Training refines brain representations for multitasking

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Since the information processing revolution of the 1950s, and Broadbent's filter theory (1), a core problem for psychology and neuroscience has been loss of performance with multitasking or divided attention. Multitasking costs have practical importance, from air traffic control to teenage homework; in analysis of the human cognitive architecture, multitasking costs suggest collision in processing requirements for simultaneously attempted activities. Core principles established early on are the effects of practice and similarity. As tasks are practiced, they become increasingly "automatic," subjectively freeing up attention and reducing multitasking costs (2–4). When tasks are widely dissimilar, multitasking can be astonishingly effective, as in the classic demonstration of simultaneous speech shadowing (listening to a continuous spoken text and immediately repeating it aloud) and sight-reading on the piano (5). Now in PNAS, Garner and Dux (6) suggest a link between these two phenomena in the effects of practice on a distributed frontal, parietal, and subcortical cognitive control system.

In their study, Garner and Dux (6) combined behavioral measurements with functional MRI (fMRI) to ask how brain representations change as practice reduces multitasking costs. In an initial session, 100 participants had brain activity measured with fMRI during two single tasks—responding with one hand to a picture, or with the other hand to a tone—and when both tasks were carried out at once. Participants were then split into two groups, one spending three additional sessions practicing these same tasks and their combination, the other receiving experience in an unrelated control task. Measurements of brain activity during the picture task, tone task, and their combination were then repeated in a final fMRI session.

It seems easy to explain the classic finding of easier multitasking when concurrent tasks are dissimilar. Dissimilar tasks are likely to engage somewhat different brain systems, decreasing the chance of collision or cross-talk between their processing requirements. Even dissimilar tasks, however, often recruit activity in common regions of the lateral frontal, dorsomedial frontal, and parietal cortex (7), making these a plausible basis for some aspects of multitasking cost (8). In their study, Garner and Dux (6) asked what happens to the frontoparietal—and associated subcortical—task representations after several days of training.

As expected, the results (6) confirmed the effect of training on behavioral multitasking costs. Although response times were increased in both tasks when the two were performed together, this cost was much reduced after the tasks and their combination had been trained. Also as expected, in both sessions there was widespread frontoparietal recruitment for each task performed alone, and most strongly for both performed together. In a subset of these regions—the dorsomedial frontal cortex, parietal cortex, with a similar pattern also in the putamen—enhancement of frontoparietal recruitment in the multitasking condition, like behavioral cost, also decreased after training. The critical findings, however, concern the effects of training on separation of task representations. The hypothesis was that different tasks may acquire more distinct neural representations as training progresses, even within those frontoparietal and subcortical regions that both tasks recruit. Distinct neural representations, like recruitment of separate brain systems by widely dissimilar tasks, may decrease the problem of collision or cross-talk, decreasing the performance cost of simultaneous performance.

To test this hypothesis, Garner and Dux (6) turned to multivoxel pattern analysis of activity in their critical frontoparietal-subcortical

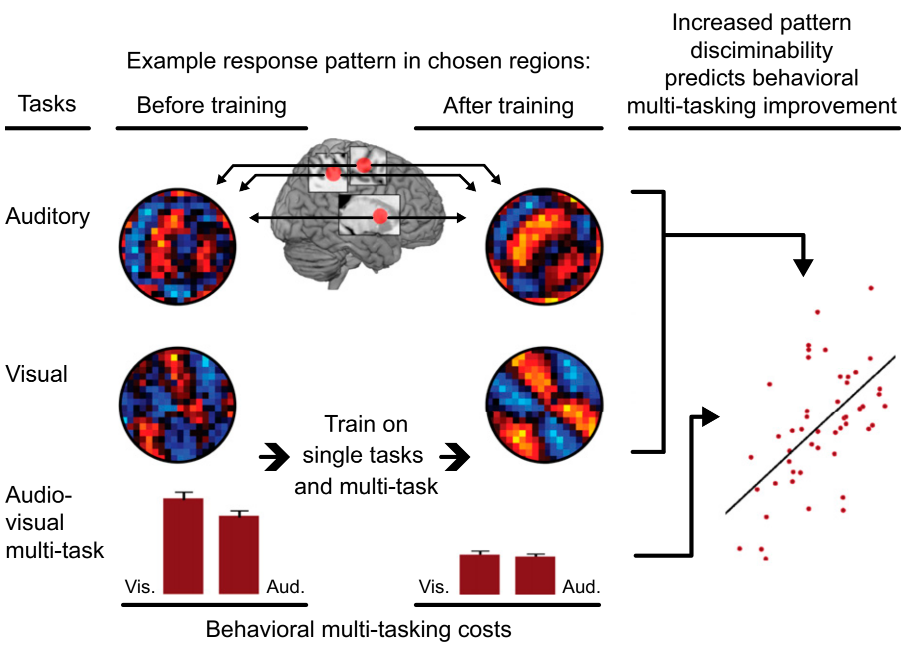

Fig. 1. After training, increased discriminability of frontoparietal multivoxel response patterns to two tasks predicts behavioral improvements when performing these tasks together. Adapted from ref. 6.

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regions: the dorsomedial frontal cortex, inferior parietal lobule, and putamen. To measure separation of neural representations for the picture and tone tasks, the authors compared exact voxelwise patterns of activity for the two. Patterns will of course be different for the brains of different individuals; the question is whether, within one individual, patterns are reliably different for the two tasks. Within the trained group, the results showed a striking relationship. After training, the individuals who had gained most in terms of reduced multitasking cost also showed increased differentiation of voxelwise activity patterns for the two tasks (Fig. 1).

Although measurements with fMRI are several steps removed from neural activity, the results (6) hint at increasing neural specialization after training, leading to crisper, more focused task representations. If the result of training is that neurons become more dedicated to one task or the other, this may be one basis for reduced dual-task interference. Such a proposal would fit with many lines of evidence suggesting dynamic neural properties across the frontoparietal cortex, with neurons continuously adjusting their response characteristics to fit the requirements of behavior (7); and more generally, it would match the idea of more fine-tuned, selective neural activity with increasing task or stimulus familiarity (e.g., ref. 9). The results also suggest important individual differences in such dynamic adjustment, with some individuals much more flexible than others in their response to training.

The results raise intriguing questions. Increased separation of frontoparietal-subcortical task representations with training may be only one part of the explanation for reduced multitasking cost. It is also widely suggested that, as tasks are trained, control may increasingly be handed off to different brain systems; it may be, for example, that domain-specific regions can increasingly manage well-learned behavior, without the need for more domain-general frontoparietal involvement. This would be consistent with overall reductions of frontoparietal activity after training (10). Behaviorally, an unresolved question is whether the critical aspect of training concerns single tasks, simultaneous tasks, or both. "Automaticity" has typically been conceived as a property of highly familiar, individual tasks, as we see when a novice driver is unable to continue a conversation while shifting gears, but many years later drives with the mind apparently free for other concerns. In experimental psychology, however, another idea has always been in the background—that practicing a particular dual task may allow the system to learn how these two particular activities can be combined (11)—and in the findings of Garner and Dux (6), this too is a plausible factor in increased neural separation, as trained participants received both single- and dual-task experience.

Garner and Dux give new insight into brain mechanisms of freeing attention as a new skill is acquired.

Can the brain be trained for improved multitasking in general, or only for improvement with the specific tasks that have been trained? Although the former is appealing, it is the latter that is addressed by the findings of Garner and Dux (6). In line with everyday experience, training has enormous effects on the ability to carry out the particular task that has been trained; much harder is finding transfer to very different activities, suggesting a more general cognitive ability (12). Restricted though they are, the enormous effects of training on individual skills and mental representations provide the infrastructure on which our complex mental lives are largely built; as Bryan and Harter expressed it in 1899, "Automatism is not genius, but it is the hands and feet of genius" (2). More than a century later, Garner and Dux (6) give new insight into brain mechanisms of freeing attention as a new skill is acquired.

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