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The case for an ecological approach to cognitive training

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Strong claims have been made about the efficacy of cognitive training. In particular, the idea that working memory (WM) training enhances intelligence initially generated enthusiasm but, on further inspection, is now met with skepticism. In our view, this is an unfortunate setback due to inappropriate task design and does not refute the core idea of cognitive enhancement. Growing evidence suggests that successful training programs integrate complexity, novelty, and diversity to maximize ecological validity.

The case for an ecological approach to cognitive training

Not a week passes without an article or a report praising the remarkable plasticity of the brain and the numerous ways it can be trained and rewired for greater accomplishment. Various incentives for brain training have been proposed, such as enhancing academic achievement, performance in the workplace, delaying cognitive decline, and preventing dementia. Furthermore, some scientists have suggested that brain training will become a normal part of our schedule in the near future, like fitness training today [1]. Despite these optimistic claims, the impact of existing training programs remains limited. As a result, careful reconsideration of training program designs is necessary if we are to materialize current expectations.

From neuroplasticity to WM training

A brief reminder of the scientific roots surrounding cognitive training helps put recent trends in perspective. Over the past few decades, compelling evidence for neuroplasticity outside the critical period of development has opened new venues for behavioral interventions [2,3]. Taking advantage of the malleability of our neural networks across the lifespan, cognitive training has emerged as a valid alternative to more invasive interventions such as transcranial magnetic stimulation (TMS) or pharmaceutical enhancers to improve cognitive abilities.

In search of a training regimen that could induce improvements to a wide range of cognitive abilities, researchers have turned to WM. WM is a construct developed to explain the role of short-term memory in complex cognition [4] and is essential for a wide range of tasks such as reasoning, problem solving, and decision making. WM capacity (WMC), the maximal information that can be manipulated in WM at a given time, typically varies across individuals and is strongly correlated with general intelligence (*g*) [5]. WMC and *g* also share neural correlates, particularly regions of the prefrontal cortex [6]. This makes WM an ideal target for training programs seeking general improvements in cognition.

Besides being theoretically motivated, the use of WM tasks in cognitive training is also convenient, because experimental and psychometric research in this field has been extremely fruitful in the past few decades (see [7] for a recent review in the visual domain). Over the years, cognitive psychologists have developed many standardized tests to measure WMC, such as the *N*-back and complex span tasks. With relatively minor modifications, tasks designed for the measurement of WMC have been redesigned to train WM. Also, many tasks have been developed that do not correlate with WMC (e.g., visual search), therefore providing valid training regimens for active control groups. Previous literature has indicated the need for control conditions to be as demanding as experimental conditions – cognitively, but also in terms of motivation, expectations, and efforts – while not demanding WM resources [8]. These types of randomized controlled experiments are considered the gold standard because of their methodological precision.

Limitations of WM training

There are serious limitations to this approach. First, the architecture of WM is complex and includes two major components: domain-general and domain-specific processes. Structural equation models have demonstrated that different measures of WMC correlate strongly [9] even when testing items are different [5,10]. In other words, WMC is largely influenced by domain-general mechanisms and therefore does not vary notably depending on the type of testing item. Training upsets this equilibrium. Tasks designed to measure WMC such as the *N*-back and complex span are repetitive and predictable in the context of training. For example, the timing of displays, the type of stimuli, and response requirements are consistent across the task, to provide an accurate measure of WMC. Intense practice exacerbates the importance of domain-specific processes, because these tasks, when administered repeatedly, allow honing strategies or skills rather than tapping domain-general processes. Therefore, their validity to measure WMC after training remains unclear and the nature of post-training improvements is often ambiguous.

Second, a strong correlation between WMC and *g* does not necessarily imply that both constructs will follow a similar trend of improvement with training (Box 1). This is a common fallacy in cognitive training experiments

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Box 1. Pretraining correlation does not imply training covariation

Two variables that are strongly correlated do not necessarily covary when one is being artificially inflated (e.g., via training). Figure I presents simulated data (normally distributed, $N = 1000$) showing the relationship between WMC and *g* before and after WM training. Figure IA shows the case of an increase in WMC and *g* following training, with a stable correlation ($r = 0.70$). As a result, gains in WMC and *g* are also correlated (Figure IB). This scenario is the one often presented when WM training is shown to improve intelligence. An equally plausible possibility is presented in Figure IC, where gains in WMC following training do not translate into gains in *g*, as is the case if training taps mechanisms underlying the unshared variance between WMC and *g*. In this scenario, the correlation between the two variables is artificially reduced after training ($r = 0.50$) and gains do not correlate (Figure ID). Other possibilities exist, but these extremes allow us to visualize how a strong initial correlation does not guarantee collinear post-training improvements.

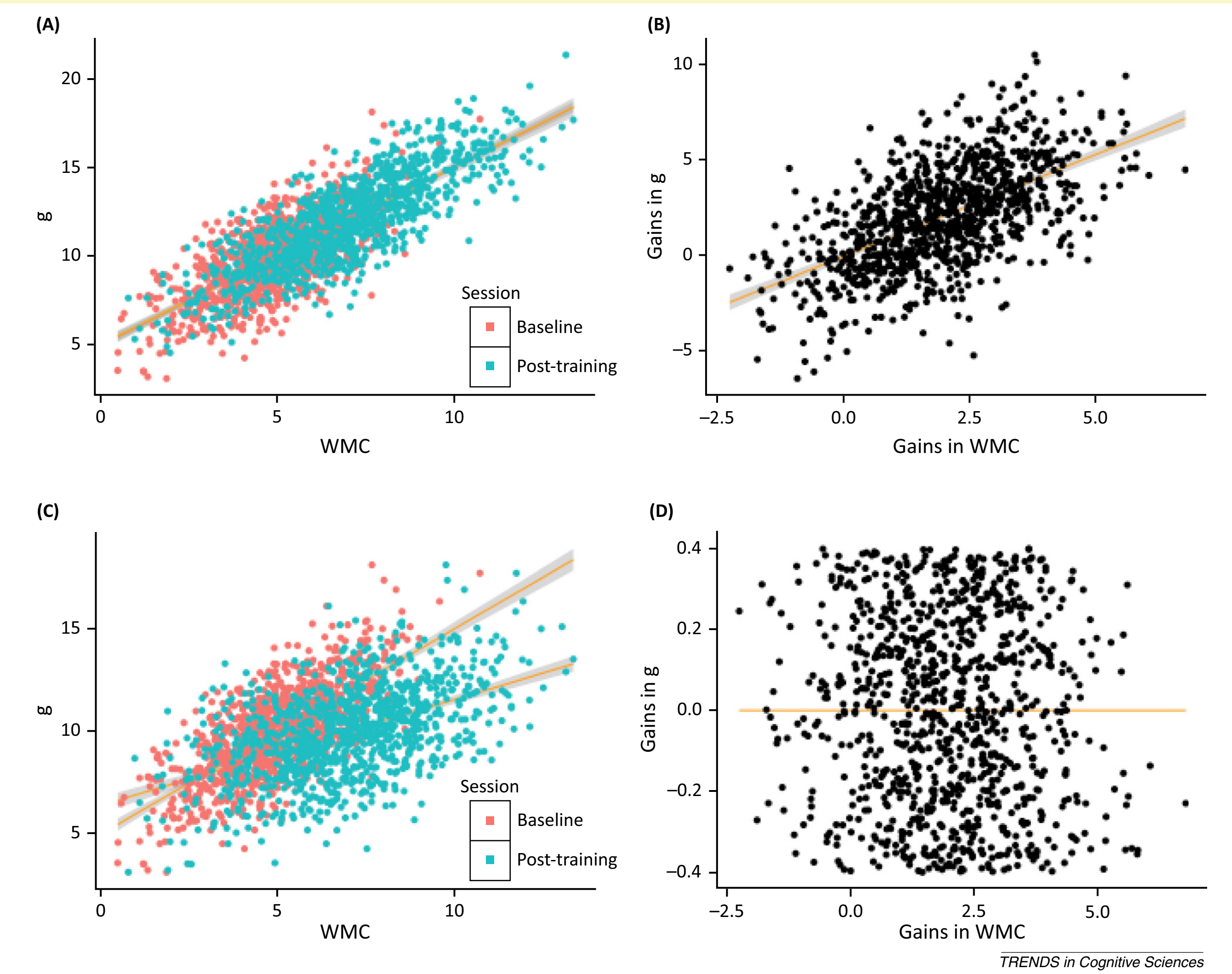

Figure I. Two different outcomes for working memory training.

including hypotheses solely based on initial correlation among constructs. Furthermore, WMC and *g* are highly correlated in the context of latent variable models but not necessarily at the level of individual tasks [5]. For example, the *N*-back task, a measure of WMC, is only moderately correlated with Raven's Advanced Progressive Matrices, a task commonly used to measure *g*.

More generally, the notion that training a single component of cognition will induce general transfer is a little optimistic. Whenever possible, the human nervous system seeks efficiency [11] and is therefore prone to alleviate cognitive load via effective strategies. How can a training program constantly challenge domain-general mechanisms, triggering wide and durable changes? Current trends in cognitive science offer preliminary answers to this question.

Working toward ecological interventions

Despite the central role of WM in human cognition, perhaps WM tasks are not the most pertinent way to train the brain. To some extent, the same applies to computerized brain training: most of the tasks included in brain-training software are impoverished and non-ecological, with few real-world applications. A close review of neurophysiological research in cognitive training indicates that tapping domain-general mechanisms [12] to induce transfer to a wide range of situations requires training programs to include three components: complexity, novelty, and diversity [11]. Typically, WM training includes only the former, via adaptive paradigms (i.e., continuously updated based on individual performance). However, novelty and diversity are usually ignored [8], but are always present in successful training designs [13,14].

There are numerous ways to incorporate complexity, novelty, and diversity within training designs. In particular, engaging in complex activities that combine motor and cognitive demands, such as playing music [15] or sports [11], seems to trigger superior cognitive gains while simultaneously mastering skills in an activity and encouraging social interactions. Based on the considerable success of physical exercise and, to some extent, video gaming paradigms in cognitive enhancement, combinations of cognitive and physical demands are an optimal way to foster cognitive abilities. This approach is not without its challenges: complex training activities performed in open environments – with lower predictability – are difficult to control and to embed within experimental designs, because they typically increase degrees of freedom concerning the types of response that can be recorded. In this regard, flexible yet controllable virtual environments are promising, especially given the recent rise of affordable motion-sensing devices in video game consoles (e.g., Microsoft Kinect).

An additional benefit of implementing training programs based on ecological activities pertains to the ratio between commitment cost and expected outcome. In the case of WM or computerized training, this value is relatively high, because enrolling in a program often has substantial time costs and results in limited gains. By contrast, ecological interventions can trigger far-reaching improvements in cognitive abilities, health and well-being, while remaining relatively inexpensive. Therefore, engaging in ecological activities appears to be a significantly better investment.

Concluding remarks

Can cognition be improved? Certainly. However, optimal training programs have yet to be designed. The notion that the brain remains malleable across the lifespan has prompted insightful and engaging research in the field of cognitive training. Given both the remarkable plasticity of the brain and the massive funding poured into cognitive training research, scientists have a responsibility to inform the public objectively, based on sound and well-designed experiments addressing the numerous remaining challenges (Box 2). In our opinion, the idea of training cognitive abilities should not be abandoned because of recent skepticism about WM training. Future training experiments ought to build on prior work targeting WM mechanisms with a more ecological perspective to refine theoretical models of cognition and extensively benefit applied fields.

Box 2. Future challenges in cognitive training

Cognitive training faces several challenges or areas that need further experimental investigation. These include the following.

- Determining the best combination, or ratio, between purely cognitive and physical solicitations to improve cognitive function.
- Determining the optimal frequency and duration of cognitive training programs.
- Providing a working framework for individualized training tailored to one's particular needs and expectations.
- Combining behavioral measures with neural data to refine theoretical models of cognitive enhancement.
- Designing ecologically valid interventions incorporating complex and diverse environments while retaining control over training parameters (e.g., virtual reality).

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