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Cognitive Training: How Evidence, Controversies, and Challenges Inform Education Policy

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Abstract

Both scientists and the general public want to know whether basic cognitive abilities can improve with dedicated behavioral training. This would have many practical implications, including possible increases in academic achievement. The current brief review of behavioral approaches to cognitive enhancement focuses on the cognitive abilities most predictive of academic success: fluid intelligence, working memory, executive functions, spatial thinking, and visual attention. Researchers are currently testing a range of possible approaches to enhancing these cognitive skills. These include everything from having people repeatedly practice the same types of psychology tests that are used to measure the cognitive abilities, to developing custom cognitive training platforms, to the use of commercial entertainment video games. Existing data warrant guarded optimism, but more research is needed to justify widespread adoption. Policymakers can help (e.g., by promoting best-practice science), and researchers need to consider ethical issues as the field progresses.

Keywords

cognitive enhancement, academic achievement, intervention methods

Tweet

Cognitive capacities that underlie academic achievement might improve via behavioral training. Yet debates persist. More high-quality research needs to inform how to design cognitive training to help students get A's.

Key Points

- Individual differences in certain cognitive abilities predict academic achievement.
- These cognitive abilities might improve via dedicated behavioral training.
- However, direct evidence showing that behavioral interventions for cognitive enhancement can in turn increase academic achievement is both sparse and mixed.
- Although some degree of positivity is warranted, there are issues ranging from the interpretation of individual empirical results to the general methodology that is employed.
- There are many opportunities for policymakers to promote best-practice science in the field.

Introduction

Currently, much interest follows the possibility that human cognitive function can improve via purposeful training (Strobach & Karbach, 2016). The relevant research ranges from basic science outlining how to maximize the brain changes in response to experience (Bavelier, Levi, Li, Dan, & Hensch, 2010; Deveau, Jaeggi, Zordan, Phung, & Seitz, 2014) to applied work attempting to utilize cognitive training to improve the lives of individuals in the real world (Biagianti & Vinogradov, 2013; Ross et al., 2016).

One such application of cognitive training lies in education. Indeed, the idea that certain basic cognitive abilities predict educational outcomes and therefore that improving those abilities could, in turn, result in greater academic performance is an old one. For instance, at the turn of the 20th century, Alfred Binet (1975) wrote of his students (who today would likely be diagnosed with a mixture of learning disabilities):

> Faced with pupils who could neither listen, nor see, nor stand still, we decided that our first job was not to teach them the things which seemed to us the most useful to them, but to teach them how to learn. This is why . . . we designed what we called "mental orthopedics exercises" . . . Just as physical orthopedics

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> correct a curvature of the thoracic spine, mental orthopedics straighten, cultivate, and fortify such mental abilities as attention, memory, perception, judgement, and the will. We do not try to teach the child new concepts; we strive to increase the efficiency of his mental faculties. (English Translation, III. The Education of Intelligence, p. 111)

Building on a recent consensus report (Green et al., 2019), we examine the current evidence on cognitive training, emphasizing applicability to educational ends. This literature provides reason for optimism, although the evidence has criticisms to address, room for improvement, and a need for more and better data. Some controversies may stem from disagreement regarding best-practice methodology, and the consensus report made methodological recommendations. Finally, we conclude with suggestions for funding agencies, policymakers, and regulatory agencies given both the current state of the field and the needs going forward.

Which Cognitive Abilities Best Predict Educational Outcomes?

Considering the potential for cognitive training to improve educational outcomes, first, requires identifying those cognitive abilities most closely linked to academic success. These abilities should then, in turn, become the primary targets of cognitive training.

Fluid Intelligence

This construct captures the general ability to flexibly engage with, and adapt to, changes in the world. It includes recognizing patterns and extrapolating from them to fill in missing data, to reason, and to solve problems. Despite debates regarding how best to measure it, standardized measures of fluid intelligence are among the best single cognitive predictors of academic achievement (Frey & Detterman, 2004; Rohde & Thompson, 2007). This makes sense, as the earliest measures of intelligence were designed explicitly to predict which students would or would not show later success in school (Binet & Simon, 1916).

Working Memory

Working memory refers to the ability to hold onto information for a short time and to mentally manipulate and update this information on the fly, even in the face of interference from other incoming information. Like fluid intelligence, working memory abilities strongly link to academic success (Gathercole, Pickering, Camilla, & Zoe, 2003). Working memory deficits consistently appear in students who struggle in math or reading. Furthermore, measures of working memory taken as early as preschool correlate with later academic success (Bergman Nutley & Söderqvist, 2017; Swanson & Alloway, 2012).

Executive Functions

This term unfortunately has a host of different meanings depending on the area of psychology using it (Karbach & Unger, 2014). Most commonly, the term refers to a range of abilities including the capacity to ignore task-irrelevant information, to shift between competing tasks, and to update information in working memory. The constructs of fluid intelligence, working memory, and executive function are related. Consistent with this fact are the clear links between executive functioning and scholastic outcomes (Bull, Espy, & Wiebe, 2008; Titz & Karbach, 2014; Willoughby, Kupersmidt, & Voegler-Lee, 2012; also see Jacob & Parkinson, 2015).

Spatial Thinking

As the name implies, spatial thinking involves those mental processes utilized when assessing physical relationships either between or within objects. Spatial skills link to educational performance in general, and specifically within science, technology, engineering, and mathematics (STEM; Uttal, Miller, & Newcombe, 2013). The observed links between spatial skills and STEM achievement hold even controlling for other possibly confounding variables, such as mathematical or verbal abilities (Wai, Lubinskin, & Benbow, 2009). Spatial skills (most notably mental rotation) are also one of the few cognitive functions that reliably differ between males and females (with males on average outperforming females; Voyer, Voyer, & Bryden, 1995). The possibility of purposefully improving spatial skills has thus been of all the more interest to researchers, given the underrepresentation of females in STEM fields.

Visual Attention

This describes the ability to focus the sight on some information for greater processing, while inhibiting the processing of other visual information. Although visual attention has only rarely been linked with overall scholastic outcomes, some theories posit that visual attention deficits underlie reading difficulties in at least some subset of individuals with dyslexia (dyslexia being a catch-all term describing an age-inappropriate reading ability to read). In particular, some subset of individuals with reading difficulties demonstrates problems properly distributing visual attention across space and time (Facoetti et al., 2003).

Further Strengthening the Link: Education Itself Improves Cognitive Performance

Given that formal education apparently places long-term load, or demand, on high-level abilities such as fluid intelligence, working memory, executive function, spatial thinking, and visual attention, does education itself change cognitive abilities? In other words, could one consider formal education as, in essence, a form of extremely long-term (albeit somewhat untargeted) cognitive training?

No debate surrounds the correlations linking measured intelligence and academic performance. However, establishing a causal relation, and if so determining its direction, is more difficult. Typically in psychology, causal questions require true experiments, which randomly assign participants to conditions and measure that assignment's impact. However, ethics prevent randomly assigning some children to receive schooling and others not. Some researchers have attempted to bypass this issue by manipulating the content of schooling (e.g., see designs such as McAuliffe, 2003, who showed that adding a small set of spatially demanding activities to a standard high school physics course resulted in improvements on an untrained spatial task). But, in general, most of the current evidence regarding whether schooling itself enhances cognitive abilities comes from various correlational or quasi-experimental studies (i.e., where participants are in various groups, but are not randomly assigned to those groups; students who attend schools based upon where they live would be an example). Although these designs are less definitive than true experiments, the available data nonetheless provide strong reason to believe that the "behavioral training" one receives in school does, in fact, augment some of the high-level cognitive abilities just discussed.

In a now-classic review, Ceci (1991) highlighted evidence pointing to a possible causal link between schooling and intelligence. One broad class of study in this review focused on intermittent schooling. For instance, measured intelligence grows steadily during school months and then drops during summer vacations. Furthermore, this drop is most pronounced among children whose summer activities least mimic the school environment. Another broad class of research assessed the impact of delayed schooling. For example, Black children who started formal schooling as soon as racial integration was ordered in the United States went on to show higher levels of intelligence than socioeconomically matched children who did not start formal schooling at that time (because their school systems shut down rather than integrate). A more recent meta-analysis (Ritchie & Tucker-Drob, 2018) aggregated results from three subtypes of quasi-experimental designs (including some of the types above) and concluded that each year of education increases intelligence by 1 to 5 points.

"Cognitive Training": Not a Single Thing, But a Broad Range of Approaches

If high-level cognitive abilities both underpin educational achievement and are potentially modifiable through the experience, cognitive training seems plausible. Although here we are reviewing only behavioral approaches to cognitive enhancement (thus, not brain stimulation, neuropharmacological agents, etc.), even this is too broad a category. The range of "behavioral interventions for cognitive enhancement" is now simply enormous. Some paradigms rely extensively on principles that they derive from the science of neuroplasticity (Nahum, Lee, & Merzenich, 2013). Other approaches are inspired by Eastern meditation practices (Tang et al., 2007), or use commercial video games designed with no training purposes in mind, but that nonetheless seem to possess a host of valuable characteristics with regard to cognitive change (Green & Bavelier, 2003). Other techniques are essentially unaltered measures of the cognitive constructs of interest as training tasks (i.e., directly training on working memory measures or executive function measures; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008) or else put the cognitive constructs in slightly more "game-like" interventions (Anguera et al., 2013). Given the degree of variation in the field, the question of, "Do behavioral interventions for cognitive enhancement work?" is ill-posed. There is no single kind of cognitive training.

Empirical Results: Positives and Nulls, Clarity and Controversy

Before asking whether cognitive training could enhance educational outcomes, first consider whether cognitive training can actually enhance cognitive functioning itself. Although the impact of formal schooling suggests effects of experience, formal schooling represents thousands of hours of experience, whereas most cognitive training platforms aim for impact after tens of hours.

Evidence that behavioral training can alter core cognitive abilities. Recent meta-analyses generally conclude that fluid intelligence, working memory, executive functions, spatial thinking, and visual attention all can benefit from dedicated cognitive training. For example, a recent meta-analysis focused on the impact of training on one particular working memory task, the *N*-back task, on one cognitive ability, fluid intelligence (Au et al., 2015). Fluid intelligence increased more from pretest to posttest for participants trained on the *N*-back task as compared with those trained on an active control task. A second meta-analysis reached a similar conclusion regarding *N*-back training (albeit with a smaller estimated effect size; Melby-Lervåg, Redick, & Hulme, 2016). This latter meta-analysis further demonstrated that working memory training, broadly construed, improved working memory abilities (i.e., increased performance on new, untrained working memory tasks).

In terms of executive functions, a recent meta-analysis showed that executive function training caused gains on untrained tasks that tapped the same executive function subcomponent used in training (e.g., inhibitory control or cognitive flexibility). However, there was no effect on different executive function subcomponents (Kassai, Fuo, Demetrovics,

& Takacs, 2019). Thus, "executive function" training may be too broad a label.

For spatial skills, a meta-analysis indicated that spatial skill training improved spatial skills over control groups (Uttal, Meadow, et al., 2013). These results were mirrored by a meta-analysis showing that individuals trained on one particular form of video game (action video games) consistently gained in spatial cognitive abilities, as compared with controls (Bediou et al., 2018). Furthermore, the same type of video game training benefited visual attentional skills.

All told, comprehensive meta-analytic techniques suggest that dedicated behavioral training can enhance new tasks that also tap cognitive constructs associated with scholastic achievement.

Evidence that behavioral training can alter academic achievement. Given the evidence that (a) some core cognitive abilities are associated with academic achievement and (b) dedicated behavioral training can purposefully enhance those cognitive abilities, cognitive training could serve to enhance academic achievement. To date though, the evidence of such a causal link is both sparse and mixed (see Titz & Karbach, 2014, for a thorough review). The few existing studies have predominantly focused on children with cognitive or learning issues (e.g., learning disabilities, attention deficits, working memory deficits, low academic achievement). Furthermore, the outcome measures have rarely been actual academic achievement. Instead, the measures are more commonly "school-related skills" (e.g., reading fluency, performance on standardized math problems). Some studies have observed positive outcomes—including improved reading comprehension, reading fluency, basic number skills, and arithmetic (Dahlin, 2011; Franceschini et al., 2013; Holmes & Gathercole, 2014). Yet meta-analyses have not consistently linked cognitive training (working memory training specifically) and either arithmetic performance or reading comprehension (Melby-Lervåg et al., 2016).

The available studies vary substantially in approach (e.g., some studies have utilized as few as 10 sessions of training, others as many as 35; some studies have included an active control group, others have not; some studies have utilized custom cognitive training software, other studies have utilized off-the-shelf video games), so any broad conclusions are premature. Instead, the mixed results call for more rigorous research, with larger samples, with clearer tests of the impact of various manipulations (e.g., intervention type or training duration), and with individual difference factors (e.g., who might benefit most from training).

Counter-evidence, current disagreements, and important subtleties. Despite some reason for optimism regarding the evidence, the field has been controversial. For instance, although one meta-analysis discussed earlier reported some positive results with respect to the impact of working memory training on fluid intelligence (e.g., with regard to *N*-back training), the authors argued that no such positive impact on fluid intelligence emerges when aggregating across all forms of working memory training (Melby-Lervåg et al., 2016). Similarly, whereas another meta-analysis (Bediou et al., 2018) reported positive impact from training on action video games, another meta-analysis—across a broader set of video games—found more equivocal results (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013). Which training tasks to combine in meta-analyses is a difficult choice. Evaluating the big questions in cognitive training undoubtedly requires some aggregation. Yet, cognitive training tasks, even those that might share a label (e.g., "video game training" or "working memory training"), can nonetheless differ substantially in terms of the actual experience (Dale & Green, 2017; Green et al., 2017). How best to separate or to combine across tasks in the research literature is therefore an area of active interest.

Toward Consensus Methodological Standards

Despite the substantial amount of research on behavioral interventions for cognitive enhancement, progress in the field has been arguably hampered by the lack of scientific consensus around the best methodological practices for such behavioral interventions. Simply put, no gold standard methodology exists in the cognitive training domain, as exists in, for instance, the pharmaceutical industry (Green, Strobach, & Schubert, 2014). This in turn opens the field to many methodological critiques—in particular whether the existing methodology can support the inferences made to date (e.g., whether effects attributed to cognitive training interventions might be placebo effects instead; Boot, Simons, Stothart, & Stutts, 2013; Redick, Shipstead, Wiemers, Melby-Lervag, & Hulme, 2015; Simons et al., 2016).

A recent consensus paper (coauthored by ourselves and 56 expert colleagues) thus sought to suggest possible standards for the field (Green et al., 2019). The paper explored a number of pertinent topics in depth, including proposed best practices in participant sampling, assignment to groups (i.e., whether to randomly or pseudorandomly assign participants to groups), outcome assessments, and publishing practices. For present purposes, our article focuses on two related issues: control tasks and double-blinding.

In brief, in a study asking whether a given cognitive training improves educational outcomes, the purpose of a control group is to determine whether the cognitive training has more impact than a placebo alone. In pharmaceutical research, placebo effects typically involve an inert condition (e.g., a sugar pill), which participants cannot distinguish from the true drug. If a drug does not produce benefits larger than a sugar pill alone, it would not go to market. In the cognitive training field, the difficulty is determining the equivalent of a sugar pill.

Unlike the medical field, two behavioral training tasks cannot be outwardly identical to participants, with one being active and one being inert. Indeed, the very things that make a behavioral training paradigm "active" or "inert" include what the participant experiences and what the participant is asked to do. The best that can be done is therefore to attempt to blind the participants to the intent of the training. One suggestion is therefore for researchers to employ a control condition that seems as face valid as the experimental intervention, from the participants' perspective. Combining this with further attempts to blind participants could entail describing both the experimental and control training tasks to the participants as being likely to induce cognitive change. The design of control training tasks that are, at once, completely benign with respect to cognitive change, while being believable as a true experimental intervention (at least to a naïve participant), is not necessarily trivial. More work is needed in distinct areas, including how to best assess participant expectations, how to design control tasks to best match up with participant expectations, and whether expectations alone can induce cognitive change.

Regulation of Interventions That Claim to Improve Cognitive Function

Given the current state of the field, we now turn to suggestions for policymakers and regulatory agencies. One key question in the domain of behavioral interventions for cognitive enhancement concerns what body, organization, or agency is best positioned to regulate the relevant commercial products. The Food and Drug Administration (FDA) does regulate subsections of cognitive enhancement devices (e.g., those that utilize neurological devices or neuropharmacological agents). However, because purely behavioral interventions, deployed in normal healthy adults, pose essentially no risk to safety, such use likely does not fall under the FDA (although deployment in patient populations, particularly if in lieu of other medical treatments, may). A second regulatory agency, the Federal Trade Commission (FTC), is positioned to regulate not the use of the interventions per se, but the claims made by commercial products in advertising. The lack of methodological clarity in the field has certainly muddied this water, both for those that have sought to commercialize products and for those who have sought to regulate the commercialization.

Previous statements by the FTC have suggested the need for "double-blind" and "adequately controlled" studies before claims of efficacy can be made in advertisements. Note, again, that participants cannot be blind to treatment, at least not in the same way as in a pharmaceutical trial.[1] Additional research is needed on how best to blind participants to the intent of cognitive training tasks/controls and how best to assess whether this has been done. Until then though, given the complexities involved, any regulation should involve an interplay among scientists, industry groups, and regulatory bodies.

Regulatory bodies and policymakers have many possible roles in this sphere beyond simply regulating advertising. Regulatory bodies could incentivize good practices in the development and distribution of cognitive enhancement products (Green & Seitz, 2015). For instance, rather than treating evidence of efficacy as a strict binary (as in "Yes, there is sufficient evidence of efficacy" or "No, there is not sufficient evidence of efficacy"), a labeling system that certifies various degrees of evidence provides a better match to the realities of the field and could provide a market advantage for good actors in the space. Given the fact that such products are often within consumers' normal use patterns, consumers might prefer to know if certain products, for instance, have shown positive results in basic science studies, even if they have never gone through a full "clinical trial." Such a structure would thus allow consumers to be fully informed with regard to which products have achieved what level of evidentiary standard.

Suggestions for Funding Agencies

Many of the suggestions for improving research in this domain involve significant extra costs as compared with the status quo. For instance, utilizing different personnel for testing and training participants allows for researcher blinding, but also significantly increases personnel costs. Similarly, moving to include more real-world measures (e.g., actual academic achievement), in addition to lab-based measures of various cognitive abilities, will substantially increase participant numbers. As a simple example, if the targeted effect size for an intervention's impact on a cognitive function known to underlie academic achievement is in the medium range, the impact of the intervention on actual academic achievement has to be lower than that. Such effects are worth pursuing, but will require substantially larger sample sizes to detect (or fail to detect) with confidence. Furthermore, because the predicted impact of cognitive training on academic achievement is typically with respect to long-term academic achievement, as opposed to immediate achievement, the assessment of such longitudinal effects will require stable funding over the period of, in some cases, many years.

Ethical Considerations With Respect to Education

Policymakers should consider several ethical issues regarding behavioral interventions for cognitive enhancement to boost scholastic achievement. One broad set of considerations centers around when such products would be utilized by children—specifically whether the use would displace traditional academic content (i.e., during school hours that normally offer more traditional lessons). Although the idea of utilizing time in school to build basic cognitive abilities is not outlandish on its face (again, this basic proposal goes back at least as far as Binet and his "mental orthopedics"), a steeper evidentiary standard must be met to justify such content displacement, compared with traditional school activities not being displaced by the intervention (i.e., if the intervention was part of an after school program). Indeed, if an individual chooses to have his or her child engage with a particular cognitive training program after dinner each night and that product “doesn’t work” (i.e., produces no general change in cognitive function), there is certainly an opportunity cost. However, this opportunity cost is likely to be fairly minor, given the activities displaced. If, on the contrary, a school chooses to have their students engage with a cognitive training program when they would otherwise be engaging with lessons in reading or mathematics, the cost of a “failure” is certainly much steeper. At least in our mind, no existing cognitive training product has met the evidentiary standard that would warrant such class time displacement.

A second broad set of ethical considerations centers around equitability of access. Initial inequities in access to content, programming, or activities that are valuable for promoting scholastic performance may not only produce immediate differences in academic outcomes, but can also snowball into much larger long-term differences. Given that the students who have the most need for general boosts in cognitive function might not be the same students who are most capable of paying for potentially expensive cognitive training, this certainly raises concerns about the “rich getting richer.”

Conclusion

In all, the existing literature on behavioral interventions for cognitive enhancement suggests that there are reasons to be optimistic that such interventions could eventually result in consistent real-world improvements in academic achievement. However, much additional work would need to meet such a high standard of evidence. To this end, policymakers and regulatory bodies should support not only more and better data in the field, but also high standards for the use of such interventions.

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Note

1. Note, also, that many clinical trials within the pharmaceutical domain likely fail to live up to true double-blinding. Almost all active substances have at least mild side effects (e.g., headache, dry mouth, etc.), whereas truly inert substances will not. Thus, it is often possible for both participants and research personnel even in “gold standard double-blind placebo-controlled studies” to make educated guesses regarding treatment condition based upon the presence/absence of side effects, and evidence suggests that they in many cases do so (Hrobjartsson, Forfang, Haahr, Als-Nielsen, & Brorson, 2007).

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