Video Game Training and Effects on Executive Functions

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Contents

Abstract In the present chapter, we reviewed studies investigating the effects of video game training (particularly action video games) on the executive functions shifting, dual tasking, updating, and inhibition. These studies provide evidence that video game training improves the performance in task-switching (i.e., shifting) and dual-task situations. Evidence for an effect of video game training on working memory updating is mixed, and this effect might not be a consequence of video game training. The literature on effects of action video gaming rather suggests no relation between training in action video games and improved inhibition. In sum, this set of findings is consistent with the assumption that transfer from action video game training to executive function measures is domain-specific and might depend on similarities between the trained video game and the laboratory task.

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Introduction

The video game industry expands as its sales volume and the number of the industry's clients constantly increase. Surveys show that the annual video game sales exceeded 43.4 billion (in the USA exclusively) and more than 1.2 billion individuals worldwide are considered as video gamers (Spil Games 2013), including more than 164 million Americans (The Entertainment Software Association 2018); this frequent use of video games is largely independent of gender, education, and income (e.g., BIU 2012). Cognitive research provided evidence in recent years that experienced video gamers outperform non-experienced people in a number of basic cognitive functions (e.g., Bavelier et al. 2012, 2018; Bediou et al., this volume; however, see Simons et al. 2016, for a more skeptical view on training-related plasticity). These positive effects in video gamers led us to focus on the particular effects of video game experience on executive functions (see also Karbach and Kray, this volume).

Executive functions typically control our behavior when we perform in demanding and complex situations including situations in which the management of different tasks or task sequences is required. These functions define a set of general-purpose control mechanisms, often linked to the prefrontal cortex of the brain, that modulate the operation of various cognitive subprocesses and thereby regulate the dynamics of human cognition (Baddeley 1986; Miyake and Friedman 2012; Miyake et al. 2000). Different types of executive functions have been classified by different authors, for example, shifting, dual tasking, updating, and inhibition. While their processing can be time-consuming and inefficient under unpracticed conditions, recent studies suggest that executive functions can be improved as a result of extensive training and training-induced improvements can be transferred to non-practiced situations (Anguera et al. 2013; Strobach 2020; Strobach et al. 2014). This training-related plasticity is particularly relevant when aiming to compensate for the strong age-related declines in executive functions and frontal lobe tasks (Raz 2000; Strobach et al. 2015).

The present chapter includes a concise review of empirical studies and meta-analyses investigating the potential optimization and transfer of different types of executive functions as a result of video game experience. Here, we primarily focus on studies within the action video game genre. Since many studies have been concerned with assessing the impact of this game genre on executive function as action video game playing seems highly adequate for training executive control skills. In action video games, gamers have to control and conduct multiple simultaneous tasks at a high speed. Important information, such as interim targets and assignments, must be updated all the time (Spence and Feng 2010) and gamers need to adapt their actions and action goals under permanently changing task conditions (Bavelier et al. 2012). The most prominent action games are first-person shooters such as the *Counter-Strike, Unreal Tournament*, *Call of Duty*, *or Medal of Honor* series of games and third-person shooters like the *Grand Theft Auto* series. In these games, gamers play in an open virtual world with a first-person or third-person perspective on the main character. They usually have to fight against enemies, find objects, and navigate through this world.

The relation between action video games and executive functions (as well as other game genres and mental domains) is usually investigated from two methodological perspectives. First, there are cross-sectional comparisons between individuals self-reporting a high amount of experience with these games. The executive function performance in these habitual video gamers is typically contrasted with the one of individuals reporting no such experience; these individuals are either unexperienced in video games in general or are not experienced in action video games in particular but built up experience in other game genres (for the sake of simplicity, we refer to these latter individuals as non-gamers). However, if comparisons between gamers and non-gamers show performance differences, in particular performance advantages in gamers, do these advantages in gamers mean that there is a causal link between video game experience and optimized executive functions? The answer is no, not exactly (Green et al. 2014, 2019). Advantages in gamers do not necessarily have to be a result of video game experience (Schubert and Strobach 2012). The advantage could be, for instance, inherited or just given before they started playing video games (which would mean that the advantage would then be independent of the video game experience). As a consequence, research on video games has implemented more and more well-controlled training interventions with non-gamers in order to assess potential causal links between game experience and optimized executive functions. Usually, these training studies have a pretest–training–posttest design with tests on executive functions during pretest and posttest and one group of non-gamers with training in an action video game across several hours. To control for methodological impacts such as test-retest effects or general motivational issues, one or more control groups complete a similar general design of pretest–training–posttest. During training, these groups usually perform control procedures different from action video gaming but perform (again in the present case) tests assessing executive functions during pretest and posttest.

In the video game literature, two theoretical perspectives were introduced to generally explain mechanisms of transfer effects from video gaming to situations beyond the game context (e.g., laboratory-based transfers to measures of executive functioning). The first explanation to account for potential transfer effects is that these effects are all due to a single more general level of improvement, which then aids performance in all transfer tasks. One proposal of general training-related transfer is that video gamers improve in probabilistic inference, or "learning to learn." As a result of training, according to this "learning to learn" account, action video gamers generally become more effective in using evidence from repeated presentations of a task to guide their decision-making and allocation of cognitive resources (Bavelier et al. 2012). This "learning to learn" account predicts that, as a result of appropriate action video game training, there should be transfer effects to all types of executive functions, that is, shifting, dual tasking, updating, and inhibition.

In contrast, transfer effects may be due to video games having several separate demands in common with laboratory tasks that measure perception, attention, or cognition (Oei and Patterson 2015). According to this "common demands" account (Dahlin et al. 2008), transfer from action video games to executive function measures is specific and depends on similarities between the trained video game and the laboratory task. There may be some specific learned properties of the game, but there may also be higher level more abstract procedures that are developed during the game that may allow transfer from the game to behavioral measures. Taatgen (this volume) argues that skills required to perform a task can be broken down into "primitive information processing elements" of which some are task-general and some are specific. Only if two tasks share overlapping elements, those learned from training can be applied in test situations, producing transfer (see also Salminen et al. 2016, for the case of transfer in working memory updating). As a consequence, alternatively to the prediction of the "learning to learn" account, the "common demands" account predicts that transfer effects might not be general for all types of executive functions (i.e., shifting, dual tasking, updating, and inhibition) but might be specific for the functions where the game and task share common demands. In the final section of this chapter, we will evaluate the literature on action game experience and effects on executive functions regarding these accounts (i.e., "learning to learn" versus "common demands"), explaining general mechanisms of transfer effects.

Shifting

Also referred to as "attention switching" or "task switching," this type of executive functions concerns the ability to shift back and forth between multiple tasks, operations, or mental sets (Monsell 2003). Shifting involves the disengagement from irrelevant information (e.g., the task set of a previous task) and/or the active engagement in relevant information (e.g., the task set of an upcoming task). Evidence for optimized shifting derives from studies on task-switching practice (e.g., Berryhill and Hughes 2009; Karbach and Kray 2009; Strobach et al. 2012a, Wendt et al. 2017): These studies showed that performance costs associated with the shifting processes (e.g., task-switch costs reflected by larger reaction times [RTs] in trials with switches between different tasks in contrast to trials with task repetitions) are reduced with practice and, consequently, illustrate optimization of executive functioning of shifting.

Before we go into detailed studies and the theoretical explanations about training effects from these studies, we give a meta-analytic overview of the relation between action video gaming and shifting. Powers et al. (2013) showed a moderate benefit of experience in action video gaming in the shifting domain with Bediou et al. (2018) replicating this finding with rather upper-medium benefits of this experience type. The latter study could show that this effect was moderated by age with larger effects in young than in older adults. While the latter study did not test for shifting in an intervention training perspective, the former study could not show a benefit for this executive function domain.

Focusing on individual empirical studies, persons with experience in action video games showed less switch costs than non-gamers in a paradigm including predictable switches and repetitions (e.g., Colzato et al. 2010). This finding is the first – although cross-sectional – example of evidence for optimized executive functions in terms of improved shifting abilities. Strobach et al.'s (2012b) training intervention in young adults consisted of fifteen 1-hour sessions, in which two groups of non-gamers played different games. The first group worked on a puzzle game with only one main task and only low executive function demands. The second group played an action game with high executive function demands. In a test on task-switching performance before the training started, the switch costs do not differ between both groups of puzzle and action gamers. Afterwards, however, the results indicated lower switch costs in the action game group in comparison to the puzzle group. This training study shows that switch costs can be reduced with action game training specifically and that this reduction cannot be traced to inherited, given, or previously acquired attributes. These results provide evidence for a causal link between video game experience and optimized executive functions for shifting between different tasks. Further, this finding was generalized to numerous alternative task-switching situations, sharing varying numbers of input and output processors with typical action video games (Cain et al. 2012; Green et al. 2012).

However, the task-switching advantage of non-gamers after action video game training might be limited to situations with predictable task switches and the requirement to constantly update working memory: how many trials have been completed in the current task and to count down for the upcoming switch (Green et al. 2012; Strobach et al. 2012b). In a task-switching paradigm with the random and unpredictable occurrence of switch and repetition trials (e.g., the particular task is cued), updating of working memory is not required, and participants do not need to take into account the nature of previous trials. There is no evidence for superior shifting between tasks in action video gamers versus non-gamers as well as after training of an action video game, strategy game, or puzzle game in such an unpredictable task-switching situation (Boot et al. 2008; Oei and Patterson 2014). The observation of advanced task-switching performance of action video gamers predominantly in situations with predictable task switches might point to an impact of superior updating functions related to this group of participants. In our view, this assumption may represent an issue for fruitful future investigations (see also the updating section).

A further mechanism that may specifically explain action video gamers' improved performance in task-switching situations is a superior ability to control selective attention and thus active engagement in relevant information of an upcoming task (i.e., selective attention-dependent preparation, Karle et al. 2010). The effectiveness of engagement might be that relevant information of an upcoming task is only activated to a degree in working memory that is necessary to efficiently perform this task. In such a case, the following effort for an effective disengagement of this task information is reduced to a minimal degree. The reduced effort for task disengagement might free processing resources for alternative tasks, a potentially effective strategy for successful performance in complex gaming contexts.

Dual Tasking

Do action video gamers also have advantages when they perform different tasks simultaneously at the same time (instead of a sequential performance of different tasks as in the task-switching paradigm)? Are there any signs of optimized executive functions when the gamers are put in dual-task situations? Dual-task situations require the coordination of different tasks and task information due to executive functions (among others, dual tasks require the control of which task is performed first and which task second [Schubert 2008; Szameitat et al. 2006]). For instance, this coordination leads to longer RTs in dual-task situations compared to single-task situations, leading to dual-task performance costs.

Similar to the shifting domain, Powers et al. (2013) showed a moderate cross-sectional benefit of experience in action video gaming in the dual-task domain. Bediou et al. (2018) replicated this finding with rather upper-medium benefits of this experience, and this effect was moderated by age with larger effects in younger than in older adults. Focusing on individual empirical studies, Gaspar et al. (2014) were not able to find evidence for different dual-task costs between action video gamers vs. non-gamers however. In detail, a simulated street-crossing scenario was combined with a working memory task in their dual-task situation. The number of trials on which participants successfully crossed the street and the latency of initiating the crossing were impaired in the dual task compared to performance in the isolated crossing task under single-task conditions. However, there was no reduction of dual-task costs specific for action video gamers. These findings of a lacking dual-task advantage in this group were consistent with those of Donohue et al. (2012) that combined a multiple object tracking task, a paper and pencil search task, and a driving tracking task with answering trivia questions. Although these tasks are certainly relevant in daily life, they are no established measures of dual-task performance and differ considerably from reliable and valid laboratory paradigms.

This conclusion is supported by a number of studies, which showed positive effects of action video gaming on dual-task skills (Chiappe et al. 2013; Strobach et al. 2012b). For example, Strobach et al. (2012b) compared the performance of gamers and non-gamers in dual- and single-task situations including speeded and well-controllable choice RT tasks. There was no difference in single-task RTs between gamers and non-gamers. However, there was a difference in dual tasks: Gamers showed lower RTs and therefore a better performance particularly in dual-task situations compared to non-gamers. This result confirmed the assumption of an optimization of executive functions associated with the coordination of two simultaneous tasks. Also, with focus on dual-task performance, non-gamers increasingly benefitted from action video game training more than from puzzle training, which indicates a causal link between video game experience and optimized executive functions in dual-task situations (see also Schubert and Strobach 2012). These conclusions were supported from a dual-search situation combining an identification and comparison search task (Wu and Spence 2013); performance in this dual-task situation was specifically improved after non-gamers' action video game training vs. puzzle game training. The possible effect of video gaming on dual tasking is still a matter of debate, as a meta-analysis showed no robust effects of action video game training (in comparison to active control interventions) on dual tasking (Bediou et al. 2018). Nevertheless, the reported null effect might be explained by the small number of studies in this field, which requires further meta-analyses with larger samples of included studies.

Updating

Updating and monitoring of representations and information in working memory is another dimension of executive functions (Miyake et al. 2000). In detail, this dimension is related to the monitoring and coding of incoming information that is related to a task at hand. Further, updating processes serve to revise items held in working memory by replacing old information that is no longer relevant with newer, more relevant information. For instance, updating plays an important role in working memory tasks of the *n*-back type, in which a participant is presented with a sequence of stimuli and instructed to indicate when the currently presented stimulus matches the one from *n* steps earlier in the sequence (Jonides and Smith 1997).

Action video gamers show faster and more correct responses than non-gamers in the *n*-back paradigm, which indicates an optimized functionality of the updating function (Colzato et al. 2013). Further, even puzzle game training in non-gamers was effective in producing superior performance in a mental rotation task; transfer in this case is plausible, given that the mental rotation task was both visually and conceptually similar to this training game (Boot et al. 2008). However, in a spatial *n*-back task and a Corsi block-tapping task, no increase in accuracy could be registered, neither in action video gamers versus non-gamers nor after non-gamers' action game training, strategy game training, and puzzle game training (Boot et al. 2008). In sum, given the current state of the literature in the field, it remains unclear whether there really is a (causal) link between game experience and the executive function updating. This unclear conclusion is supported by meta-analyses in the field. While these analyses showed at least small effects of experience in action video games in cross-sectional studies, there is no meta-analytic evidence for an effect of video game training in longitudinal studies on updating (Powers et al. 2013).

Inhibition

A further executive function is inhibition, which is related to the ability to deliberately inhibit or stop dominant, automatic, or prepotent responses when necessary. A prototypical inhibition task is the color Stroop task (MacLeod 1991). In this task, participants are instructed to respond to the ink of color words; these color words are congruent (e.g., GREEN in green ink) or incongruent (e.g., GREEN in red ink). Typically, RTs in incongruent trials are larger than in congruent trials (i.e., the Stroop effect), indicating the requirement to inhibit or to override the tendency to produce a more dominant or automatic response on naming the color word. However, practice of a Stroop tasks results in a reduction of the Stroop effect within this task, indicating a task-specific training effect by an increased RT reduction in congruent versus incongruent trials (e.g., Davidson et al. 2003; Wilkinson and Yang 2012).

Given the current state of the literature, we are however skeptical about a positive effect of action video gaming on inhibition. In individual empirical cross-sectional studies, the Stroop effect was not reduced in participants that played a difficult version of an action video game versus a non-difficult version of such a game in the study of Engelhardt et al. (2015). This finding demonstrates no evidence for an impact of action video gaming on inhibition, which is also supported by the results of studies with alternative paradigms testing varying facets of inhibition. That is, action video gamers in contrast to non-gamer controls showed no superior performance in a Go/No-Go task (in this task, participants have to press a button [Go] given certain stimuli and inhibit that action under a different set of stimuli [No-Go], Oei and Patterson 2014) and in a stop-signal task (in this task, participants are presented with a stimulus prompting them to execute a particular manual response, and this stimulus may or may not be followed by a stop signal calling for the immediate abortion of that response, Colzato et al. 2013). Consistently, from a meta-analytic perspective, findings from longitudinal studies showed that action video game trainings had no impact on inhibition performance (Powers and Brook 2014). In sum, at the current state there is no convincing evidence that experience in action video games can improve executive functioning associated with the inhibition of responses when necessary.

Meta-Analyses on General Executive Functioning

Due to the increasing number of empirical studies, recently several meta-analyses have been conducted investigating the relationship between action video games and general executive functioning; in this regard, the term general executive functioning means that these studies performed analyses on executive functioning without disentangling the relation between video gaming and specific executive function domains. In habitual gamers versus non-gamers, Powers et al.'s (2013) combination of executive functions comprised executive function batteries, dual/multitasking, inhibition tasks (e.g., Stroop task, Simon task, Flanker task), intelligence tests, task switching, and working/short-term memory measures. Their meta-analysis showed a small but robust effect of experience in action video gamers versus non-gamers. Realizing more strict inclusion criteria on empirical studies and investigating the impact of publication biases, Sala et al. (2018) found only very small effects of experience in action video gamers on executive functions. However, this effect could be only very small since Sala et al. applied a categorization of executive functions in different domains. While their cognitive control domain included tests such as task switching, Go/No-Go, Simon, and Stroop tasks (thus rather exclusively shifting and inhibition), updating was categorized as memory in combination with tests such as span, *n*-back, and recall tasks (i.e., a combination of rather short-term and long-term memory aspects as well as working memory updating). This study thus divided executive functions in the system of Miyake and Friedman (2012) and applied in this chapter (see also Karbach and Kray, this volume) across different categories of analysis and combined it with long-term memory processes.

The meta-analysis of Wang et al. (2016) showed moderate effects of training of action video games on executive functioning; in this analysis executive functioning combined planning, working memory, reasoning, inhibition, mental flexibility, as well as monitoring of action as was primarily assessed by working memory tasks, stopping tasks, the Trail Making Test – Part B, Stroop tasks, the flanker task, and Raven's Advanced Progressive test. The effect of training on executive functions was moderated by age (younger adults showed an increased benefit than older adults), education, session duration, number of sessions, total training duration, and the type of the control group. Powers et al. (2013) found rather small to even only negligible effects of action video game interventions which was replicated in a later meta-analysis of the same group (Powers and Brook 2014). However, as we have seen above when discussing the individual executive function domains, follow-up analyses identified clear effects in specific domains.

Conclusions

To wrap up the previous sections, we reviewed empirical studies and meta-analyses investigating the effect of experience in video games (in particular action video games) on the executive functions shifting, dual tasking, updating, and inhibition. There is evidence that, at least under particular task conditions, massive video game experience may improve the performance in task-switching (i.e., shifting) and dual-task situations. Further, preliminary evidence for experience-based improvement in working memory updating exists. In contrast, the literature on effects of action video gaming rather suggests no relation between experience in action video games and improved inhibition.

Let's consider the general mechanism that may explain transfer effects from video gaming to test situations on executive functions. While the introduced version of the "learning to learn" account predicts a transfer from action video game experience to all types of executive functions (Bavelier et al. 2012), the "common demands" account rather predicts a specific transfer, depending on similarities between the trained video game and the laboratory task (Oei and Patterson 2015). First, from a more general perspective, there is evidence for transfer effects on shifting, dual tasking, and updating, while there is no such evidence for the case of inhibition. The observation of different validities of transfer effects across the executive function domains is consistent with the "common demands" account and indicates that switching between different sequential tasks, performing simultaneous tasks, as well as the updating of task information represent relevant demands in (action) video games. In contrast, the inhibition of responses seems to be no essential component in playing these games when applying the logic of the "common demands" account. This might be surprising given the usual characteristics of action video games. A closer look at these games suggests that withholding of motor responses and their interruption represent indeed important demands of action video games. Therefore, the fact that currently no valid evidence for effects of action video games on inhibition demands has been reported may be suggestive for two conclusions: It may suggest that the fast interruption and withholding of motor responses is not trainable and transferable at all (Strobach et al. 2014). Alternatively, it may suggest that the current experimental paradigms, which had been used in action video game studies, do not reflect the type of particular inhibition demands inherent to action video games.

Second, from a more detailed perspective, the observation of differential effects of video games on different types of executive functions is also consistent with this theory. For example, there is evidence that puzzle game training, but not action video game training, is able to improve performance in mental rotation (Boot et al. 2008); while the first training type shares common elements with the mental rotation task, the latter ones do not. Further, performance in dual-task situations with speeded, well-controllable component tasks is affected by action video game experience (e.g., Strobach et al. 2012b), while such experience does not seem to affect dual-task situations that are less similar to the gaming environment (e.g., paper and pencil search; Donohue et al. 2012). We are sure that these observations can be complemented with other type of training games and other different functions as well, if a careful analysis is conducted on the type of overlap between training and transfer function.

In sum, we evaluated the existing literature on action video games and executive functions as demonstrating evidence for transfers on the executive functions shifting, dual tasking, and updating, while this literature shows no evidence for transfer to the inhibition function. However, it is also obvious that each type of executive function requires attempts to replicate existing findings as well as additional analyses in future studies (Colzato and Hommel, this volume). These analyses should specify the effects of action video games and other game genres on different executive function types using different experimental paradigms. Preferably, this specification should be realized in the context of training experiments in order to make conclusions about the causal links between game experience and potential changes in executive functioning.

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