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Current Opinion in Behavioral Sciences

Expertise and generalization: lessons from action video games

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Training is typically characterized by a trade-off between developing efficient performance, or expertise, and maintaining the ability to generalize one's knowledge beyond the trained domain. Here we ask whether it may be possible to train individuals to enhance their generalization abilities despite this natural trade-off. We first review the proposal that enhanced attentional control and cognitive flexibility may be potential mechanisms that will produce broad generalization. We then consider the case of action video game play which has been associated with enhancements in both attentional control and cognitive flexibility as well as generalization beyond the trained intervention.

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Current Opinion in Behavioral Sciences 2018, **20**:169–173

This review comes from a themed issue on **Habits and skills**

Edited by **Barbara Knowlton** and **Jörn Diedrichsen**

https://doi.org/10.1016/j.cobeha.2018.01.012

Expertise: a double-edged sword

Expertise, or reaching an outstanding level of skill in one domain, is typically the result of thousands of hours of practice in the given domain. And while the path to expertise is commonly multi-faceted, it is nearly always the case that some degree of automatization of function can be found at the heart of expert level performance. Such automatization allows what were initially complex and cognitively demanding sequences of actions or thoughts to be executed automatically with minimal effort and/or cognitive load. This not only serves to produce actions or thoughts that are fast and accurate, but critically, releases limited cognitive resources for alternative tasks. For example, a novice who is first learning to drive a manual transmission car may need to expend considerable cognitive effort determining what pedal to press, which direction to move the shift knob, among others. This in turn leaves no resources free for conversing with the front seat passenger or following a map. Conversely, in an expert driver, basic driving functions have been largely automatized and cognitive resources are thus available to complete these additional tasks.

However, while there is clear value to automatizing function, it has long been accepted that automatization also comes at a cost [1,2]. In particular, by repeating the same task over and over, experts may develop skills that are so task-specific that they lack the flexibility to adapt to alterations in the automatized tasks and sub-tasks [3–7]. For example, the performance of skilled typists plummets when certain seemingly minor changes are made in the keyboard characteristics [8]. Together, the evidence strongly supports the idea that expertise is often accompanied by the development of skills that are incredibly specific to only those precise actions/thoughts associated with skilled performance. What is less clear is whether it is possible to train individuals to become experts, not at a specific task or domain, but rather at flexibly adapting and transferring their skills and knowledge as new circumstances arise?

Training that fosters generalization — lessons from action video game play

Over the past 15 years, evidence has accumulated showing that playing one particular form of video game, known as action video games (primarily what are known as first-person or third-person shooter video games), leads to rather broad generalization, with performance enhancements noted in domains as varied as visual perception (e.g., enhanced contrast sensitivity & better peripheral detection — [9–11]), top-down attention (e.g., better change detection, reduction in attentional capture [12–15]), visuo-spatial cognition (e.g., better mental rotation; enhanced visual short-term memory [16,17]) and finally multi-tasking and task switching (e.g., lesser switch cost, greater ease at multi-tasking [18–20]). In a recent meta-analysis combining the results of 73 studies and 3773 total participants, self-declared action video game players were found to outperform non-gamers by about half a standard deviation across all aspects of cognition combined. Importantly, the same trend was seen when considering only true experiments, wherein non-gamer participants were specifically trained on an action video game and any cognitive gains were contrasted against those seen in an active control group that was trained on a commercial non-action video game. Indeed, a second meta-analysis on 21 intervention studies involving 609 participants showed that action game training produced a benefit on cognition of around 1/3 of a standard deviation (as compared to control-trained individuals) [21••]. Such results indicate that action video game play is not just correlated with enhanced cognitive abilities, but does in fact, cause improvements in these abilities.

The broad generalization seen to result from action video game training is consistent with the fact that such games naturally mesh complexity, novelty, and variability, ensuring the game play can never be fully automatized [22•,23]. Action gamers certainly develop some game-specific behaviors akin to expertise after hours spent on a particular title, as when gamers anecdotally report that they cannot play a game where the *y*-axis mapping is different from their practiced routine (i.e., whether pushing the mouse up makes the player look up or look down). Yet, the incredible diversity of situations encountered across various action video game titles ensures constant engagement of two key cognitive processes: attentional control and cognitive flexibility. For instance, because enemies can appear at virtually any location, at any time, in any number/combinations, it is not possible to learn an automatic sequence of actions that will produce game success. Instead, action video games continuously challenge attention allocation and the flexible evaluation of goals and sub-goals [24••,25]. A key prediction of this work is that playing such games results in enhanced attentional control and cognitive flexibility which in turn fosters generalization.

Attentional control and cognitive flexibility are two central and complementary executive functions [26,27], which, as predicted, are enhanced after action video game play. Many behavioral studies now document enhancements associated with action video game play on a range of tasks tapping attentional control — from an enhanced ability to redirect eye-gaze and attention when initially wrongly allocated [15,28], to superior visual search performance [14,29], to better distractor suppression [30]. Similarly, although less well established, action video game play has also been positively associated with tasks requiring cognitive flexibility such as multi-tasking, task switching, or forms of working memory [16,20]. An efficient diagnostic task to assess the two key components of attentional control and cognitive flexibility appears to be the Multiple Object Tracking task, wherein individuals must track moving objects from amongst a display containing many visually identical distractor objects. This task requires both attentional tracking over time and flexible working memory indexing and updating. Accordingly, this task has recently been shown to load on two orthogonal factors: one related to a generalized capacity for efficient perception and awareness — a key function of attentional control — the other related to cognitive flexibility — or the capacity to hold and flexibly manipulate information in working memory [31].

A prediction: an inverted U-shape curve for generalization as training proceeds

Enhanced attentional control and cognitive flexibility have been proposed to provide a mechanism for generalization, while expertise is achieved at least partially via automatization, a process that inherently entails releasing demands on attentional control and cognitive flexibility. As expertise sets in, these two functions become less challenged and their enhancement is expected to fade away. Indeed, much as physical fitness decays in the absence of continued physical demand, so do enhancements in cognitive abilities in the absence of continued cognitive demand [32,33]. Generalization is therefore expected to decrease as learning progresses toward expertise, a prediction in line with the highly specific skilled performance noted in experts.

Generalization is also expected to be rather limited during the earliest stages of training. This early period is characterized by a quickly saturating learning phase that mostly corresponds to the learners' mastering the basic rules or strategies required by the new task. Learning these basic rules is certainly demanding, tapping long-term memory systems in particular. Yet, until these rules are somewhat consolidated, it will be unclear to the learner to what, or how to direct their processing resources, thus minimizing the overall load on both attentional control and cognitive flexibility. To clarify this point, consider an athlete playing a new sport. Until the fundamental rules, goals, and strategies of the sport are understood, the physical challenge will not be maximal. The same idea applies here with respect to cognitive challenges.

The phase of learning predicted to induce the greatest generalization is therefore after this earliest phase, but before expertise sets in. It corresponds to a phase of learning which is rather slow and often associated with the view that 'practice makes perfect.' Early in the slow learning phase, the task is sufficiently well understood to result in load being placed on attentional control and cognitive flexibility — load which will, of course, be slowly released as the learning moves toward expertise. Thus, generalization as a function of training time is expected to be an asymmetric U-shaped curve (Figure 1).

Although this remains a prediction, it is instructive to consider such a view in the context of the impact of playing the video game Tetris on mental rotation. Given the above framework, we would expect naïve participants who are asked to play an intermediate amount of Tetris (e.g., 10–30 hours), to show some degree of transfer from their Tetris training to new mental rotation tasks. Such a finding has indeed been documented in the existing literature [34,35]. At the same time, we would also expect that expert Tetris players — i.e., individuals who play competitively and who have hundreds, if not thousands,