location	40.45	**<.001**	0.55	1 (0)	4.82 (3.25)
		Control Training Tasks: Proportion of Accuracy			
Object-Perception	18.86	**<.001**	0.41	0.99 (0.02)	1.00 (<0.01)
Shape-Perception	14.30	**.001**	0.35	0.99 (0.03)	1.00 (0.01)
Landmark-Perception	37.71	**<.001**	0.58	0.97 (0.03)	0.99 (0.01)
		Control Training Tasks: Average Item Reaction Time			
Object-Perception	270.30	**<.001**	0.91	2.56 (0.40)	1.89 (0.27)
Shape-Perception	48.70	**<.001**	0.64	1.88 (0.37)	1.59 (0.26)
Landmark-Perception	87.05	**<.001**	0.76	2.68 (0.43)	2.31 (0.40)

Note. Significant *p*-values are printed bold.

[a] OLM training group: $F(1, 33)$, active control group: $F(1, 27)$.

Transfer Effects

Figure 4 illustrates the trajectory of mean effect sizes (Cohen's *d*) for performance gains in the administered tasks for each of the transfer abilities in each experimental group from T1 to T4. LME models were used to evaluate training-induced transfer gains on the level of cognitive abilities (i.e., spatial episodic memory, verbal episodic memory, reasoning, visual perception) rather than on the level of single tasks (cf. von Bastian & Oberauer, 2013). One advantage of LME models over more traditional analyses such as ANOVAs is that LME models can simultaneously account for multiple sources of variance in the data (for a more detailed discussion see Baayen, Davidson, & Bates, 2008). These sources of variance can be specified as fixed effects (e.g., experimental conditions) or random effects (accounting for the variability in sampling of individuals or tasks).

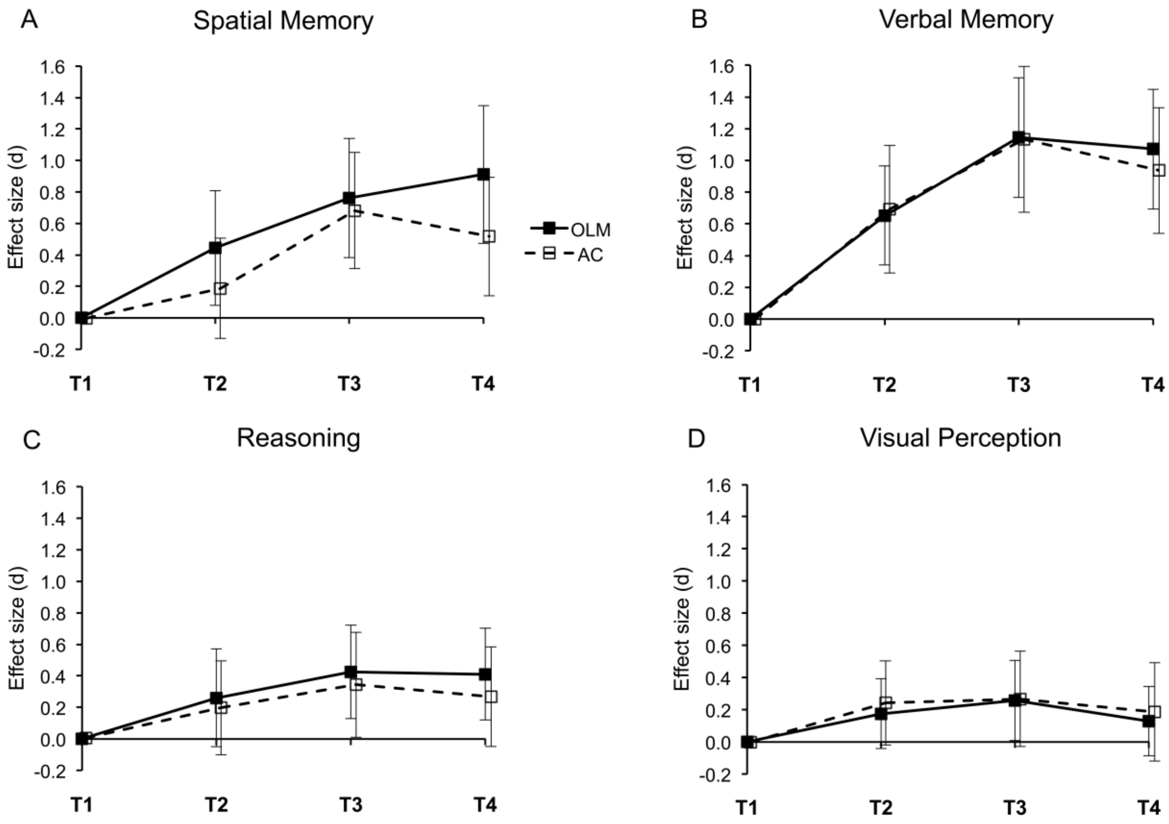

Figure 4. Trajectory of mean effect sizes (Cohen's d) of performance gains averaged across the tasks measuring each of the four transfer abilities from T1 to T4 for the two experimental groups. A) Spatial episodic memory (near transfer). B) Verbal episodic memory (intermediate transfer). C) Reasoning (far transfer). D) Visual perception (control for visual perception control training). Error bars represent 95% confidence intervals. Effect sizes for repeated measures and their confidence intervals were calculated using ESCI (Cumming, 2011).

As fixed-effects predictors, we entered group (OLM vs. active control) coded as simple contrast, time of assessment (T2, T3, and T4) coded as sliding contrast (Venables & Ripley, 2002), and baseline performance as centered continuous covariate. As crossed-random effects (Baayen, et al., 2008), we entered subject to account for random variability between individuals, and task to account for random variability between different tasks measuring the same ability. Following recent recommendations (Barr, Levy, Scheepers, & Tily, 2013), we attempted to fit the design-driven maximal random-effects structure with random effects for both intercepts (i.e., random variation around the overall mean of the dependent variable) and slopes (i.e., random variation in the size of effects of all predictors). As models including a random effect of task on the slope of group did not converge, the final models included only random effects of both subject and task on the intercept and on the slopes of time of assessment. Models including random effects only on the intercept yielded qualitatively the same results. Results of the final model are summarized in Tables 5 (fixed effects) and 6 (random effects).

Table 5

Parameter Estimates for Fixed Effects Related to the Transfer Measures

Predictor	*B*	*SE*	*t*	*p*
Spatial Episodic Memory				
Intercept	-0.01	0.05	-0.10	.922
Baseline	0.43	0.04	10.99	< **.001**
Group[a]	0.24	0.11	2.28	**.030**
T3[b]	0.41	0.08	5.25	< **.001**
T4[b]	-0.04	0.08	-0.49	.629
Group[a] x T3[b]	-0.13	0.16	-0.80	.429
Group[a] x T4[b]	0.29	0.16	1.85	.075
Verbal Episodic Memory				
Intercept	0.00	0.06	-0.04	.968
Baseline	0.48	0.05	9.65	**.003**
Group[a]	0.13	0.13	1.04	.376
T3[b]	0.45	0.08	5.34	**.014**
T4[b]	-0.14	0.08	-1.69	.193
Group[a] x T3[b]	0.08	0.17	0.47	.670
Group[a] x T4[b]	0.15	0.17	0.89	.441
Reasoning				
Intercept	-0.01	0.06	-0.19	.850
Baseline	0.39	0.03	12.12	< **.001**
Group[a]	0.26	0.12	2.20	**.031**
T3[b]	0.14	0.09	1.67	.100
T4[b]	-0.02	0.07	-0.32	.746
Group[a] x T3[b]	0.01	0.12	0.09	.929
Group[a] x T4[b]	0.05	0.12	0.42	.678
Visual Perception				
Intercept	0.00	0.04	0.11	.915
Baseline	0.69	0.03	21.64	< **.001**
Group[a]	-0.01	0.08	-0.14	.889
T3[b]	0.08	0.07	1.12	.275
T4[b]	-0.19	0.08	-2.36	**.028**
Group[a] x T3[b]	0.03	0.13	0.25	.805
Group[a] x T4[b]	0.10	0.13	0.76	.458

Note. Significant *p*-values are printed bold.
[a]OLM group contrasted against the active control group.
[b]Contrasted against the preceding time of assessment.

Table 6
Parameter Estimates for the Random Effects Related to the Transfer Measures

Random Effect	*SD*			
	Spatial Episodic Memory	Verbal Episodic Memory	Reasoning	Visual Perception
Subject				
Intercept	0.34	0.43	0.43	0.27
T3[a]	0.06	0.13	0.04	0.11
T4[a]	< 0.01	0.09	0.11	0.06
Task				
Intercept	0.00	0.00	0.00	0.00
T3[a]	< 0.01	< 0.01	0.13	0.05
T4[a]	< 0.01	< 0.01	0.07	0.08
Residual	0.78	0.67	0.68	0.62

[a] Contrasted against the preceding time of assessment.

Spatial episodic memory (near transfer). The significant effect of the baseline covariate (b = 0.43, p < .001) reflects that performance at T2-T4 is positively correlated with baseline performance. The predictor for the group contrast was significant (b = 0.24, p = .030) over and above this relationship, indicating that, across T2-T4, the OLM group performed better in the spatial episodic memory tasks than the active control. The effect of T3 contrasted against T2 was also significant (b = 0.41, p < .001), which means that performance was - irrespective of group membership - better at T3 than at T2. After T3, performance did not change significantly.

Verbal episodic memory (intermediate transfer). Baseline performance significantly predicted performance across T2-T4 (b = 0.48, p = .003). Performance increased irrespective of group membership significantly from T2 to T3 (b = 0.45, p = .014). No significant group differences and no significant group x time interactions were observed.

Reasoning (far transfer). Over and above the significant effect of baseline performance (b = 0.39, p < .001), the OLM group performed significantly better than the active control ($b = 0.26$, $p = .031$) across T2-T4. Neither the effects of time nor the group x time interactions reached significance, indicating that performance of both groups was relatively stable across T2-T4.

Visual perception (control). Baseline performance significantly predicted performance across T2-T4 ($b = 0.69$, $p < .001$). There was a significant decrease in performance irrespective of group membership from T3 to T4 ($b = -0.19$, $p = .028$). No significant group differences and no significant group x time interactions were observed.

Taken together, the results suggested that the OLM group improved more than the active control in spatial episodic memory (near transfer) and reasoning (far transfer) across T2 through T4, but not in verbal episodic memory (intermediate transfer). There were no group differences in visual perception (control) performance across T2 to T4. Whereas general additional performance increases were observed from T2 to T3 in both spatial and verbal episodic memory, this was not the case for reasoning (performance remained relatively stable across T2-T4) and visual perception (performance decreased from T3 to T4). However, none of the group x time interactions (i.e., T3 vs. T2 or T4 vs. T3) were significant, indicating that change in performance was similar for both training groups.

Discussion

The aim of this study was to investigate whether process-based training of the ability to encode and retrieve associations between simultaneously processed information units from long-term memory (operationalized by OLM) in healthy older adults improves performance in the trained tasks and induces enduring transfer effects to episodic memory and reasoning. To evaluate transfer effects, we included an active control group completing a visual perception training intervention with the same stimuli and duration as the OLM training intervention, and administered a cognitive test battery before, in the middle (after 15 training sessions), at the end (after 30 training sessions), and four months after training. The test battery included tests assessing spatial episodic memory, verbal episodic memory, and reasoning, which according to the transfer framework by Noack et al. (2009) represent near, intermediate, and far transfer. In addition, to demonstrate discriminant validity, visual perception tests were administered. Transfer effects over the course of training until follow-up were analyzed on the level of cognitive abilities indicated by at least two heterogeneous tests with linear mixed effect models. We predicted that process-based OLM training would lead to large and linear performance improvements in the trained tasks. According to the associative deficit hypothesis and to findings showing that associative episodic memory contributes to reasoning performance, OLM training could potentially induce near, intermediate, and far transfer, but the few available studies on process-based episodic memory training in older adults generally failed to demonstrate any transfer. We did not expect OLM training to yield transfer to visual perception and the visual perception control intervention, if at all, to induce near transfer to visual perception only.

Training Gains

As predicted, performance increases in the trained OLM tasks across the 30 training sessions were large and linear, indicating room for even further improvement with longer training in all three training tasks. Our findings are in line with previous studies on process-based episodic memory training (Jennings & Jacoby, 2003; Jennings et al., 2005; Lövdén et al, 2012; Stamenova et al., 2014) and those on process-based working memory and executive function training in healthy older adults (Karbach & Verhaeghen, 2014). Our results thus demonstrate that older adults' performance in encoding and retrieving visuo-spatial associations from long-term memory can be successfully improved by process-based training.

Transfer Effects

We found that process-based OLM training induced transfer to spatial episodic memory and reasoning, but not to verbal episodic memory. Thus, according to the transfer framework by Noack et al. (2009), it yielded near and far, but no intermediate transfer effects. From a theoretical perspective, it is unclear why we observed this pattern of transfer. The ability to encode and retrieve associations between simultaneously processed information units from long-term memory has been shown to be impaired in old age across all types of material (Old & Naveh-Benjamin, 2008) and, according to the associative deficit hypothesis (Naveh-Benjamin, 2000), underlies episodic memory deficits of older adults in general. However, considering the finally included indicators for the three transfer abilities, our results suggest both domain- and process-specificity of OLM training. More specifically, successful performance in the OLM training tasks and the spatial episodic memory and reasoning tasks depended on the encoding and retrieval of *self-generated* associations between simultaneously processed *visuo-spatial* information units from long-term memory. In contrast, the finally included verbal episodic memory tasks primarily required processing of *semantically* related *verbal* information. Indeed, associative memory processes seem to contribute little to performance in episodic memory tasks with semantically related verbal information such as texts or word lists (see Saling, 2009), with several studies reporting reduced or even non-existing performance decrements in older adults for semantically related in comparison to unrelated word pairs (e.g., Badham, Estes, & Maylor, 2012; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Patterson, Light, Van Ocker, & Olfman, 2009). Consequently, reasoning rather than verbal episodic memory transfer tasks overlapped to a greater degree with the OLM training tasks in terms of material and required cognitive processes, possibly explaining why we found transfer to reasoning, but not to verbal episodic memory. Transfer of OLM training may more likely occur for verbal episodic memory if measured by tasks requiring associative memory processes, and less likely occur for reasoning if assessed by verbal tasks.

There are two further, potentially complementary explanations for the observed pattern of transfer. First, different associative memory processes may be involved in OLM, spatial episodic memory, and spatial reasoning than in verbal episodic memory. Mayes, Montaldi, and Migo (2007) suggested that there are functional differences between remembering between-domain and within-domain associations. Lesion and neuroimaging studies indicate that different neural networks support these two types of memory. Process-based OLM training practices encoding and retrieving of between-domain associations (associations between visual (objects) and spatial (locations) information). Hence, it should yield transfer to abilities which involve remembering between-domain associations such as spatial episodic memory or spatial reasoning, but not to abilities which require remembering within-domain associations, including verbal associative episodic memory or verbal reasoning.

Second, because the correct retrieval of object-location associations depends on the retention of both objects and locations in memory (Postma et al., 2008), OLM training practices also memory for objects and memory for locations alongside associative memory. Object memory and location memory are also involved in spatial episodic memory, but not in verbal episodic memory. Moreover, object memory and location memory have been shown to strongly correlate with reasoning, even when measured by verbal tasks only (Siedlecki & Salthouse, 2014). Consequently, transfer of process-based OLM training to verbal reasoning may be even more likely than transfer to verbal episodic memory.

The potential explanations outlined above should be tested in future studies. For example, one could investigate the transfer effects of process-based OLM training on verbal episodic memory tasks with semantically related *and* unrelated information or on verbal *and* spatial reasoning tasks. Furthermore, one could compare transfer effects of memory training for within-domain versus between-domain associations, or transfer effects of OLM training versus object memory or location memory training.

Although performance gains in accuracy and speed in the visual perception control training tasks were linear and large across the training period, we found no significant differences between the training groups in transfer to visual perception. In the visual perception transfer tasks, different stimuli (words, numbers, geometrical figures) were presented than in the visual perception and OLM training regimes. Thus, our results indicate material-specific effects of visual perception training, which is in line with the limited research on visual perception training in older adults (Andersen, Ni, Bower, & Watanabe, 2010). On the other hand, the absent transfer of OLM training to visual perception implies that the positive transfer of this intervention to spatial episodic memory and reasoning was not driven by improvements in visual perception, but in associative memory.

Process-based OLM training seems to lead to lasting improvements in spatial episodic memory and reasoning ability in older adults, given that transfer effects to these abilities remained stable from post-training to the four-month follow-up.

Our findings stand out from the few prior studies on process-based episodic memory training interventions in healthy older adults (Jennings et al., 2005; Lövdén et al, 2012; Stamenova et al., 2014) which have generally failed to demonstrate transfer to untrained cognitive tasks, including those assessing episodic memory and reasoning. An advantage of our study was that we evaluated transfer effects on the level of cognitive abilities rather than with single cognitive tasks. Moreover, in contrast to previous process-based episodic memory training studies, the selection of trained and assessed transfer cognitive abilities was based on clear theoretical assumptions and empirical evidence on their relationships to one another. Finally, our intervention may have targeted episodic memory processes more effectively than previous interventions.

Limitations

A limitation regarding the performance gains in the trained OLM tasks is that we do not know which level of difficulty the participants were able to complete at baseline. Because all participants started training on a relatively low level of difficulty, we cannot disentangle whether their performance gains in the trained tasks reflect achievement of their true initial capacity or improvements beyond their initial capacity. To avoid this confound, in other studies criterion tasks (i.e., test versions of the experimental training tasks with medium difficulty) were administered before and after training (e.g., Brehmer, Westerberg, & Bäckman, 2012; Lövdén et al, 2012; von Bastian & Eschen, 2016; von Bastian, Langer, Jäncke, & Oberauer, 2013). Another possibility would be to provide participants with an individual initial level of difficulty reflecting their baseline capacity. Future studies should therefore follow one of the above approaches to capture performance gains beyond initial capacity.

One limitation to our transfer results is that, in contrast to OLM training, visual perception control training was not adaptive. It has been argued (e.g., Shipstead & Engle, 2012; von Bastian & Oberauer, 2014) that the use of non-adaptive controls potentially overestimates transfer effects, because non-adaptive training may be less motivating than adaptive training and thus control training participants may expend less training effort. However, if this had been the case, transfer effects to all outcome abilities should have been observed, not only to spatial episodic memory and reasoning. Moreover, we observed comparable achievement motivation during the first training half and, although training motivation and valence were more stable in the OLM training group than in the control group, no general group differences in these measures and arousal across the entire training period. Furthermore, we found large linear performance gains across training sessions in both groups, suggesting that the control group expended comparable training effort as the OLM training group. Therefore, transfer effects of OLM training were more likely driven by improved associative memory processes rather than differences in motivation or training effort.

A second limitation regarding our transfer results is that we used identical cognitive tests across T1-T4. As these tests were administered for three times within nine weeks from

T1 to T3, relatively strong retest effects may have obscured possible transfer effects. The improvements in spatial and verbal episodic memory performance across the two groups from T2 to T3 are probably caused by such retest effects. However, to the best of our knowledge, there are no test batteries currently available which include at least three heterogeneous tasks for each of the four selected outcome abilities *and* four parallel versions of these tasks. We refrained from constructing such parallel versions because of the complexity of such an endeavor, the uncertainty whether demonstrated equality of parallel versions in a calibration sample would also be found in the study sample, and the difficulty of achieving an equal distribution of the four parallel tasks versions across T1-T4 and the two experimental groups.

Finally, it is unclear whether OLM training would yield similar positive transfer effects in the general population of older adults and whether such effects would produce meaningful improvements in everyday cognitive tasks. Our sample was relatively young (60-75 years), did not suffer from neurological or mental disorders, was highly educated, and had slightly above-average cognitive abilities as indicated by the screening tests. However, in previous research, age did not consistently predict the magnitude of training and transfer gains of process-based working memory or executive functioning training in healthy older adults (Karbach & Verhaeghen, 2014). Moreover, training and transfer gains tend to be larger in patients with neurological and mental disorders (Weicker, Villringer, & Thöne-Otto, 2016) and in healthy older adults with relatively low initial cognitive status (von Bastian & Oberauer, 2014). Hence, OLM training may yield even larger training and transfer effects in less healthy and cognitively less fit older adults.

Conclusions

The present study provides first empirical evidence that process-based training of the ability to encode and retrieve associations from long-term memory in healthy older adults can induce transfer to untrained episodic memory and reasoning tasks, and that these transfer effects are largely maintained for four months after training. However, improvements during process-based OLM training transferred only to visuo-spatial episodic memory and visuo-spatial reasoning, but not to verbal episodic memory. This can possibly be explained by the following reasons: a) the trained associative memory processes contributed only little to performance in the verbal episodic memory tasks which included semantically related verbal information, b) functional differences between the ability to remember within-domain associations, which is important for verbal episodic memory, and the ability to remember between-domain associations, which was practiced in OLM training, or c) transfer of OLM training was caused by practice of both associative and visuo-spatial item memory processes. Replication studies using larger and less selective samples, and transfer tasks allowing for more precise differentiation of the above explanations are needed to determine the long-term impact and limitations of process-based training of the ability to encode and retrieve associations from long-term memory in healthy older adults. However, taken together, the present study offers reason for optimism that such training is a promising novel avenue to counteract age-related declines in episodic memory and reasoning.

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