Brain-Training Pessimism, but Applied-Memory Optimism

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As is convincingly demonstrated in the target article (Simons et al., 2016, this issue), despite the numerous forms of brain training that have been tested and touted in the past 15 years, there's little to no evidence that currently existing programs produce lasting, meaningful change in the performance of cognitive tasks that differ from the trained tasks. As detailed by Simons et al., numerous methodological issues cloud the interpretation of many studies claiming successful far transfer. These limitations include small sample sizes, passive control groups, single tests of outcomes, unblinded informant- and self-report measures of functioning, and hypothesis-inconsistent significant effects. (However, note that, with older adults, a successful result of the intervention could be to prevent decline in the training group, such that they stay at their pretest level while the control group declines.) These issues are separate from problems related to publication bias, selective reporting of significant and nonsignificant outcomes, use of unjustified one-tailed t tests, and failure to explicitly note shared data across publications. So, considering that the literature contains such potential *false-positive publications* (Simmons, Nelson, & Simonsohn, 2011), it may be surprising and disheartening to many that some descriptive reviews (Chacko et al., 2013; Salthouse, 2006; Simons et al., 2016) and meta-analyses (Melby-Lervåg, Redick, & Hulme, 2016; Rapport, Orban, Kofler, & Friedman, 2013) have concluded that existing cognitive-training methods are relatively ineffective, despite their popularity and increasing market share.

For example, a recent working-memory-training meta-analysis (Melby-Lervåg et al., 2016) evaluated 87 studies examining transfer to working memory, intelligence, and various educationally relevant outcomes (e.g., reading comprehension, math, word decoding). The studies varied considerably in terms of the sample composition (age; typical vs. atypical functioning) and the nature of the working-memory training (verbal, nonverbal, or both verbal and nonverbal stimuli; n-back vs. span task methodology; few vs. many training sessions). Despite the diversity in the design and administration of the training, the results were quite clear. Following training, there were reliable improvements in performance on verbal and nonverbal working-memory tasks identical or similar to the trained tasks. However, in terms of far transfer, there was no convincing evidence of improvements, especially when working-memory training was compared to an active-control condition. The meta-analysis also demonstrated that, in the working-memory-training literature, the largest nonverbal-intelligence far-transfer effects are statistically more likely to come from studies with small sample sizes and passive control groups. This finding is not particularly surprising, given other work showing that most working-memory training studies are dramatically underpowered (Bogg & Lasecki, 2015) and that underpowered studies with small sample sizes are more likely to produce inflated effect sizes (Button et al., 2013). In addition, small samples are predominantly the reason irregular pretest-posttest patterns have been observed in the control groups in various working-memory and video-game intervention studies (for review, see Redick, 2015; Redick & Webster, 2014). In these studies, inferential statistics and effect-size metrics provide evidence that the training "worked," but investigation of the descriptive statistics tells a different story. Specifically, a number of studies with children and young adult samples have examined intelligence or other academic achievement outcomes before and after training. Closer inspection indicates that training "improved" intelligence or academic achievement relative to the control condition because the control group *declined* from pretest to posttest—that is, the training group did not significantly change from pretest to posttest.

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However, if the brain-training methods outlined in Simons et al. (2016) have little efficacy outside of the narrow range of the tasks that are repeatedly practiced, are there interventions that might be more effective? Certainly, we think that cognitive functioning can be altered, although most research has not been able to determine whether a particular intervention produces temporary, state-like change or enduring, trait-like modification (Ilkowska & Engle, 2010). Whereas others have reviewed non-cognitive interventions such as aerobic exercise (Erickson, Hillman, & Kramer, 2015), meditation training (Diamond & Lee, 2011), and pharmaceutical use (M. E. Smith & Farah, 2011), we will focus on cognitive techniques based on over 100 years of research that individuals can implement with relatively little cost and essentially no risks or negative side effects. However, as will be seen, each technique requires an intentional, active effort on the part of the learner that is likely viewed as less enjoyable than playing a video game.

Learning Strategies From Applied Memory Research

Given the lack of consistent evidence for working-memory training programs, many of which are designed and implemented at great cost, we propose a reinvigorated and reimagined implementation of lower-cost learning-strategy "training programs." Applied memory research, particularly in the interdisciplinary space wedding cognitive and educational psychology, has consistently shown benefits of several core groups of related learning strategies. Indeed, the translation of basic memory research to educationally relevant contexts has been a focus of recent major publications by leaders in the field (e.g., Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; Roediger & Pyc, 2012). These learning strategies have been mainly examined in the context of studies with clear applications to the traditional classroom. However, the existing strong evidence in favor of these strategies suggests an opportunity to further expand their implementation in various training environments.

In this section, we describe several core memory strategies as alternatives to costly interventions such as working-memory training programs. Echoing the organizational schemes from Dunlosky et al. (2013) and Roediger and Pyc (2012), below we summarize three categories of strategies established by memory research as effective for long-term memory: *elaboration, testing,* and *spacing*. After describing each strategy, we discuss the conclusions regarding translation to educational contexts in recent research.

The first major category, *meaning-based elaboration*, stems from Craik and Lockhart's (1972; see also Craik & Tulving, 1975) evidence for the theory that deep processing of information at the encoding stage, through semantic connections, is superior to more shallow (surface) types of processing. There are several subcategories of strategies based on the elaboration principle. For example, use of the self-schema during encoding is based on the *self-reference effect*, which suggests that memory will be stronger for information related to oneself (e.g., Klein & Kihlstrom, 1986; Rogers, Kuiper, & Kirker, 1977). That is, learners who actively make connections to their own lives should be more successful in remembering the content of educational materials compared to learners who use relatively shallow strategies such as rereading or highlighting the text. This variety of elaboration has not been a focus of recent translational research, however.

Two related meaningful elaboration strategies are *elaborative interrogation*, which involves asking oneself questions during learning (e.g., B. L. Smith, Holliday, & Austin, 2010), and *self-explanation*, which involves describing to oneself why a particular strategy choice was made during problem-solving (e.g., Wong, Lawson, & Keeves, 2002). Both Dunlosky et al. (2013) and Roediger and Pyc (2012) have argued that these are promising strategies in the educational domain but have also called for more research in applied contexts. Toward this goal, a recent review presented evidence that training in self-explanation strategies led to more connected and coherent knowledge as learners developed expertise (Richey & Nokes-Malach, 2015).

Next, the use of *imagery* enables elaboration by utilizing multiple modalities for encoding. Supplementing the rehearsal of language-based information with mental images greatly benefits memory. According to Paivio's (1986) *dual-coding theory*, using verbal and image-based encoding enhances the number of routes for retrieval (see also Bower & Winzenz, 1970; Paivio, Smythe, & Yuille, 1968). Though basic memory research has established the use of imagery as a consistently and highly impactful strategy across a variety of materials and situations, Dunlosky et al. (2013) categorized the strategy of imagery for text as potentially limited to specific text-learning situations (e.g., when students have stronger existing domain knowledge from which to generate images) and therefore in need of further research to establish boundary and transfer conditions.

The third category of elaboration is the use of *mnemonics*, which can be verbal or visual but are often a combination of both. Mnemonic devices help to impose an organizational or chunking scheme onto to-be-learned material, which makes the material more meaningful to the learner (though the degree to which the mnemonics involve meaningful elaboration does vary) and ultimately more memorable at a later time (e.g., Bellezza, 1996). Common examples of mnemonic techniques include first-letter mnemonics (e.g., acronyms, acrostics), keyword

mnemonics, the pegword method, the method of loci, and the use of songs, rhymes, and stories. Dunlosky et al. (2013) focused their review of the extant literature on the keyword technique, which involves creating a similar-sounding keyword for a to-be-learned term, then connecting the keyword to the term's definition via a mental image. They concluded that keyword mnemonics may be most helpful for foreign language learning and expressed concerns about the shorter-term nature of the learning. Yet some research has in fact demonstrated long-term learning, with transfer to applied assessments, for the keyword technique (e.g., Carney & Levin, 2008). Additional studies are needed to determine the best fit of specific mnemonic strategies to different types of content and learning environments.

The next major category of empirically supported memory strategy is *testing* (or *retrieval-based learning*). Research has consistently demonstrated that practicing retrieval of information from long-term memory is a potent learning event in and of itself. That is, compared to simply rereading a text, engaging in effortful retrieval of text information (i.e., taking a test) results in far better memory outcomes (e.g., Karpicke, 2012; McDaniel, Howard, & Einstein, 2009; Roediger & Karpicke, 2006). Dunlosky et al. (2013) concluded from their extensive review that *practice testing* is extremely effective for longer-term learning in a variety of learning situations. We also note that testing is one example of a broader category of memory strategy called *generation*, which is based on the idea that memory is better for learner-created materials than instructor/trainer-created ones (e.g., Slamecka & Graf, 1978; for more on generation in relation to educationally relevant materials, see McCabe, 2015).

Turning now to *spacing* (or *distributed processing*) as a third memory principle with great potential for translation to training programs, research has repeatedly shown a large benefit from taking breaks between periods of study, as compared to massing or cramming studying into one session, even with total study time held constant (e.g., Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Kornell & Bjork, 2007; S. M. Smith & Rothkopf, 1984). One reason why spacing is a slightly different type of learning strategy is that it refers more to the schedule of study than to a specific encoding technique. Thus, a combination of strategies from the first two categories (elaboration and testing) implemented on a schedule to spread out learning sessions over time, with breaks in between, should be even more effective. Spacing and testing have garnered the most support as promising memory principles to be applied to real-world contexts. These strategies were enthusiastically endorsed by both Dunlosky et al. (2013) and Roediger and Pyc (2012).

Almost three decades ago, Dempster (1988) lamented the lack of application of the well-documented spacing effect to educational contexts. After all, some of these strategies, including spacing, have been known to be effective since Ebbinghaus (1885/1913). Those in charge of research on education and training programs should consider whether we have come any further in applying spacing and other memory principles established by decades of research in cognitive psychology. Although the memory strategies discussed above have been mainly explored in traditional educational contexts (i.e., K-12 and higher education), there is no reason why they could not be expanded to training situations in areas such as the military, work training, and older adult education. Teachers and trainers, along with researchers, have a responsibility to learners. They should understand and apply the best practices for learning and durable memory, representing the current state of knowledge and consensus in the field.

In general, though, people are likely not aware of the benefits of these strategies, given that when college students were asked about the most effective learning strategies, either directly through self-report (Kornell & Bjork, 2007) or indirectly through the evaluation of learning scenarios (McCabe, 2011), they showed low metacognitive awareness that these strategies (e.g., testing, spacing) should be most helpful for learning. This speaks to a major challenge in implementing these strategies in applied learning contexts—namely, to convince the people in charge of the "training," whether these are teachers designing classroom activities or students deciding how to study, that these strategies support durable learning and long-term retention.

In fact, some of the strategies discussed above are not obvious and are even quite counterintuitive, having been dubbed "desirable difficulties" by Bjork (1994). Desirably difficult learning situations are those that the learner may perceive as slow, effortful, and error-prone, yet which demonstrate substantial long-term memory benefits. In the present learning moment, it may not feel like significant learning is actually taking place; thus, learners (and teachers) may avoid these strategies and may even opt for less effective but more intuitively appealing and "easy" strategies such as highlighting or rereading.

Those studies that have examined the impact of learning-strategy "training" in higher education have shown promising results, at least with regard to improved student knowledge about the empirically supported study strategy choices (e.g., McCabe, 2011) and increased metacognition and subsequent academic performance (e.g., Azevedo & Cromley, 2004; Fleming, 2002; Tuckman, 2003; see McCabe, 2014, for an instructional resource about incorporating learning- and memory-strategy demonstrations in the classroom). We call for additional controlled research to determine the effectiveness and generalizability of learning-strategy training in real-world educational

situations. In particular, researchers and educators should examine the relative impact of these strategies when directly compared to each other in similar learning environments, and also the combined impact when the strategies are used in tandem (e.g., testing or self-explanation or imagery implemented on different spaced/distributed schedules). And now that we know there is a metacognitive disconnect with regard to what learners believe is the best way to learn, we need to explore how to train them to use the empirically based strategies; in an ideal world, learners (some of whom will become teachers and trainers) would develop a tool kit of these effective habits of mind when encountering to-be-learned information.

Another obstacle to implementation is that even if those in charge of training know about the strategies, they may feel more swayed by intuitively appealing yet unsubstantiated ideas, including ideas about learning styles (Pashler, McDaniel, Rohrer, & Bjork, 2008) and, as discussed extensively in the target article, working-memory training (Rabipour & Davidson, 2015). It is also possible they are not convinced that the memory principles will be realistically helpful in their specific classroom or learning context (see Daniel & Poole, 2009, for a critique of the *memory-first approach*). And, of course, it does take motivation to change and/or implement a brand-new training program. We recommend the popular press book *Make It Stick: The Science of Successful Learning* (Brown, Roediger, & McDaniel, 2014) for teachers and trainers as an effective means of translating many of the memory principles discussed here.

Conclusion

Working-memory training as currently implemented does not work. One hundred years of research on basic memory phenomena has discovered many procedures that do!

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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