The Absence of Far Transfer in Cognitive Training and Potential Solution Pathways

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Abstract

An important objective of cognitive training is to enhance multiple cognitive functions through repeated practice of specific tasks or games. However, domain-specific cognitive training struggles to produce far transfer. Cognitive training theory suggests that the lack of far transfer indicates relative independence among cognitive functions. Neuroimaging research has revealed that while cognitive functions share numerous local brain regions and brain network activities, their global activity patterns differ. Domain-specific cognitive training reinforces cognitive-specific global brain activity patterns, impeding transfer; conversely, domain-general cognitive training incorporates multiple cognitive domains and may generate far transfer. Future investigations should attend to the distinct mechanisms and application contexts of domain-specific versus domain-general cognitive training, thereby further propelling the advancement of cognitive training and cognitive structure theories.

Full Text

The Lack of Far Transfer Effects in Cognitive Training and Potential Solutions

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Abstract

The primary goal of cognitive training is to improve multiple cognitive abilities through repeated performance of particular tasks or games. However, domain-specific cognitive training struggles to produce far transfer effects. Cognitive training theories suggest that this absence of far transfer indicates the relative independence of cognitive functions. Brain imaging studies have revealed that although cognitive functions share numerous local brain regions and network activities, their global patterns of brain activity differ. Domain-specific cognitive training strengthens these cognitive-specific global brain activity patterns, thereby hindering transfer, whereas domain-general cognitive training, which encompasses multiple cognitive domains, may generate far transfer. Future research should examine the distinct mechanisms and application contexts of domain-specific versus domain-general cognitive training to further advance cognitive training and cognitive structure theories.

Keywords: cognitive training, transfer effect, domain-general, domain-specific, cognitive structure theory

1 Introduction

Cognitive training is the process of improving specific cognitive functions through repeated execution of particular tasks or games. The phenomenon where training one cognitive function enhances other cognitive functions is known as the transfer effect. Transfer effects are typically classified as near transfer or far transfer. Although researchers define these concepts differently, most studies refer to near transfer as improved performance on tasks similar in structure and content to the trained task, while far transfer refers to improved performance on tasks that differ substantially from the trained task or in daily life activities [1, 2]. The transfer effect is a core concept in cognitive training and represents a key objective for practitioners. On one hand, psychometric tests reveal that most mental abilities are positively correlated [3]; on the other hand, different psychological functions share extensive local and global brain activity patterns [4, 5]. These observations have led to the expectation that training one cognitive function—preferably a fundamental one—through cognitive tasks could promote improvements in multiple cognitive abilities and even intelligence development.

However, a growing consensus in cognitive training research suggests that training effects rarely generalize across different cognitive domains, resulting in a pervasive lack of far transfer [6, 7]. Current theories of transfer effects generally ground the mechanism of transfer in the sharing or application of cognitive structures, and these theories uniformly posit that near transfer occurs readily while far transfer is extremely difficult to achieve [8]. The empirical and theoretical evidence for the absence of far transfer in cognitive training seems to indicate that cognitive functions are relatively independent, which contradicts both the positive correlations among cognitive functions and the substantial overlap in their neural substrates. If cognitive functions are indeed closely related, why does far transfer remain so elusive?

This paper reviews empirical research and theoretical explanations for the lack of far transfer in cognitive training. Based on findings from brain imaging studies, we propose a shift from domain-specific to domain-general cognitive training as a potential solution for achieving far transfer.

2.1 The Absence of Far Transfer in Commercial Cognitive Training

Cognitive training represents an important pathway for psychology to serve society. To date, commercial cognitive training has developed into a massive market worth tens of billions of dollars [1]. This large user base provides valuable samples for examining transfer effects. Nevertheless, Simons et al. [9] noted in their 2016 review that many studies on commercial cognitive training suffer from design flaws or exaggerated transfer effects due to corporate sponsorship, and these studies fail to provide adequate evidence for far transfer. Subsequently, systematic reviews by Rossignoli-Palomeque et al. [10] on children and adolescents and by Rabipour et al. [11] on older adults demonstrated that commercial cognitive training produces no long-lasting cognitive enhancement effects, let alone far transfer, regardless of participants' plasticity levels. Large-scale online studies by Owen et al. [12] with 11,430 participants and Hampshire et al. [13] with 60,222 participants showed that long-term training yields modest improvements in the trained cognitive functions but reveals no transfer effects on closely related tasks or in daily problem-solving. More recently, Nguyen et al. conducted a meta-analysis of 43 studies using commercial games to train healthy older adults and those with mild cognitive impairment, finding that after controlling for publication bias, these interventions improved only processing speed while having no effect on attention, memory, executive function, or fluid intelligence [14].

These critiques of commercial cognitive training encompass two aspects. First, training effects are weak, yielding extremely low cost-benefit ratios. This may indicate that cognitive functions possess remarkable stability and do not change significantly after just a few months or even hours of practice, or it may reflect how the over-commercialization of cognitive training undermines its targeted effectiveness. Second, the absence of far transfer fails to meet people' s expectations for cognitive training outcomes. This lack of far transfer may be determined by the independence of cognitive structures, or it may result from the training' s minimal improvement in cognitive functions themselves, making transfer to other functions even more unlikely. The suboptimal effects of commercial cognitive training have initially exposed the predicament of cognitive training, but the distortion, unprofessionalism, and over-packaging in explaining the underlying scientific principles do little to reveal the true causes of this dilemma.

2.2 The Absence of Far Transfer in Basic Cognitive Function Training

Compared to commercial cognitive training, laboratory-based cognitive training offers better control over various variables, enabling more accurate assessment of transfer effects. Working memory training has received the most attention in laboratory settings. However, recent meta-analyses indicate that working memory training produces transfer effects approaching zero on verbal and nonverbal intelligence [6], fluid intelligence [15], cognitive control, and academic achievement [16, 17]. This absence of transfer effects is not due to inconsistent research findings [18].

Furthermore, Simonet et al. [19] compared the transfer effects of complex executive function training involving motor, perceptual, and control components with those of simple executive function training, finding that neither produced generalization to other cognitive abilities. A meta-analysis incorporating 9,553 studies on various training methods, including executive function training, classroom activities, and games, revealed that transfer effect assessment is confounded by small sample sizes, publication bias, and inconsistent results, showing no clear far transfer effects in literacy, numeracy, language, intelligence, or social domains [20]. Additional research indicates that education has minimal impact on General Cognitive Ability (GCA), primarily changing abilities learned in school [21]. GCA refers to the common inter-individual variance across all cognitive ability tests, also known as intelligence, Spearman' s g, or general mental ability [3]. Thus, even education—a comprehensive form of cognitive training—modifies only domain-specific cognitive abilities.

These meta-analyses demonstrate that far transfer remains difficult to detect even under rigorous experimental control, while direct training effects and near transfer typically achieve only small to moderate effect sizes. Although laboratory studies yield slightly stronger effects than commercial cognitive training, training even those cognitive functions that effectively predict academic performance and behavioral outcomes—such as working memory and executive function—fails to transfer to other cognitive functions [22, 23]. The absence of far transfer appears to suggest that cognitive functions are indeed highly independent, yet two alternative explanations remain plausible: first, cognitive training may not actually improve cognitive abilities but merely enable trainees to develop strategies for handling similar tasks [24, 25]; second, cognitive abilities may be holistic [26, 27], and overlapping cognitive structures may not facilitate transfer of training effects.

2.3 The Absence of Far Transfer in Game, Music, and Chess Training

Experts or masters achieve remarkable accomplishments through domain-specific knowledge or skill training [28], providing an excellent vehicle for detecting far transfer by effectively ruling out the possibility that weak training effects prevent transfer. Domain-specificity refers to mental abilities for solving problems confined to a particular field, whereas domain-generality refers to content-independent mental abilities for complex tasks [3]. Since domain-specific knowledge is difficult to generalize across domains, this becomes another potential reason for the absence of far transfer.

Regarding game training, Sala et al. [29] examined over 300 studies on video game training using random-effects meta-analysis models, finding near-zero far transfer effects. Another meta-analysis revealed that while scores in certain games show moderate correlations with specific cognitive abilities, game skills show no correlation with general cognitive ability [3]. This suggests that because different gamers employ different techniques or strategies, game scores alone may inadequately represent training effects.

Regarding music training, although musicians outperform non-musicians on various domain-general cognitive abilities such as memory, fluid intelligence, and processing speed [30, 31], studies have found that music training groups show near-zero effects on general cognitive ability compared to active control groups [32]. A twin study found no IQ differences between twins with and without music training, indicating that despite musicians requiring thousands of hours of training to achieve remarkable accomplishments, these achievements do not transfer to general cognitive ability [33]. Another study found that musicians' general cognitive ability is related to musical aptitude rather than music training [34]. It can be argued that music training does not improve general cognitive ability; rather, intelligent individuals are more likely to succeed in music [3].

Similarly, while chess masters exhibit superior cognitive abilities compared to average individuals [35, 36], chess training groups show no significant effects on cognitive and academic abilities compared to active controls [37]. Some scholars suggest that the cognitive benefits of chess training may be placebo effects [3].

Taken together, whether commercial or laboratory-based, whether training basic cognitive functions or domain-specific skills, and whether producing strong or weak training effects, various types of cognitive training struggle to generate far transfer. The absence of far transfer as a universal phenomenon implies that cognitive functions are relatively independent, which has important implications for cognitive structure theories and urgently requires reasonable theoretical explanation.

3 Theoretical Explanations of Transfer Effects

Although cognitive training research is flourishing, theories of cognitive training remain extremely scarce. This scarcity stems partly from the belief that cognitive training, like muscle training, is natural and requires no explanation, and partly from the view that skills acquired through training are highly specific, making generalized cognitive training nearly impossible and thus unnecessary to theorize [8]. The limited existing cognitive training theories primarily explain the absence of far transfer based on cognitive structures. However, most of these theories lack operational derivations, and empirical research struggles to adhere to their theoretical premises [8], creating a disconnect between theory and evidence that has prevented breakthrough progress in transfer effect research.

3.1 Component- and Rule-Based Theories

Woodworth and Thorndike [38] proposed the identical elements theory, the earliest theoretical explanation of cognitive training. This hypothesis posits that transfer occurs only when two skills share identical knowledge components, making far transfer extremely difficult and rare due to reduced component overlap. Nearly 90 years later, Singley and Anderson [39] introduced a modern version of identical elements theory, identifying the shared element as the production rule—a specific knowledge representation form concerning how to take multiple actions to achieve multiple goals. Production rules are highly specific; for instance, production rules for multi-digit addition cannot be applied to multi-digit subtraction, making transfer difficult. Taatgen [40] further decomposed production rules, proposing the Primitive Information Processing Element (PRIM) theory. PRIM uses operators as basic units, with different operators combining to form rules. Different rules can be reused across tasks; for example, carrying rules are shared between multi-digit addition and multiplication. PRIM theory suggests that task performance improvements may result merely from sharing rules rather than from cognitive ability transfer.

Whether component- or rule-based, these theories agree that far transfer is difficult but fail to specify the conditions under which it might occur. Within this framework, the following inferences can be made: Scenario 1: If two cognitive functions share common components or rules (hereinafter "components") and these components are core components of both functions (primary determinants of performance level), transfer should occur; however, due to core component overlap, the two functions are highly similar, constituting near transfer. Scenario 2: If shared components are not core components of either function, training effects will not transfer, and the two functions differ substantially, resulting in absent transfer. Scenario 3: If shared components are core to the trained function but not to the transfer function, transfer will also be difficult to demonstrate, with the two functions differing substantially and transfer absent. Scenario 4: If shared components are core to the transfer function but not to the trained function, the two functions differ substantially but transfer may still occur—this constitutes far transfer. Scenario 5: If two cognitive functions share no components, the trained function cannot transfer to the new function, the two functions differ substantially, and transfer is absent. Within this framework, near transfer occurs when trained and transfer functions share core components, while far transfer occurs when non-core components of the trained function serve as core components of the transfer function; in all other scenarios, transfer is absent (see Figure 1 [Figure 1: see original paper]).

Based on this framework, although attention and working memory can influence multiple cognitive functions, these functions do not contain the core components required for transfer, preventing migration from occurring. Game, music, and chess training typically involve multiple components that may serve as core components of other cognitive functions, but because these trainings largely include or substantially overlap with transfer functions, such cases can only be considered near transfer. Thus, component- and rule-based theories adequately explain the current phenomenon of absent far transfer. Within this framework, while far transfer may be possible, its conditions are extremely demanding. Theoretically, achieving far transfer requires first decomposing several cognitive functions and determining the weight of each component within them, then identifying the functions to train and transfer to through reasonable combination. Although decomposing cognitive functions has theoretical value, directly training the required cognitive function is obviously more direct and efficient.

3.2 Strategy-Based Explanations

Recent research suggests that cognitive training may not actually improve corresponding cognitive abilities but may simply enable participants to acquire more effective strategies for task completion. Von Bastian and Oberauer [41] proposed the capacity-efficiency model of cognitive training and transfer, positing that training can produce transfer through two pathways: increasing available cognitive resources (capacity) or improving the efficiency of existing resource use (efficiency). Efficiency improvements include acquiring new strategies, obtaining general task knowledge, increasing automation, and enhancing information processing speed [42]. In numerous studies, transfer occurs primarily due to improved cognitive efficiency rather than increased cognitive resources. Some researchers argue that near transfer may be superficial transfer, where performance improvements on tasks structurally similar to training tasks result merely from acquiring surface-level strategies rather than genuinely improving the expected cognitive ability [43]. Forsberg et al. [25] provided direct evidence for the strategy hypothesis by teaching young participants visualization strategies that improved their performance on n-back tasks, but these strategies did not transfer to working memory tasks with different structures, demonstrating that strategies struggle to produce far transfer.

Other researchers have described the transition from controlled to automatic processing during training based on rule-based theories, which essentially supports the strategy hypothesis. The triarchic theory of learning posits that novices in new cognitive tasks primarily rely on metacognitive systems to generate and establish new behavioral routines. These routines may involve strategies such as information chunking or mental imagery. Once routines are formed, the metacognitive system' s role diminishes, and learners primarily use cognitive control networks to execute these routines. After sufficient practice, learners shift from controlled to automatic processing [44]. The cognitive routine framework similarly holds that cognitive training learns new skills by developing new cognitive routines [45]. When facing unfamiliar training tasks, general cognitive resources are needed to identify and execute routines; by training' s end, routine processing becomes automated.

Strategy-based explanations view strategies as specific to task structures rather than cognitive components, with transfer effects manifesting as applying identical strategies to structurally similar tasks. Participants' performance improvements on specific tasks merely reflect better coping with task demands; once the context changes, new strategies must be learned. These perspectives also adequately explain why near transfer occurs readily while far transfer is extremely difficult.

Due to the absence of far transfer, Gobet and Sala [46] suggest future research should focus on near transfer or domain-specific effects of training itself. Moreau [47] more radically argues that cognitive training has no future and calls for researchers to shift interest to other fields. However, the contradiction between independence and interrelatedness of cognitive functions remains unresolved, and the construction of educational theories still requires empirical support from cognitive training, making research on cognitive training and transfer effects essential.

4 Insights from Brain Imaging Studies on Transfer Effects

Whether sharing cognitive components, rules, or task strategies, "sharing" is the core concept in current transfer theories. From a brain mechanism perspective, what exactly do different cognitive functions share?

Cognitive functions share substantial local brain activity and network connectivity. Gonzalez-Castillo et al. [4] found that when brain signal signal-to-noise ratios are sufficiently high, nearly all brain regions can be detected responding to the same cognitive task with distinct activity patterns. This whole-brain response may relate to energy reallocation across the brain during task performance [48]. Fox et al. [49] noted that most cognitive tasks activate frontal and parietal regions related to cognitive control and deactivate the default mode network (DMN). Cocuzza et al. examined whole-brain functional connectivity while participants completed 64 cognitive tasks, finding that the fronto-parietal network (FPN) and cingulo-opercular network (CON) participated in all tasks but with different connectivity patterns across tasks [50]. Additionally, numerous studies have found that various cognitive tasks share largely identical brain network nodes, with most connections between these nodes showing similar patterns across tasks and only a small portion showing inter-task differences [51-54]. These findings indicate that cognitive functions are not independent, yet this extensive sharing of brain regions or network activity has not facilitated transfer effects. So what kind of brain activity creates barriers between cognitive functions?

The distinction between cognitive functions lies in different patterns of brain activity. On one hand, some cognitive functions depend on unique brain region activity. For instance, face recognition relies on specialized processing in the fusiform face area [55]. Such specialized processing typically cannot transfer to cognitive activities in other domains. On the other hand, shared brain regions and network connections exhibit different activity patterns across cognitive functions. General cognitive ability primarily depends on dynamic switching capabilities between networks such as DMN, FPN, and CON [56], whereas domain-specific cognitive functions depend on specific brain activity patterns formed through collaboration between shared and non-shared brain regions. Even when memorizing identical material, different brain activity patterns correspond to good versus poor memory performance [57].

Thus, brain activity also exhibits domain-specific and domain-general characteristics. Cognitive function realization depends on the organic integration of both. Domain-general brain networks can effectively modulate domain-specific brain networks, but not vice versa [58]; domain-specific cognitive training typically does not generalize specific brain activity patterns but instead strengthens their specificity [59]. Within the domain-specific and domain-general framework, domain-specific cognitive training solidifies cognitive-specific brain activity patterns, leading to functional differentiation, whereas domain-general cognitive training spans multiple cognitive domains, leading to functional generalization. Barbey (2018) noted that intelligence or general cognitive ability does not correspond to a fixed whole-brain activity pattern; individual differences primarily manifest in brain network organizational efficiency and flexible reorganization capacity. Therefore, the more cognitive training leans toward domain-general cognitive functions, the more it requires brain networks to flexibly switch between specific brain activity patterns corresponding to different cognitive functions, and the greater the likelihood of transfer (see Figure 2 [Figure 2: see original paper]).

5 Summary and Outlook

The lack of far transfer in cognitive training remains an unresolved problem after more than 100 years [43]. Although some studies report significant far transfer effects, after excluding issues of conceptual definition, experimental design quality, and statistical artifacts, the effect size of far transfer is essentially zero [3]. Cognitive training theories typically explain the absence of far transfer through shared cognitive components, rules, or strategies, but because these theories mostly lack operational derivations or empirical research struggles to adhere to theoretical premises, research on transfer effects has not achieved substantive breakthroughs [43]. Recent brain imaging studies have found that what distinguishes different cognitive functions is not domain-specific brain activity but whole-brain activity patterns composed of both domain-specific and domain-general brain activity. Domain-specific cognitive training differentiates and fixes brain activity into a specific pattern, which may be why far transfer is difficult to achieve. Therefore, this paper argues that cognitive training should return to the fundamental framework of domain-specificity and domain-generality, and the absence of far transfer in domain-specific cognitive training may be resolved through domain-general cognitive training.

Within the domain-specific and domain-general framework, both types of training have unique value. On one hand, domain-specific cognitive training remains an effective approach for enhancing specific cognitive functions. Efficient cognitive processing is a specific, high-fidelity process that completes specialized cognitive processing with minimal brain regions and specific connections [60]. Domain-specific cognitive training can enhance the specificity of cognitive processing, thereby improving the efficiency of specific cognitive functions. On the other hand, domain-general cognitive training holds promise for producing far transfer and may even improve general cognitive ability or intelligence. A meta-analysis based on 600,000 participants indicated that schooling can improve intelligence scores by 1-5 points [61], an effect never achieved by current cognitive training [3]. Whether domain-general cognitive training can achieve better brain-intelligence enhancement effects remains to be seen. From an applied perspective, the interactive-specialization hypothesis of brain development [62] and the dedifferentiation hypothesis of brain aging [63] suggest that cortical circuit specificity increases with development and decreases with aging. Consequently, domain-general and domain-specific cognitive training may have different advantages at different life stages. Additionally, both independent and co-occurring cognitive function abnormalities exist in brain diseases and cognitive development [64], giving domain-general and domain-specific cognitive training 各自独特的价值 in disease rehabilitation.

The domain-specific and domain-general framework may resolve the contradiction between independence and interrelatedness of cognitive functions. The independence of cognitive functions is an external manifestation of functional differentiation and transfer difficulty caused by domain-specific cognitive training, whereas the interrelatedness of cognitive functions may result from domain-general cognitive functions modulating domain-specific cognitive functions. Brain imaging studies have found that the global signal (GS), as the average of whole-brain signals, positively correlates with signals in each brain region and also causes positive correlations between brain region signals; after regressing out GS, many negative correlations between brain region signals become apparent [65]. Thus, the independence and interrelatedness of brain region signals are modulated by GS, consistent with domain-general brain networks modulating domain-specific brain networks. Furthermore, according to the general principle that more integrated brain signals execute more integrated cognitive functions [66], GS, as the largest-scale signal integration in the whole brain, may be closely related to domain-general cognitive functions. Research showing that GS modulates whole-brain network dynamics [67] and that intelligence depends on dynamic switching of whole-brain networks [56] supports this possibility. Therefore, the asymmetric relationship between domain-general and domain-specific cognitive functions and its brain mechanisms may resolve the contradiction between independence and interrelatedness of cognitive functions and prompt theoretical research to break through its original framework and establish more comprehensive cognitive structure theories.

The domain-specific and domain-general framework requires new research paradigms and cognitive structure theories. In addition to behavior- and computer-based cognitive training, non-invasive brain intervention techniques are flourishing and becoming important means of brain function modulation [68]. Techniques 偏向精准干预 such as transcranial magnetic stimulation and high-precision transcranial electrical stimulation 致力于调节特定的脑区及相关的神经回路 [69] and may enhance domain-specific cognitive training effects, while various low-precision transcranial electrical stimulation techniques may modulate overall brain activity excitability and 有望提升领域一般性认知训练的效果 [70]. Combining physical stimulation' s modulation of neural activity with cognitive tasks' modulation of psychological functions may achieve effects that address both symptoms (cognitive functions) and root causes (neural activity). These cognitive training approaches need to use brain imaging technology to probe the brain mechanisms of training and transfer effects on one hand, and to optimize training protocols and propose new training paradigms based on brain imaging-revealed brain functional organization patterns on the other. Additionally, hierarchical [71] and gradient [5] organization patterns of brain functional activity at local and global scales provide important foundations for constructing new cognitive structure theories. Within the domain-specific and domain-general framework, brain imaging technology 有望助力认知训练产生更显著的迁移效应，甚至可能实现远迁移; the integration of brain imaging technology and cognitive training will also promote further development and refinement of cognitive structure theories.

Finally, clarifying whether far transfer occurs and under what conditions is an important pathway for establishing and testing cognitive structure theories and represents a significant breakthrough in education, training, and rehabilitation. Returning to the fundamental framework of domain-specificity and domain-generality and strengthening research on domain-general cognitive training may be an effective path to solving the problem of far transfer absence in cognitive training. Within this framework, the organic integration of cognitive training and brain imaging technology 有望阐明认知训练及迁移效应的脑机制 and promote the deepening of cognitive structure theories.

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Note: Figure translations are in progress. See original paper for figures.