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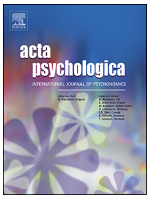

Effects of task repetition but no transfer of inhibitory control training in healthy adults

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ABSTRACT

Executive functions (EFs) comprise the updating, shifting and inhibition dimensions. According to the Unity and Diversity Model, the inhibition dimension is fully accounted for by a general EFs factor. This suggests that training of inhibition should transfer, in part, to updating and shifting. Therefore, we tested the effectiveness of a three-week inhibition training (high-conflict Stroop task) and explored near transfer effects to an untrained inhibition task (antisaccade task) and far transfer effects to untrained tasks demanding task-set shifting (number-letter-task), working memory updating (n-back task) and planning abilities (Stockings of Cambridge task). We employed a randomized pretest/treatment/posttest study design in n = 102 healthy young adults, assigned to an intensive Stroop training (n = 38), an active control condition (n = 34) or no training intervention (n = 30). In the Stroop training group, Stroop performance improved with practice, while performance in the active control group remained unchanged. The Stroop training group showed improvements in overall Stroop task performance from pretest to posttest, but we observed neither near nor far transfer effects. Additionally, specifically stronger gains on incongruent Stroop trials compared to congruent trials were observed in the Stroop training group when color bar trials were excluded from the pretest-posttest-analysis. Generally, there were substantial improvements from pretest to posttest independent of training condition in all transfer tasks. In sum, our data do not support the existence of transfer effects from inhibition training in healthy young adults.

1. Introduction

Executive functions (EFs) refer to a set of effortful general-purpose control mechanisms that dynamically regulate thoughts and behaviors by modulating cognitive sub-processes (Diamond, 2013; Jurado & Rosselli, 2007; Miyake et al., 2000; Miyake & Friedman, 2012). EFs are of particular significance when automatic or instinctive responses are not effective (Diamond, 2013). EFs play a crucial role in mental (Burgess, Alderman, Evans, Emslie, & Wilson, 1998) and physical health (Allom, Mullan, & Hagger, 2016; Moffitt et al., 2011), success in education (summarized by Diamond, 2013) and other life aspects (Moffitt et al., 2011).

Miyake and Friedman (2012) postulated a framework regarding the organization of EFs, the Unity and Diversity Model (Fig. 1). Unity and diversity of EFs (first addressed by Duncan, Johnson, & Swale, 1997; Teuber, 1972) refers to the phenomenon that a collection of moderately (Unity) but not perfectly (Diversity) correlated core EFs (i.e. Updating, Shifting, Inhibition) determine performance in cognitive control tasks (Miyake et al., 2000). *Updating* comprises the ability to monitor, replace, process and dynamically manipulate working memory representations (Diamond, 2013; Miyake et al., 2000; Neil & Jones, 1990). *Shifting* defines the ability to flexibly select, combine or switch between rules and task-sets (Monsell, 1996, 2003). *Inhibition* refers to the ability to deliberately stop automatic, dominant and prepotent responses to facilitate alternative thoughts and behaviors when needed (Miyake et al., 2000; Miyake & Friedman, 2012). Response inhibition enables self-control by overcoming strong internal predispositions, when relying on instincts, habits or impulses is not efficient (Diamond, 2013; Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014). These core facets of EFs build the foundation for higher order EFs, namely reasoning, problem solving and planning (Diamond, 2013).

According to the Unity and Diversity Model, any expression of EFs is the result of (i) processes common to all facets of core EFs (i.e. shared variance of a “Common EF” factor) and (ii) facet-specific processes (i.e. variance independent of “Common EF”). *Common EF* subsumes processes such as active task goal maintenance, task management and goal representations and the ability to use this information to bias goal-directed low-level processes (Friedman & Miyake, 2017; Miyake & Friedman, 2012). Updating- and shifting-specific factors comprise processes such as gating of information and working memory retrieval

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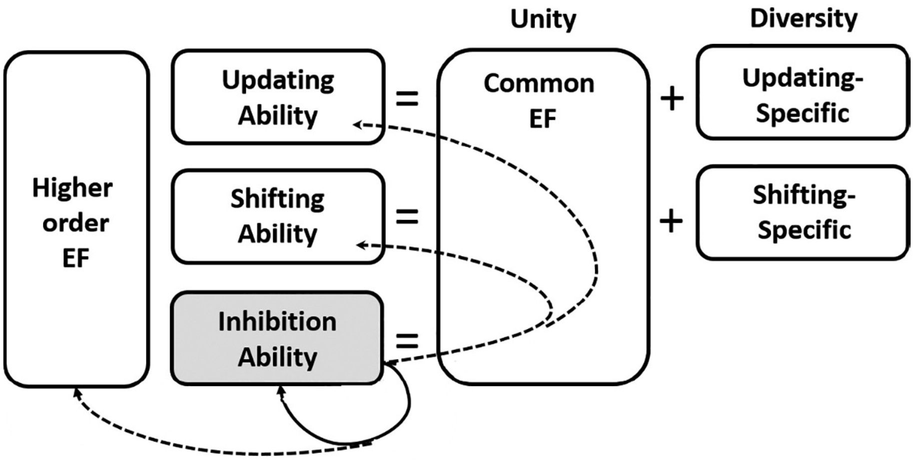

Fig. 1. The Unity and Diversity Model.
Legend: Schematic illustration of the Unity and Diversity Model of EFs adapted from Miyake and Friedman (2012). The expression of three core EFs (i.e. Updating, Shifting, Inhibition) which underlie higher order EFs, shown on the left of the equation, are determined by variance of processes underlying all facets of EFs (Common EF; Unity) and facet-specific variance (Updating-Specific Factor and Shifting-Specific Factor; Diversity) shown on the right of the equation. Variance of common processes fully determine inhibition abilities (highlighted in grey). Improvement of inhibition abilities through training should, therefore, transfer to other untrained cognitive abilities due to the structural organization of EFs proposed by the Unity and Diversity Model. Solid arrows illustrate near transfer effects whereas dashed arrows illustrate far transfer effects hypothesized in the current study.

and the ease of transition to new representations in prefrontal cortex, respectively (Friedman & Miyake, 2017; Miyake & Friedman, 2012). However, no inhibition-specific factor exists in the model, as research showed an almost perfect correlation between inhibition and *Common EF* (Friedman et al., 2008; Friedman & Miyake, 2017; Friedman, Miyake, Robinson, & Hewitt, 2011). This finding suggests that inhibition depends on processes common to all core EFs (Friedman et al., 2011).

Improving cognition (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Lustig, Shah, Seidler, & Reuter-Lorenz, 2010) and brain function (Berkman, Kahn, & Merchant, 2014; Enriquez-Geppert, Huster, & Herrmann, 2013; Jolles & Crone, 2012) by training is a topic of considerable interest (Strobach & Karbach, 2016). A key goal of such training interventions is the assessment of transfer effects on other, untrained tasks. Near transfer effects refer to facilitation in performance within the same domain or cognitive function that was trained (Enriquez-Geppert et al., 2013; Lussier, Gagnon, & Bherer, 2012; Perkins & Salomon, 1992). Far transfer effects are performance benefits in other domains or functions (Enriquez-Geppert et al., 2013; Lussier et al., 2012; Perkins & Salomon, 1992).

Training studies have largely focused on memory updating (reviewed by Shipstead, Redick, & Engle, 2012; meta-analyses by Karbach & Verhaeghen, 2014, and Melby-Lervåg, Redick, & Hulme, 2016). Training-related memory gains transfer to untrained memory updating tasks (near transfer) (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008) and untrained non-memory updating task (far transfer) (Karbach & Verhaeghen, 2014; Schwaighofer, Fischer, & Markus, 2015). Near transfer effects in working memory hold for nearest transfer, whereas transfer is often smaller or even absent when the structure of the task changes (Soveri, Antfolk, Karlsson, Salo, & Laine, 2017). Far transfer effects have also been reported on episodic memory (Dahlin, Nyberg, Bäckman, & Neely, 2008), inhibition (Klingberg et al., 2005), task switching (Salminen, Strobach, & Schubert, 2012), attentional processing (Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013), reasoning (Klingberg, Forssberg, & Westerberg, 2002), reading skills (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012), mathematical reasoning (Holmes, Gathercole, & Dunning, 2009) and fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). However, other studies report no transfer effects (Baniqued et al., 2015; Foster et al., 2017; Redick et al., 2013) and results from two recent meta-analyses show no convincing evidence that working memory training generalizes to other measures of "real world" cognitive skills (Melby-Lervåg et al., 2016; Schwaighofer et al., 2015).

Switch training interventions demonstrated a significant reduction in switch costs (Berryhill & Hughes, 2009; Zinke, Einert, Pfennig, & Kliegel, 2012). Studies provide a mixed picture of the extent to which transfer is possible in the task-switching paradigm (Gaál & Czigler, 2017; Minear & Shah, 2008; Zinke, Einert, et al., 2012). Other studies show near transfer effects (Zinke, Einert, et al., 2012) and far transfer effects on measures of inhibition (Karbach & Kray, 2009; Kray, Karbach, Haenig, & Freitag, 2012), verbal working memory (Kray et al., 2012) and fluid intelligence (Karbach & Kray, 2009) but not reasoning (Kray et al., 2012).

Inhibitory control (IC) has been shown to improve by training in adults (Wilkinson & Yang, 2012; Zhao, Chen, & Maes, 2016) and children (Dowsett & Livesey, 2000; Zhao et al., 2016). Transfer effects of behavioral (Zhao, Chen, Fu, & Maes, 2015) and cognitive IC have been investigated in healthy (Liu, Zhu, Ziegler, & Shi, 2015; Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009; Zhao et al., 2015) and clinical (Johnstone, Roodenrys, Phillips, Watt, & Mantz, 2010) samples of children. Further studies assessed IC transfer in healthy (Enge et al., 2014) and clinical (Thummala & Satpathy, 2009) adult populations as well as older populations (Ji, Wang, Chen, Du, & Zhan, 2016; Wilkinson & Yang, 2012, 2016a, 2016b).

Some evidence supports the notion that inhibition improvements due to training transfer to untrained inhibition tasks. A recent meta-analysis shows that repeated sessions of computerized IC training lead to benefits in other domains of self-control (Friese, Frankenbach, Job, & Loschelder, 2017). However, effect sizes were small ($g = 0.21$) and there is not sufficient evidence to conclude that repeated IC is indeed the critical factor that drives the observed training effects. In children, an inhibition playground training game improved performance in the go-no/go task but not in the Stroop task, suggesting limited transfer (Zhao et al., 2015). Millner, Jaroszewski, Chamarthi, and Pizzagalli (2012) showed robust training related improvements in the Simon task and the emotional go-no/go task in healthy young adults, which transferred to interference control in an untrained flanker task. In older adults, Ji et al. (2016) reported training gains in inhibition processes, which only transferred to an untrained inhibition task that demands IC in the sense of deleting relevant information from the focus of attention and intentional forgetting (*deletion*) (Lustig, Hasher, & Zacks, 2007). The same study detected far transfer effects on fluid intelligence (Gf). Additional evidence of IC related far transfer effects comes from a recent study (Liu et al., 2015), which showed a trend for improvements in abstract reasoning abilities (Raven's Matrices) in children who received a computerized inhibition training.

In contrast, other studies did not report transfer effects of inhibition training (Enge et al., 2014; Johnstone et al., 2010; Liu et al., 2015; Thorell et al., 2009; Wilkinson & Yang, 2012, 2016a) or reported only short-lived transfer effects in children but not in adults (Zhao et al., 2016).

In sum, it remains unclear whether inhibition training effects transfer to other EFs domains. This question is of particular importance given the overlap of the inhibition factor with the common EFs factor