

## **The Brain-Games Conundrum: Does Cognitive Training Really Sharpen the Mind?**

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*Editor's Note: Few topics in the world of neuroscience evoke as much debate as the effectiveness of cognitive training. Do you misplace your keys regularly? Forget appointments? Have trouble remembering names? No worries. A host of companies promise to "train" your brain with games designed to stave off mental decline. Regardless of their effectiveness, their advertising has convinced tens of thousands of people to open their wallets. As our authors review the research on cognitive-training products, they expose the science surrounding the benefits of brain games as sketchy at best.*

The numbers are staggering. Brain-training products are a billion-dollar industry whose revenues are predicted to surpass \$6 billion by 2020.<sup>1</sup> One of the more popular brain-training programs, *Lumosity*, recently reached the milestone of 50 million members,<sup>2</sup> likely in part due to an advertising campaign that spanned radio, television, and the Internet. Nintendo's *Brain Age* has sold millions of copies and is among the best-selling Nintendo DS games of all time.<sup>3</sup> These statistics suggest a belief that brain training produces meaningful benefits, and this belief does not appear to be restricted to individual consumers. The fact that health-insurance companies have begun making brain-training products available to their clients suggests a perception in the health-care industry that the products work.

But the issue of what does and doesn't work is complex. The basic assumption behind almost all commercial brain-training programs is that practicing one or more tasks leads to improved performance of other, untrained tasks. The programs often present individuals with a series of simple games that might require the player to remember the properties of briefly presented pictures, to keep track of multiple moving objects, to recognize complex patterns, or to rapidly detect the presence of target objects in the visual periphery. With practice, players become faster and more accurate at performing these tasks. These products would be of little value if players improved *only* on the trained games, however. The critical question is whether *transfer of training* occurs. Does extended practice of the trained games result in general perceptual and cognitive improvements that boost performance of meaningful, real-life tasks such as driving, remembering names and faces, and keeping track of finances?

### **Where It Began**

Psychologists have systematically studied the issue of transfer of training for over a century. The early work of American psychologist Edward Thorndike (1874–1949) set the stage for much of the research that followed. Thorndike, a professor at Columbia University's Teachers College, conducted a series of influential studies in which participants practiced one task (for example, estimating the area of a rectangle) repetitively for an extended period of time. After participants demonstrated improvement, he would ask them to perform a different, so-called transfer task (such as estimating the area of a triangle). Thorndike consistently observed large gains on practiced tasks, but these gains were weakly (if at all) associated with improved performance on transfer

tasks. Thorndike also tested the idea that training in Latin would result in a more disciplined mind, which would improve performance in a variety of other subjects. He observed no such advantage.

Thorndike's research led him to conclude that transfer of training occurred only if the practiced task and the transfer tasks shared "identical elements,"<sup>4</sup> and that the elements of most tasks are different enough from those of other tasks that transfer of training was rare. He believed that "the mind is so specialized into a multitude of independent capacities that we alter human nature only in small spots, and any special school training has a much narrower influence upon the mind as a whole than has commonly been supposed."<sup>5</sup>

Thorndike's conclusions are consistent with modern theories proposing that practice results in cognitive adaptations that develop over time and are specific to the practiced task,<sup>6</sup> as well as with theories of learning that link improved task performance to the retrieval from memory of specific instances of the same task encountered previously.<sup>7</sup> The implication of Thorndike's empirical findings and theoretical views is that attempts to train a person on one task and thus bring about improvements in tasks other than the trained task are likely to fail unless the tasks are similar in terms of their elements or components.

Other scholarly views, however, allow for greater possibilities when it comes to transfer of training. Some research suggests that important moderators influence the degree of transfer resulting from training. One moderator is the degree of variability encountered during training, such that more variable training leads to greater transfer.<sup>8,9</sup> Transfer may also be more likely to occur when performance of the practiced task and the transfer task depend on overlapping neural circuits. For example, some researchers observed transfer between a trained and an untrained task to the extent that both tasks activated a region of the brain called the striatum, while they observed no transfer when this region was not activated during an unpracticed task.<sup>10</sup> Finally, certain types of training may sharpen abilities that are so fundamental to a wide variety of tasks that performance of additional untrained tasks improves. For example, the performance of all tasks requires some degree of learning. If cognitive training helps individuals make better use of statistical/probabilistic information within a task, it could account for superior performance across a variety of untrained tasks. (For discussion of the "learning to learn" hypothesis of transfer, see endnote 11.)

While many theoretical accounts of learning reflect skepticism regarding the ability of cognitive training to improve the performance of untrained tasks, under certain conditions and with certain types of training, these effects may be observable. These theoretical accounts make it clear that it is not safe to assume that all types of cognitive training will produce meaningful benefits affecting important everyday tasks.

Empirical evidence that certain software packages and digital games are capable of improving perceptual and cognitive abilities that transfer to untrained tasks is mixed. Some studies had positive results, while others did not. And even in studies with positive results, interpretations of transfer effects aren't always straightforward. This is still a very active area of research.

### **Popular Approaches**

There are three popular approaches to improving cognition: brain-training programs, working-memory training, and video-game training. The ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) clinical trial was the largest test of whether brain training can improve perceptual and cognitive abilities in older adults.<sup>12</sup> Over 2,800 participants were randomly assigned to one of four conditions: memory training, reasoning training, speed-of-processing training, or a no-contact control group. Intervention groups received 10 training sessions, each approximately 60 to 75 minutes long (some participants also received a few booster sessions in the years following training). Transfer tasks included laboratory-based tests of cognition (proximal outcomes) and self-reported and simulated performance-based measures of daily functioning (primary outcomes).

Immediately after training, researchers observed large improvements that were specific to each type of training intervention (for example, speed-of-processing trained participants improved on laboratory tasks measuring speed but not on tasks measuring memory or reasoning). Participants maintained most of these improvements even when they were tested 10 years later. However, researchers observed no improvements on measures of everyday functioning immediately after training, one year after training, or two years after training. However, tests of participants 5 and 10 years later indicated more promise. Compared to the no-contact control group, five years after training, the reasoning group self-reported fewer daily-living problems, the speed-of-processing group was less likely to cease driving, the speed-of-processing and reasoning groups were involved

in fewer at-fault automobile crashes, and the speed-of-processing group reported less of a decline in health-related quality of life. Researchers attributed these delayed effects to the facts that (1) at the start of the intervention participants were cognitively healthy, and (2) a certain amount of decline was necessary in order to reveal transfer effects.

Other studies have had less encouraging results, however. For example, Adrian Owen and colleagues randomly assigned more than 11,000 online participants between the ages of 18 and 60 to receive six weeks of reasoning training, to receive six weeks of visuospatial/attention training, or to be part of an active control group that answered trivia questions.<sup>13</sup> Despite the tremendous sample size, neither training group demonstrated improved general ability on a battery of neuropsychological tests.

In general, it is hard to draw straightforward conclusions from the current body of literature on brain training, even when significant effects are observed. With the notable exception of the ACTIVE trial, these studies generally focus on outcome measures based on abstract neuropsychological tests and utilize weak control groups. A recent test of a popular commercial cognitive-training program, for example, assessed transfer with an abstract digit/tone categorization task.<sup>14</sup> While researchers observed some evidence of transfer to neuropsychological tests of alertness and distraction, the extent to which transfer to the performance of *important everyday* tasks was unclear. As with any intervention, brain-training studies need to prove convincingly that transfer-task improvement cannot be accounted for by a placebo effect.<sup>15</sup> That is, researchers need to rule out any possibility that the group receiving brain training didn't improve more than the control group did simply because their treatment caused them to *expect* this outcome.<sup>16</sup> Julia Mayas et al. compared a group that received intense brain training to a control group that participated in discussion groups.<sup>14</sup> It is unclear whether participants who merely discussed issues related to aging would expect as much improvement on the transfer task compared to participants who received challenging and adaptive cognitive training.

Much of the recent cognitive-training literature has focused on the potential of working-memory training to improve IQ and, specifically, fluid intelligence (the ability to reason and to solve novel problems). Susanne Jaeggi, Martin Buschkuhl, John Jonides, and Walter Perrig first reported that training that involved juggling multiple pieces of information in the mind affected fluid

intelligence.<sup>17</sup> Training was adaptive, as participants had to remember visual and auditory information on each trial and compare this information to the information heard and seen one, two, three, or *N* trials back (referred to as an N-back task). When participants were able to remember information more successfully, they were given more information to remember (*N* was increased throughout training). Compared to participants who did not receive training, participants who received N-back training improved more on transfer assessments that included problems from standard measures of IQ.

Jaeggi and colleagues interpreted the adaptive nature of their training and the necessity of working memory to solve complex problems as being supportive of transfer to measures of intelligence. However, after this initial positive finding, other scholars raised a variety of methodological criticisms of this and other working-memory-training studies.<sup>18</sup> Furthermore, other studies could not replicate the effect of working-memory training on fluid intelligence.<sup>19–21</sup> A recent meta-analysis found that when most existing studies were considered together, working-memory training appeared to have a small but reliable effect on measures of IQ.<sup>22</sup> But the most rigorous studies—those that included an active control group to help address the problem of placebo effects—found almost no effect at all. Given the mixed state of the literature, two problematic possibilities exist: (1) working-memory training may not improve fluid IQ, or if it has an effect, the effect may be small, and (2) important but unknown moderators may determine who benefits from this type of training and who does not.<sup>23</sup>

Over the past decade, some commercial and custom video games have also generated excitement about their potential to improve a variety of perceptual and cognitive abilities. This excitement has been heavily influenced by the groundbreaking work of C. Shawn Green and Daphne Bavelier.<sup>24</sup> Their initial study, which focused on the effects of fast-paced action video games (typically involving violent, first-person shooters), found not only that action gamers demonstrated superior visual and attentional abilities compared to nongamers, but also that nongamers could improve these abilities with just a small amount of action-game training. This finding led to dozens of additional investigations into other abilities that might be improved through action-game training. Researchers have linked superior attention, vision, processing speed, dual-tasking ability, and decision-making to action-game play through cross-sectional studies comparing gamers to nongamers, intervention studies training nongamers to play action games, or both.<sup>25</sup> Other studies

have suggested that game training could ameliorate age-related cognitive decline.<sup>26</sup> Unlike focused N-back training, video games tap a variety of perceptual, cognitive, and motor processes, likely ensuring a greater degree of cognitive and neural overlap between trained and untrained tasks. This might explain the broad degree of transfer that seems to come from game training.

While this line of research is exciting, and it appears to indicate transfer that is much broader than that caused by any type of intervention investigated thus far, we must consider some important caveats when proposing to improve general cognitive abilities with video-game interventions. First, game effects do not always replicate,<sup>27, 28</sup> again suggesting either smaller effects on cognition than previously reported or the existence of moderators that determine whether an individual might benefit from game training. Second, scholars have raised a variety of methodological criticisms of the studies that provide evidence in support of game effects.<sup>15,29,30</sup> Finally, as with previous types of interventions discussed here, there is a dearth of studies linking video-game interventions to better performance of meaningful everyday tasks and meaningful activities such as avoiding crashes while driving, succeeding academically or professionally, and making complex life decisions such as those involved in the purchase of a new home.

### **Promises, Promises**

What do the sellers of cognitive-training products promise? Should consumers purchase and use them? A careful inspection reveals that most commercial brain-training companies are relatively conservative with respect to their advertised claims, at least when explicitly discussing potential improvements on everyday tasks. It is exceedingly unlikely for a company to claim that its product could help a driver avoid a dangerous crash, a worker advance his or her career, or an older adult live independently longer. Instead, claims in these commercials and advertisements are vague. They highlight improvements to more abstract qualities, such as reaction time, attention, and memory. Few specify the exact nature of these improvements—for example, reaction to what? Memories of what? These vague claims are justified in that the products' training tasks involve these abilities, and performance on the training tasks improves with practice.

The critical question, however, is the degree to which these improvements transfer to more meaningful activities. Cognitive-training advertisements typically ignore this issue. These ads typically feature product users (or actors portraying users) discussing *why* they are using the

product (for example, “to remember names of people I meet,” “to get ahead at work”). The companies’ websites also tend to feature user anecdotes, as well as a section explaining the science behind their product and referencing completed, peer-reviewed (but sometimes non-peer-reviewed) studies. In many instances, however, these studies examine something other than the program being advertised; they assess benefits with abstract laboratory tasks rather than everyday ones; and they lack critical control conditions necessary to link improvements to the product. While pharmaceutical advertisements are strictly regulated, this is not the case for brain-fitness program advertisements. This may partly be due to the companies’ lack of explicit claims regarding improvements to everyday, meaningful activities, as well as the lack of claims that their products are intended to treat specific conditions, such as age-related brain diseases.

### **To Be Determined**

Before confidently recommending the use of brain-training programs to improve cognition meaningfully and to address age-related cognitive decline, researchers must address the following questions and issues:

- **Comparative effectiveness.** If brain-training programs and video games are in fact effective, researchers must determine the programs’ comparative effectiveness. Per hour invested, how do brain-training programs and games compare to one another with respect to their ability to improve cognition meaningfully? How do they compare to other cognitively beneficial (and potentially more enjoyable) activities such as aerobic exercise,<sup>31</sup> digital photography, quilting, and volunteer work?<sup>32-34</sup> Do certain activities transfer especially well to tasks such as driving, while other activities improve the memory functions that support medication adherence? Answers to these questions would help shape recommendations regarding the amount and type of brain-training activities a given individual should engage in.
- **Intervention adherence.** As with physical exercise and pharmaceutical treatments, brain-training programs yield little to no benefit unless people adhere to them. A recent study found that digital game-based training associated with a variety of perceptual and cognitive improvements resulted in no benefit in a sample of older adults, likely due to the fact that adherence was poor for the intervention expected to produce the largest effect.<sup>35</sup> The



challenges of ensuring cognitive-intervention adherence may be most analogous to the challenges of promoting adherence to hypertension treatments. Given that hypertension is typically asymptomatic, treatment benefits are not readily apparent, such that the costs (e.g., drug side effects) become more salient than the real but unseen benefits. Similarly, cognitive training may not result in immediate, perceptible benefits, but it might reduce cognitive problems years in the future.<sup>36</sup> Thus it is important that researchers examine individual differences that predict adherence (for such an attempt with exercise, see endnote 37) as they determine how to promote adherence to brain-training games and programs.

- **Moderating variables.** Currently we know little about who benefits most from brain training. However, researchers have begun to use data from the ACTIVE trial in an attempt to answer this question. George W. Rebok et al. found that memory-training benefits were greater for participants with higher levels of education and better self-reported health. The discovery of moderating variables may help health-care professionals prescribe either general cognitive training or specific types of cognitive training. However, answering these questions will require fairly large samples to tease out the cognitive, environmental, disease, and genetic factors that make an individual more or less susceptible to the benefits of cognitive training.
- **Methodological rigor and replication.** Scholars have leveled a variety of criticisms against studies that report evidence of transfer of training from video games and brain-training programs to other tasks. These criticisms should be addressed before practitioners make strong recommendations that individuals engage in these activities. In addressing the potential of placebo effects, expectations for improvement on transfer tasks can be assessed upon completion of the intervention,<sup>16</sup> or in a separate group of individuals.<sup>39</sup> When expectations for improvement are equal for intervention and control groups, but actual transfer effects differ, placebo effects are unlikely. In addition to addressing methodological concerns, researchers should also note that the brain-training literature contains few direct replications. This is understandable because these types of studies are difficult and expensive to run. However, replication studies would be of tremendous value in answering the question of whether reliable transfer gains can be expected to result from any specific type of training. These types of studies should be incentivized.

## Meaningful Measures, Outcomes, and Questions

It's a no-brainer that individuals purchase and engage in brain-training programs because they wish to perform better on certain tasks that are meaningful to them. Yet the majority of studies in the literature use relatively simple, process-pure laboratory tasks to assess transfer of benefit.<sup>40</sup> Few studies assess performance on simulated everyday tasks (for example, through a driving simulation), and far fewer assess real-world outcomes (e.g., automobile crash rate, loss of independence, or loss of wealth due to fraud). These types of important and meaningful outcomes can be assessed only in large-scale longitudinal studies that follow cognitively trained individuals over a decade or more.

Other important questions relate to when cognitive training should begin, how much an individual should train, and how long training gains might last. If brain training is judged to be effective, should it begin when someone is in his 20s? In her 60s? Should individuals train every day? Most days of the week? Is it better to engage in long, spaced-out training sessions or fewer, shorter training sessions? Does an individual need to continue training in order to maintain gains, or do training gains persist long after training has ceased? Is there a point of diminishing returns at which the training task becomes so automated that it no longer exercises the abilities it was designed to improve? Can people enhance the potential benefits of cognitive training if they pair it with physical activity and/or social interaction? Only a handful, if any, studies have addressed these important issues.

These are only some of the unanswered questions regarding brain training. What, if anything, can today's doctors recommend to those who wish to enhance (or to maintain) their cognitive abilities? At this point, any blanket endorsement of a certain brain-training program would be premature. Yet there appears to be enough accumulated evidence that being cognitively inactive is not a good strategy for maintaining cognitive health. Doing something to remain active and engaged is likely an investment worth making. Cognitive activity takes many forms, and there is currently little evidence suggesting that any particular software package is best at improving cognition, or that any brain-training product is better than other engaging activities, such as learning a new language or instrument, creative writing, or learning to dance.

These latter alternatives have the advantages of being inexpensive, being especially enjoyable, and providing a useful and valuable skill—even if there were no general cognitive benefits associated with them. Aerobic exercise may be one of the safest bets for those wishing to improve their cognition, as animal models and human cross-sectional and intervention studies all indicate benefits to brain function, structure, and cognition.<sup>41</sup> This option may be particularly beneficial because it also comes with a host of physical health benefits. Exercise would be a worthwhile investment even if it had no effect on cognition.

In the future, more precise recommendations will be possible as more evidence accumulates and the methodological rigor of intervention studies continues to advance. Large-sample studies that include real or simulated performance on important everyday tasks, extended post-training testing and observation periods (similar to those used in the ACTIVE study), and large individual-difference batteries (cognitive, genetic, neurophysiological) that assess moderators of transfer effects will be especially valuable in informing these recommendations.

## **Bios**

Arthur F. Kramer, Ph.D., is the director of the Beckman Institute for Advanced Science & Technology and the Swanlund Chair and professor of psychology and neuroscience at the University of Illinois. Kramer's research projects include topics in cognitive psychology, cognitive neuroscience, aging, and human factors. A major focus of his lab's recent research is the understanding and enhancement of cognitive and neural plasticity across the lifespan. He is a former associate editor of *Perception and Psychophysics* and is currently a member of six editorial boards. Kramer, who received his Ph.D. in cognitive/experimental psychology from the University of Illinois in 1984, is also a fellow of the American Psychological Association, American Psychological Society, a former member of the executive committee of the International Society of Attention and Performance, and a recipient of an NIH Ten Year MERIT Award. His research has been featured in the *New York Times*, *Wall Street Journal*, *Washington Post*, *Chicago Tribune*, and on *CBS Evening News*, *Today Show*, *NPR* and *Saturday Night Live*.

Walter R. Boot, Ph.D., is an associate professor of psychology at Florida State University. His research interests include how humans perform and learn to master complex tasks (especially tasks with safety-critical consequences), how age influences perceptual and cognitive abilities vital to the performance of these tasks, and how technological interventions can improve the well-being and cognitive functioning of older adults. Boot has published extensively on the topic of technology-based interventions involving digital games, and is one of six principal investigators of the Center for Research and Education on Aging and Technology Enhancement. He has also been funded by the Florida Department of Transportation since 2011 to conduct studies of aging road users; specifically examining countermeasures to protect older adults as they navigate roadways as drivers, cyclists, and pedestrians. Boot received his Ph.D. in psychology from the University of Illinois at Urbana-Champaign in 2007.

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