Published in final edited form as:
Neuron. 2011 December 8; 72(5): 688–691. doi:10.1016/j.neuron.2011.10.022.

Can cognitive training improve episodic memory?

Charan Ranganath, **Kristin E. Flegal**, and **Laura L. Kelly**
Center for Neuroscience, University of California at Davis

Summary

Neuroscience-inspired approaches to train cognitive abilities are bringing about a paradigm shift in the way scientists view the treatment of memory dysfunction, but it can be challenging to prove whether such approaches have significant effects.

Episodic memory, the ability to remember a past event, is essential to the performance of numerous tasks, such as recalling the name of someone you have previously met, remembering the current date, or remembering to go to an appointment in the near future. Given the importance of memory, and its sensitivity to the effects of age and neurological insult, it is not surprising that there is widespread demand for interventions to improve memory abilities.

Until recently, the most popular approach to memory improvement had been to simply train people in effective mnemonic strategies. There is a strong theoretical basis for this approach, and studies have generally found that strategy training can improve memory (Lustig et al., 2009; Rebok et al., 2007). One limitation to strategy training, however, is that many effective mnemonic strategies are designed to work within a specific domain and do not always generalize to new situations. A second and more significant limitation is that even when people know appropriate strategies for optimizing learning they do not always use them. Spontaneous initiation of mnemonic strategies seems to depend on cognitive control, and therefore people with cognitive control deficits (e.g., older adults) might have knowledge about strategies but still fail to spontaneously use them (Brigham and Pressley, 1988). Because of these well-known limitations of strategy training, researchers are now investigating whether it is instead possible to directly train the *abilities* thought to support memory.

Ability Training

There is general agreement that memory is supported by a set of abilities, any of which can be adversely affected by aging or neurological insult. Ability training approaches are based on the premise that performance of tasks that tax these cognitive abilities can lead to improvements in function (Klingberg, 2010; Lustig et al., 2009; Mahncke et al., 2006a). Intuitively, an obvious target might be the ability to form and retrieve representations of episodes, which is thought to depend on the medial temporal lobes (MTL) (Eichenbaum et al., 2007). However, it is generally believed that memory formation and retrieval constantly

Please address correspondence to: Charan Ranganath, Ph.D., UC Davis Center for Neuroscience, 1544 Newton Ct., Davis, CA 95618, cranganath@ucdavis.edu.

engage the MTL, even when one is not attempting to do so. Thus, it is not clear whether repeated performance of episodic encoding and retrieval tasks would further tax MTL function and result in general improvements in memory. Instead, research has largely focused on processes that contribute to effective memory encoding and retrieval.

For instance, one view is that memory impairments in aging and in many clinical disorders reflect a "downstream" consequence of primary sensory deficits. According to this view, the fidelity of sensory inputs degrades with age and may be affected by various neurological and psychiatric conditions. Peripheral sensory deficits, in turn, could lead to degraded encoding of events and possibly impaired episodic memory performance (Mahncke et al., 2006a). Thus, if perceptual abilities can be improved through training tasks (e.g., phoneme discrimination with degraded stimuli), this could lead to improved memory encoding. Working from this premise, some companies have designed products aimed at improving perceptual abilities through cognitive training. For example, Posit Science (http://www.positscience.com/) has developed an intervention program using computerized tasks that place increasing demands on perceptual processing (as well as other modules which emphasize more high-level processing). This program is based in part on findings that, even in the adult brain, there is substantial plasticity in primary sensory regions (Mahncke et al., 2006a).

A strength of perceptual training approaches is that they target a potential cause of memory problems in the real world whose impact may be underestimated in laboratory experiments. In laboratory or clinical settings, researchers typically try to ensure that stimuli to be learned are highly discriminable, but in the real world, the stimuli that we encounter are often embedded in noisy contexts (such as words spoken in a loud room, or a face that is seen under poor lighting conditions). That said, it is important to point out that perceptual degradation might not be a primary cause of memory impairments seen over the course of normal aging or in memory disorders (Murphy et al., 2000).

Another approach to ability training is based on evidence showing that the prefrontal cortex (PFC) plays a critical role in successful episodic memory encoding and retrieval (see Ranganath and Blumenfeld, 2008, for review). Recent work has demonstrated that prefrontal functioning can be improved through behavioral training. For instance, intensive working memory (WM) training has been shown to increase PFC activation during a WM task (Olesen et al., 2004), and there is some evidence to suggest that such training procedures can lead to improvements on untrained tests of executive function, reasoning, and WM (Klingberg, 2010, but see Owen et al., 2010).

Regardless of the kind of training procedure that is adopted, it is reasonable to ask whether it is even possible to train an *ability* or cognitive process, as opposed to training performance on a specific *task*. Ability training is based on the premise of capitalizing on neural plasticity to improve function (Klingberg, 2010; Mahncke et al., 2006a). Strictly speaking, plasticity operates at the level of synapses, not abilities. Repeated performance of a task could lead to strengthening of cell assemblies that represent task-relevant information. It is not clear, however, whether these cell assemblies would support performance outside of the context of the trained task.

We can envision at least two scenarios by which cognitive training can elicit results that transfer to real-world situations. First, generalization could occur if the training tasks closely approximate the real-world situation in question (e.g., training in phoneme discrimination to improve real-world speech perception). Second, training could result in generalized benefits if it increases the ability to engage a beneficial process that is not usually engaged. For instance, practicing tasks that place demands on cognitive control processes might make one more likely to proactively engage these processes rather than waiting until conflict is detected (Lustig and Flegal, 2008; Paxton et al., 2006).

Does ability training improve episodic memory?

Although numerous studies have investigated the effects of ability training on WM or cognitive control in healthy individuals, few have specifically investigated the effects of training on episodic memory. Generally, the existing literature indicates positive effects of training on the measures that were trained, but the extent of generalization to untrained measures of episodic memory varies considerably across studies.

The efficacy of the Posit Science program on improving memory performance in older adults was tested in an initial study that compared a training group (performing computerized tasks that emphasize auditory perception, and also include modules that tax short-term and long-term memory) against an active control group (viewing DVDs on history, art, and literature), and a no-contact control group (Mahncke et al., 2006b). Memory performance was assessed using a standardized battery (the RBANS), and the trained group showed significant improvements in tasks that used auditory stimuli (mean effect size =.25), whereas no significant improvement was seen for the control groups. In a second study (Smith et al., 2009), a larger scale multi-site double-blind trial, a broader range of outcome measures was used and results again showed that performance on auditory verbal memory tests was improved following training (effect sizes ranging from .2–.3). It should be noted, however, that in both studies, memory improvements were restricted to measures of auditory verbal memory, and episodic memory was not extensively assessed with stimuli in other modalities.

Executive function has also been targeted for ability training in older adults, typically using WM tasks thought to rely on PFC. In one such intervention, relative to a physical activity control condition, WM training was found to produce significant improvements in visual WM and to transfer to an untrained visual episodic memory task (Buschkuehl et al., 2008). Another variant of executive function training is the “recollection training” procedure introduced by Jennings & Jacoby (2003), in which participants repeatedly perform verbal recognition tests. The manipulation in this procedure is that some unstudied items are repeated during each test, so participants must discriminate studied items from highly familiar repeated lures. This procedure taxes executive function in the sense that participants are forced to suppress prepotent responses based on familiarity, and instead make decisions based on the recollection of contextual information. Available evidence shows that healthy older adults exhibit reliable improvement on the trained task, although evidence for a generalized benefit to episodic memory is relatively weak (Jennings et al., 2005; Lustig and Flegal, 2008).

The most prominent negative finding in studies of ability training was reported by Owen and colleagues (2010). The training procedures in this study targeted multiple cognitive abilities in two experimental groups. The critical finding was that, although training was associated with reliable improvements on the training tasks, no evidence was seen for generalization to closely related measures, including a test of episodic memory. This null effect could not be attributed to low statistical power (see next section), because the training program was administered online to a sample of 11,430 adults. One counterargument is that the training procedures in this study did not adequately engage processes that would impact episodic memory – although one might expect at least some of these tasks (e.g., WM, attention) to have some effect. Another potential limitation of this study was that participants completed the tasks remotely via a web portal, and thus the amount of training completed by each participant was not directly controlled. Owen et al. (2010) discounted the number of training sessions as a critical variable, as it was not significantly correlated with the amount of improvement on the transfer tasks (despite the fact that training time correlated with improvement on the trained tasks). Still, it is possible that the duration of each session was too short to elicit meaningful effects, or alternatively, that generalization emerges in a nonlinear manner over the course of training.

Take it with a grain of salt

As noted above, the evidence is mixed regarding the extent to which behavioral interventions can lead to generalized improvements in episodic memory in healthy adults. Complicating matters further, there are several factors that make it difficult to make strong conclusions about either the positive or negative findings.

For example, the efficacy of an intervention could be exaggerated if participants who dropped out of the training protocol were not included in the results. More generally, the efficacy of an intervention might be overestimated in the literature if researchers fail to publish studies that do not observe significant training effects (“the file drawer effect”). Another potential issue is the extent to which the generalized effects of an intervention might be mediated by “placebo” effects. For instance, participants who are receiving cognitive training might have more contact with research staff or perform tasks that are more likely to give the impression of belonging to an “active” intervention as compared with the control group. These factors could increase the expectation of benefit amongst participants in the active training group, which in turn might lead to improved cognitive performance (de la Fuente-Fernandez et al., 2002).

In addition to reasons why effect sizes might be overestimated, there are also reasons why studies might fail to identify an effective cognitive intervention. The simplest reason is a lack of statistical power. In general, cognitive intervention studies are expensive and challenging to implement because participants must be trained over a sustained period of time. Because of the challenges in recruiting and retaining participants across the duration of the study, it is difficult to run a well-controlled cognitive intervention study with adequate statistical power.

A second issue to consider is the role of moderating variables. For instance, just as dosage and treatment duration are important moderating variables in studies of pharmacological interventions, the length and number of training sessions could moderate the efficacy of behavioral interventions. Another relevant variable is the participant’s initial level of functioning or degree of cognitive deficit. For example, high-functioning individuals who have a greater capacity for plasticity might show greater training gains than lower-functioning individuals. Alternatively, lower-functioning individuals could benefit more because they have more room for improvement, whereas high-functioning individuals are already performing optimally. Consistent with the first hypothesis, Bissig and Lustig (2007) found that elderly individuals who spontaneously used elaborative memory encoding strategies (possibly indicative of higher cognitive function) showed the largest effects of a memory training intervention.

A third issue to consider is mundane, but important: the outcome measures of memory performance. Often, researchers choose outcome measures that strike a compromise between reliability, ease of administration, and predictive validity. For instance, clinical tests, such as the RBANS, are designed to be fast and reliable, but they are not necessarily sensitive to specific memory processes. Such measures might underestimate the efficacy of an intervention that specifically targets particular aspects of memory (e.g., recollection, prospective memory, etc.). Fortunately, researchers are currently adapting paradigms from basic cognitive neuroscience research that have high construct validity so that they can be easily administered in clinical trials (Carter and Barch, 2007).

Unresolved questions

In general, there are several important questions that need to be addressed in future studies of ability training. One question is whether behavioral interventions should be geared towards *remediation* of cognitive deficits or towards *compensation* by focusing on abilities that are relatively spared. A related, and equally important, question is whether to adopt a “one size fits all” approach to ability training or whether the choice of a particular intervention should be tailored to specific situations. We suspect that the optimal intervention might depend on the subject population that is to be targeted. Sensory ability training might be optimal for disorders such as dyslexia in which sensory dysfunction may be a critical limitation to normal learning and memory. Training approaches that target cognitive control, on the other hand, might be better suited for addressing “normal” age-associated memory decline and in patients with memory impairments associated with schizophrenia and depression.

Another issue that merits further thought is how to assess the outcome of a memory intervention. The benchmarks for a successful outcome might depend on the type of problem that is being addressed. For instance, a large proportion of elderly individuals may be expected to show declines in memory performance over time due to the progression of dementing disorders or due to cerebrovascular disease. In these populations, it may be more realistic to ask whether cognitive training can forestall cognitive decline, rather than whether memory can be improved (Lustig et al., 2009). One could also gauge the success of a memory intervention in terms of the minimum “dosage” required to obtain an effect and in terms of the duration of the beneficial effects of training. It might be unreasonable, however, to expect that any cognitive intervention will have long-lasting effects with a minimal time investment. For instance, there is considerable evidence that aerobic exercise has beneficial effects on brain function and cognition, but it would be unreasonable to expect benefits of a brief exercise program to last after several years of sedentary living. Following the analogy between training of cognitive and physical abilities, the beneficial effects of cognitive ability training might depend on continued engagement of that ability.

Recommendations for Future Studies

Although there are important questions about whether behavioral interventions can improve memory performance, we believe that the evidence is sufficiently promising to merit future research. Based on the methods used in studies that reported positive effects and based on general principles from memory research, we recommend the following guidelines for research on and development of effective memory interventions:

1. Use multiple training tasks to avoid overspecialization. It is not difficult to show that people can get better at a single memory task with extensive practice, but it is more challenging to find training effects that will generalize to novel contexts. Training on only a single task might lead to the development of strategies that exploit knowledge of the specific types of stimuli, response modalities, or rules of the task. By using multiple tasks that tap the same process but have different rules, stimuli and response modalities, researchers can increase the likelihood that training will facilitate the development of abilities that are common to all of the tasks.

2. Start training at a relatively low level and increment difficulty as performance improves. This adaptive difficulty approach is likely to reduce participant frustration or boredom (and hence attrition).

3. Consider the effects of individual differences. There is substantial intersubject variability in the effects of cognitive training, perhaps due to differences in abilities, motivation, or both. This variability can mask the effects of an effective intervention. Potential solutions are to vary the duration of training (i.e., number and/or length of sessions) so that all participants reach a criterion level of performance, or, if training duration is fixed, to factor individual differences in training-related improvement when assessing outcome.

4. Use multiple benchmark measures (combined with functional/structural neuroimaging, if possible) to determine whether training effects generalize to non-trained memory tasks.

5. Assess the role of nonspecific factors. Ideally, studies should include a placebo control group that receives the same amount of interaction with experimenters and expectation of benefit but lacks the critical factor thought to mediate improvement. At a minimum, studies should include a no-treatment group to control for practice effects on the outcome measures. Nonspecific factors can also be assessed by including benchmark measures of processes for which no training effect is expected.

Concluding thoughts

Scientists have made significant breakthroughs in clarifying the cognitive processes that influence episodic memory. It is exciting to think that these developments in basic science may be translated to have a tangible impact on memory abilities. Although many challenges need to be dealt with in order to achieve this goal, the potential impact of this work clearly makes the effort worthwhile.

Acknowledgments

This work was supported by grant R01MH068721. Thanks to Marjorie Solomon and Sophia Vinogradov for helpful comments on earlier drafts.

References

Bissig D, Lustig C. Who benefits from memory training? Psychol Sci. 2007; 18:720–726. [PubMed: 17680944]

Brigham MC, Pressley M. Cognitive monitoring and strategy choice in younger and older adults. Psychol Aging. 1988; 3:249–257. [PubMed: 3268266]

Buschkuehl M, Jaeggi SM, Hutchison S, Perrig-Chiello P, Dapp C, Muller M, Breil F, Hoppeler H, Perrig WJ. Impact of working memory training on memory performance in old-old adults. Psychology and Aging. 2008; 23:743–753. [PubMed: 19140646]

Carter CS, Barch DM. Cognitive neuroscience-based approaches to measuring and improving treatment effects on cognition in schizophrenia: the CNTRICS initiative. Schizophrenia Bulletin. 2007; 33:1131–1137. [PubMed: 17630405]

de la Fuente-Fernandez R, Schulzer M, Stoessl AJ. The placebo effect in neurological disorders. Lancet Neurol. 2002; 1:85–91. [PubMed: 12849512]

Eichenbaum H, Yonelinas AP, Ranganath C. The Medial Temporal Lobe and Recognition Memory. Annu Rev Neurosci. 2007; 30:123–152. [PubMed: 17417939]

Jennings JM, Jacoby LL. Improving memory in older adults: Training recollection. Neuropsychological Rehabilitation. 2003; 13:417–440.

Jennings JM, Webster LM, Kleykamp BA, Dagenbach D. Recollection Training and Transfer Effects in Older Adults: Successful Use of a Repetition-Lag Procedure. Aging, Neuropsychology, and Cognition. 2005; 12:278–298.

Klingberg T. Training and plasticity of working memory. Trends Cogn Sci. 2010; 14:317–324. [PubMed: 20630350]

Lustig C, Flegal KE. Targeting latent function: encouraging effective encoding for successful memory training and transfer. Psychol Aging. 2008; 23:754–764. [PubMed: 19140647]

Lustig C, Shah P, Seidler R, Reuter-Lorenz PA. Aging, training, and the brain: a review and future directions. Neuropsychol Rev. 2009; 19:504–522. [PubMed: 19876740]

Mahncke HW, Bronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: scientific bases for a novel intervention. Prog Brain Res. 2006a; 157:81–109. [PubMed: 17046669]

Mahncke HW, Connor BB, Appelman J, Ahsanuddin ON, Hardy JL, Wood RA, Joyce NM, Boniske T, Atkins SM, Merzenich MM. Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. Proc Natl Acad Sci U S A. 2006b; 103:12523–12528. [PubMed: 16888038]

Murphy DR, Craik FI, Li KZ, Schneider BA. Comparing the effects of aging and background noise on short-term memory performance. Psychol Aging. 2000; 15:323–334. [PubMed: 10879586]

Olesen PJ, Westerberg H, Klingberg T. Increased prefrontal and parietal activity after training of working memory. Nat Neurosci. 2004; 7:75–79. [PubMed: 14699419]

Owen AM, Hampshire A, Grahn JA, Stenton R, Dajani S, Burns AS, Howard RJ, Ballard CG. Putting brain training to the test. Nature. 2010; 465:775–778. [PubMed: 20407435]

Paxton JL, Barch DM, Storandt M, Braver TS. Effects of environmental support and strategy training on older adults' use of context. Psychology and Aging. 2006; 21:499–509. [PubMed: 16953712]

Ranganath, C.; Blumenfeld, RS. Prefrontal Cortex and Memory. In: Byrne, JH., editor. Learning and Memory: A Comprehensive Reference. Oxford: Academic Press; 2008. p. 261-279.

Rebok GW, Carlson MC, Langbaum JB. Training and maintaining memory abilities in healthy older adults: traditional and novel approaches. J Gerontol B Psychol Sci Soc Sci. 2007; 62(Spec No 1): 53–61. [PubMed: 17565165]

Smith GE, Housen P, Yaffe K, Ruff R, Kennison RF, Mahncke HW, Zelinski EM. A cognitive training program based on principles of brain plasticity: results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) study. J Am Geriatr Soc. 2009; 57:594–603. [PubMed: 19220558]