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Task switching training effects are mediated by working-memory management

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ABSTRACT

Task switching is an important executive function, and finding ways to improve it has become a major goal of contemporary scientists. Karbach and Kray (2009) found that training in the Alternating-Runs Task-Switching (AR-TS) paradigm (in which the task changed every second trial) reduced the costs of switching in untrained tasks, as well as led to far transfer to interference control ability and fluid intelligence. However, AR-TS is known to involve working memory updating (WMU). Therefore, we hypothesized that AR-TS training involves WMU and not task-switching proper. Participants were trained using Karbach and Kray's protocol. Results indicate a highly specific transfer pattern in which participants showed near transfer to switching cost in the AR-TS paradigm, but did not significantly improve in another version of the task switching paradigm in which the tasks were randomly ordered or a version in which the task changed every 3rd trial. The results suggest that what has been trained is not a broad task-switching ability but rather a specific skill related to the unique WMU requirements of the training paradigm.

1. Introduction

Executive functions are cognitive abilities enabling goal directed behavior. As such, they have broad relevance to issues such as general intelligence (Friedman et al., 2006), psychopathology (e.g., Kashdan & Rottenberg, 2010; Morgan & Lilienfeld, 2000; Pennington & Ozonoff, 1996), psychological development (e.g., Garon, Bryson, & Smith, 2008; Zelazo, Carlson, & Kesek, 2008), and school performance (e.g., Diamond, Barnett, Thomas, & Munro, 2007). Knowing how to improve executive functions is therefore likely to have an enormous impact on a wide array of psychological domains.

There is no clear consensus on the taxonomy of executive functions, and whether they represent a single ability or a range of abilities (e.g., Baddeley, 1986, vs. Lehto, 1996). Nonetheless, many studies adopt Miyake et al.'s (2000) taxonomy, which was based on individual differences within the normal range. According to Miyake et al., there are three executive functions including updating and monitoring of working memory representations (WMU), inhibition of prepotent responses (inhibition) and shifting between tasks or mental sets (task switching).

Several studies in the past few years demonstrated that training in a cognitive task tapping an executive function could result in far transfer to general intelligence (e.g., Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg et al., 2005; Schmiedek, Lövdén, & Lindenberger, 2010). By "far transfer" we refer to improvements seen in a structurally different task than the training task (that involves different content and task requirements, yet tapping similar critical psychological processes), as opposed to near transfer effects which relate to specific attributes of the training task. The transfer is allegedly based on the fact that the training program and the transfer tasks have a common element through which the training occurs. Showing far transfer of executive function training is especially interesting in light of findings suggesting that individual differences in executive functions are mainly genetic in origin (Friedman et al., 2008). In line with the genetic findings, there have been some recent reports showing failures

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to find beneficial outcomes of various training programs which have previously reported as successful (e.g., Redick et al., 2012; Chooi & Thompson, 2012; Shipstead, Redick, & Engle, 2012). However, replication was *not* our *primary* goal. It served as means to test a specific hypothesis related to principles underlying successful executive function training. Specifically, our hypothesis was that computerized training, at least as currently implemented, improves only one out of three domains of executive functioning. This hypothesis is based on the observation that while most of the published studies showing promising results trained WMU, only very few studies indicate promising results in the other two domains of executive functions including task switching and inhibition. Actually, it seems that these two executive functions do not gain from computerized training, at least as currently implemented; although they may gain from other approaches including extensive educational interventions, (e.g., Diamond et al., 2007) and meditation (Greenberg, Reiner, & Meiran, 2012, 2013).

In the present work, we focused on task switching training. Before getting into the details of the training studies, it is important to introduce some key terms related to task switching. First, the task switching paradigm (e.g., Kiesel et al., 2010; Meiran, 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010, for review) yields two main performance cost estimates: switching cost, the difference between switch trials (in which the task has switched) and repeat trials (in which the task repeats from the previous trial) within mixed-tasks blocks; and mixing cost, the difference between repeat trials (from the mixed-tasks block) and trials from single-task blocks (in which only one task is executed). These costs represent the difficulty in switching and therefore serve as a target for training. Second, the term "task switching" refers to several paradigms that yield somewhat different effects. Rogers and Monsell (1995) introduced the Alternating Runs Task Switching paradigm (AR-TS), in which the tasks alternate between runs of fixed lengths (for example, Run-Length = 2 as in Karbach & Kray, 2009, means an AA–BB–AA… sequence, in which A and B represent the two tasks. That is, the task changes every 2nd trial). Another paradigm is cued-TS, in which the tasks are randomly ordered, an external cue appears just before the target stimulus, and the participants are instructed to perform the cued task (Shaffer, 1965). We will focus on these two methods, though other paradigms are also being used (for review, see Meiran, 2010). The difference between these two paradigms is that there is a constant need to keep track of the position in the run in WM in AR-TS, whereas the cued TS paradigm does not involve such a requirement.

The most influential task switching training study is Karbach and Kray's (2009), showing that TS training led to widespread transfer to switching cost, mixing cost, interference control, verbal and visual WM, and fluid intelligence in three age groups: children, young adults, and older adults. This study stands out partly because there are only very few studies showing transfer effects of TS training. Actually, two unpublished works that were conducted well before Karbach and Kray published their paper indicate very limited transfer after task switching training. These include an unpublished Ph.D. dissertation from Gopher's lab (Armony-Shimoni, 2001) as well as an unpublished work from our lab (Sosna, 2001). In Armony-Shimoni's Ph.D. study, participants were trained on the randomized-runs paradigm (Altmann & Gray, 2002, 2008; Gopher, Armony, & Greenshpan, 2000) in which task-cues appeared at the beginning of runs of trials varying in length between 4 and 12 trials. The results indicated some transfer of training effects across different kinds of stimuli (e.g., from letters to digits) or across different computational operations as long as they belonged to the same modality, such as spatial processing (e.g., from comparing which one of two groups has more items to evaluating whether a group has more or less than five items). However, when the processing mode changed (e.g., from spatial to semantic) or when the judgment goals changed (e.g., from judging high-vs.-low to judging odd-vs.-even) no transfer of training was found. Sosna's Master's Thesis included 2 experiments in which participants were trained in a cued-TS paradigm involving two spatial location tasks (up-down and right-left). In Experiment 1, there were three training sessions and switch probability varied between training groups. In Experiment 2 (6 training sessions), different versions of the training paradigm were used. In both experiments the switch costs were subjected to training effects but not to transfer effects. Importantly, in both of these studies, the training paradigm was not AR-TS, suggesting that perhaps some unique features of the AR-TS paradigm are responsible for Karbach and Kray's success. Only one study (Minear & Shah, 2008) compared training and transfer effects in cued-TS and AR-TS and the results are inconsistent with the hypothesis above since cued-TS training but not AR-TS training led to some transferrable gains, which the authors attributed to the unexpected task switches in cued-TS. Thus, we conclude that the empirical picture is far from being clear at present.

In their study, Karbach and Kray (2009) trained participants during a six week period: During the first week, the participants performed pretest measurements (switching, inhibition, WM and fluid intelligence tasks); Afterwards, they went through four AR-TS training sessions, one per week; and then came back for posttest measurements in the sixth week. Four experimental groups in each age group were tested: single-task training (control), switching training, switching with verbal self instruction and switching with verbal self instruction and variability. The verbal self instruction strategy was incorporated in order to facilitate the maintenance and selection of the tasks (as required in AR-TS). The variable training, in which the tasks changed between sessions, was incorporated in order to facilitate generalization and thus transfer to new tasks. Of greatest interest in the present paper is the fact that, among young adults, largest gains in switching and mixing costs were seen when both self instruction and variable training were incorporated. Zinke, Einert, Pfennig, and Kliegel (2012) partially replicated Karbach and Kray's (2009) findings in adolescents showing mixing cost reduction, RT decrease in a 2-back task, and choice reaction RT decrease. On the other hand, they neither showed switching cost reduction, nor gains in inhibition measures.

We found the widespread transfer in Karbach and Kray's (2009) study to be surprising for some reasons. First, their training protocol did not involve an adaptation of task difficulty. This feature stands out as other successful protocols such as Jaeggi et al.'s (2008), involved continued adaptation of task difficulty, aimed at keeping a high level of difficulty throughout the training phase. Moreover, it has been previously claimed that adaptive task difficulty may be a crucial factor in the success of training (Buitenweg, Murre, & Ridderinkhof, 2012; Shipstead