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Efficiency and capacity mechanisms can coexist in cognitive training

The motto 'practice makes perfect' has fuelled the popularity of cognitive training over the past two decades, but the field still lacks nuanced explanations for training-induced transfer effects. von Bastion et al. recently provided a comprehensive Review of cognitive training (von Bastian, C. C. et al. Mechanisms underlying training-induced cognitive change. *Nat. Rev. Psychol*. **1**, 30–41; 2022)[1], using the capacity–efficiency model to explain training effects. A critical argument in the article is that there is little evidence that overall cognitive resource capacity is enhanced by training (the capacity mechanism), but substantial evidence that performance within the existing capacity limit is optimized (the efficiency mechanism). However, neglected evidence in working memory training, from the genetic, molecular and neural systems levels, supports the capacity mechanism.

Working memory training might act on the same genes as the development-induced increase in working memory capacity. A recent molecular genetic study in humans (aged 7–19 years) reported that the gains in working memory capacity after years of typical development and the gains in working memory capacity after weeks of training are influenced by some of the same genes[2]. These results suggest that working memory capacity training can trigger the biological machinery responsible for long-term development of working memory capacity. Developing working memory capacity requires a challenging environment[3]; in this respect, working memory training mimics the typical challenging environment that fosters the natural development of working memory capacity. Critics might instead argue that the development of working memory capacity could result from efficiency mechanisms (such as encoding speed). However, there is abundant evidence that working memory capacity truly develops during childhood independently of efficiency[4]. Thus, at least for people who have not fully developed their working memory capacity, training might act on the capacity mechanism.

There is also direct molecular evidence that working memory training enhances 'capacity'. A series of experiments in mice explored the mechanism that underlies working memory training. Mice were trained to navigate mazes and progressively remembered more spatial cues and improved on untrained tasks of working memory capacity. The training group showed increased density of dopamine D1 receptors in the prefrontal cortex compared to active controls[5,6]. D1 receptors are known to play a role in how working memory stores and protects information in the brains of both animals and humans[7]. Thus, the finding of increased D1 receptor density implies that more resources can be used to maintain information, supporting the capacity mechanism.

Finally, human brain imaging studies at the systems level provide additional evidence of the capacity mechanism in action. A critical assumption is that increases in capacity from training should lead to increased brain activity (underpinning working memory performance) whereas increases in efficiency should lead to decreased activity[8]. Working memory capacity training increases frontoparietal activation of relevant brain regions in adults[9,10]. This increase correlates with behavioural improvement in working memory capacity. The frontoparietal increase was also observed during typical development of working memory capacity in children. Thus, after training, more neural resources are used to store information – another sign of increased capacity.

In the same brain imaging study, some frontoparietal regions also showed decreased activity[9], a sign of improved efficiency. This pattern raises another note: the capacity and efficiency mechanisms can coexist. There are probably circumstances in which the capacity mechanism is dominant (such as during childhood). In other circumstances, the efficiency mechanism might be dominant (such as during the first few days of cognitive training). And for most learning, both mechanisms might be engaged to differing degrees.

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Competing interests

The authors declare no competing interests.