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Cognitive training to promote executive functions

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Abstract:

Three perspectives are discussed to motivate cognitive trainings of executive functions across the lifespan. Cognitive trainings aim (1) to better understand plasticity across the lifespan, (2) to improve executive functions, and (3) to test theories on cognitive development across the lifespan. Cognitive trainings in children showed promising results in training executive functions such as inhibition, working memory and task switching with even benefits to fluid intelligence. Furthermore, the approach has been successfully applied to clinical populations such as children with ADHD. The majority of training studies concerned young adults and trained working memory—showing benefits in trained and untrained tasks. Similarly, in late adulthood cognitive trainings seem to be a promising avenue for fostering executive functions despite the general cognitive decline. However, there is an ongoing debate on transfer effects that are benefits to untrained tasks of different cognitive domains than the trained one. Transfer effects are generally rather small in the different age groups across the lifespan challenging the efficiency of cognitive trainings on executive functions. Furthermore, future research is needed to determine the exact mechanisms underlying efficient cognitive trainings.

Words: 181

Key words: training, transfer, childhood, young adulthood, late adulthood, lifespan, plasticity

1. Introduction

At least three perspectives have been employed to motivate and frame the study of cognitive trainings that may promote executive functions across the lifespan: a developmental, an applied and a conceptual perspective. The first motivation for this line of research concerns a core question of developmental psychology itself and directly refers to prominent lifespan theories, especially their notion of plasticity. According to lifespan theories of development, plasticity is a central aspect of lifelong development because it encompasses the adaptive potential of an individual to develop (i.e., change and retain stability) through experience (Baltes, Lindenberger & Staudinger, 2006; Willis & Schaie, 2009). Plasticity of cognitive functions has been examined in psychology mostly by employing systematic intervention or training approaches exploring the amount of plasticity in different domains of cognitive functioning and possible age-related differences in plasticity, executive functioning being one the more recent domains targeted in this regard. The second perspective focuses on the intervention side of cognitive trainings and adopts a preventive or even clinical approach. Here, the aim is to prevent a specific population potentially at risk such as older adults (e.g., Hertzog, Kramer, Wilson & Lindenberger, 2009) to fall below a critical threshold of functioning in executive control (considering its general importance for a broad variety of important life outcomes, such as goal-directed behavior, socioemotional development or physical health). In addition, in case that (specific) executive dysfunctions have been identified as a core marker of a clinically relevant impairment, such as inhibitory problems in children with attention deficit hyperactivity disorder (ADHD), in this framework one aims at improving or even restoring the efficiency of this compromised neuro-cognitive process through process-based cognitive trainings (e.g., Klingberg et al., 2005). In both cases, the study goals are twofold: restoring the trained executive function (training effects) and aiming for generalized improvements of those training effects in other cognitive or life domains (transfer effects). Transfer effects can be differentiated in near and far transfer effects. Near transfer refers to improvements in untrained tasks of the same cognitive ability, whereas far transfer refers to improvements in untrained tasks of different cognitive abilities than the trained one (e.g., Morrison & Chein, 2011). Somewhat more recently, transfer effects have become a key conceptual target in a third perspective taken in the literature on executive function trainings across the lifespan. Here, cognitive trainings to promote executive functions in developmental populations are employed as experimental manipulations and used to test and further shape theories and models of cognitive and socio-emotional development that propose (specific) executive functions as developmental mechanisms underlying the trajectories in higher order cognitive processes such as reasoning or prospective memory (e.g., Kliegel, Altgassen, Hering & Rose, 2011). Complementing traditional experimental approaches that have mostly manipulated cognitive control or specific executive functions via adding executive task load (and thereby reducing the efficiency of cognitive control) on top of the cognitive process of interest (e.g., Voigt et al., 2014), the conceptual training approach opts for the other direction and aims at increasing capacity in specific executive functions trough training (mimicking developmental progress) and then examining (age-related) transfer effects in the target constructs testing for a causal impact.

All three perspectives are of course complementary approaches, but are partly discussed in distinct literature families – thus, the present chapter aims at bridging these traditions and systematically reviewing available evidence across the lifespan, discussing literature on children, young and older adults

2. Childhood

Although the first cognitive training studies in children emerged in the 1980s, applying a training approach with the goal to enhance executive functions in children seems to be a relatively novel approach. In 2000, Dowsett and Livesey showed that healthy preschool children aged 3- to 5-years old were able to improve their inhibitory capacities by repeatedly working on a set of executive tasks. These findings were among the first to illustrate that even relatively short interventions (Dowsett & Livesey's study applied a total of approximately 60 minutes of training, spread over three sessions) may be able to enhance children's executive functions (see also Chevalier & Clark, Chapter 2, and Moriguchi, Chapter 5, this volume, on developmental aspects of executive functions during childhood). Following these promising results, a multitude of subsequent studies have demonstrated that cognitive training interventions can promote executive functioning in healthy children. Taken together, the literature has found to this date that by repeatedly training on executively demanding tasks, children from a very young to an adolescent age can show (albeit sometimes small) improvements in working memory (e.g., Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi, Studer-Luethi, Buschkuehl, Su, Jonides & Perrig, 2010; Karbach, Strobach & Schubert, 2015; Klingberg, 2010; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), in task switching (e.g., Karbach & Kray, 2009; Kray, Eber, & Karbach, 2008; Zinke, Einert, Pfennig, & Kliegel, 2012), as well as in inhibitory control (e.g., Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009).

After establishing the possible trainability and plasticity of executive functions, many studies aimed at examining the broader benefit of cognitive training interventions, by investigating whether a transfer of the improvements could be seen in other, non-trained domains of more general importance, such as children’s intelligence or their academic achievement. Jaeggi, Buschkuehl, Jonides and Shah (2011) for example found that after completing their cognitive training, children had not only increased their performance in a working memory task, but also showed improvements on a fluid intelligence test (for similar findings showing a positive effect of training on tests measuring intelligence, see e.g., Ang, Lee, Cheam, Poon, & Koh, 2015; Karbach & Kray, 2009; Rueda et al., 2005). Furthermore, Jaeggi et al. observed a mid-term benefit of their intervention, as children maintained their improvements on a 3-month follow-up assessment.

Besides the possible benefits of cognitive training for healthy populations, as indicated above, many researchers were interested in using executively demanding interventions to help children with specific executive dysfunctions. As, for example, symptoms of ADHD are frequently associated with executive, especially inhibitory deficits (see e.g., Brown, 2013), different studies have looked into the efficiency of executive functioning training for those children. Klingberg, Forssberg and Westerberg (2002) for example applied a working memory training with children diagnosed with ADHD and found that the intervention increased 7- to 15- year olds' performance on a working memory and an intelligence test. Moreover, Klingberg and colleagues (2005) found that ADHD-diagnosed children improved working memory, inhibitory control as well as reasoning, and furthermore that participants' parents reported their children to demonstrate fewer symptoms of inattention following the intervention (for similar findings, see Kray, Karbach, Haenig, & Freitag, 2012).

Although this illustrates that training interventions can be efficient (in healthy as well as clinical samples) and that more general benefits than only task-related improvements are possible, a recent wave of reviews and meta-analyses that aggregated several cognitive training studies and analyzed the effects and possible influence factors, challenges the early optimism especially concerning possible (clinically relevant) transfer effects. This critical view is particularly motivated by the current emergence of commercially available, computer-based training applications, which promise „significant and lasting improvement in attention, impulse control, social functioning, academic performance, and complex reasoning skills for children with ADHD" (Rapport, Orben, Kofler, & Friedman, 2013, p. 1238). For example, Melby-Lervag and Hulme (2013) argued that instead of targeting the executive resources, some of the commercial interventions are more likely to work on the short-term memory component of a task, which is not considered to be one of the main deficits in ADHD. Furthermore, the authors stated that although participants increase their performance on different cognitive tasks, the training intervention does not seem to reflect on children's behavior nor their academic performance. This suggests that the conventional training approaches – although they may improve performance in some cognitive domains – may not be specific enough to decrease symptoms related to ADHD. Rapport and colleagues (2013), who came to the same conclusion, argued that "collectively, meta-analytic results indicate that claims regarding the academic, behavioral, and cognitive benefits associated with extant cognitive training programs are unsupported in ADHD" (p. 1249). Furthermore, Rapport and colleagues underlined that when assessing the efficiency of a training program, researchers should be cautious of the Hawthorne effect: usually, raters that know which participants did and did not undergo the training (*unblinded raters*) report larger changes in symptom-related behaviors for the training group than raters that are not aware of group affiliation (*blinded raters*), which indicates that many studies might overestimate training benefits.

Taken together, the current state of research seems to indicate that although in some cases executive function training can show long-term, non-trained and real-life transfer (e.g., in healthy children), future studies will have to develop what the exact mechanisms behind these effects are, and how training approaches have to be modified to benefit specific populations (such as children with ADHD).

As an example for the third, experimental approach to executive function training in children we briefly present an ongoing research project from our own group. The conceptual target in this project is the development of prospective memory; the ability to remember to perform previously planned activities in the future such as remembering to take home a signed letter from school (Kliegel et al., 2013). Descriptively, prospective memory has been reported to increase during childhood (Kvavilashvili, et al., 2008; Mahy & Moses, 2011) but little is known about the mechanisms that drive its development. One mechanism under debate is executive functioning as individual differences in executive functions have been found to correlate with prospective memory performance in children (e.g., Ford, et al., 2012). Further, studies have documented a similar developmental trajectory of prospective memory and executive functions that show marked increases in performance during the early childhood years (Carlson & Moses, 2001; Mahy & Moses, 2011) and continue to relate to prospective memory performance in adulthood (Kliegel, Mackinlay & Jäger, 2008; West & Craik, 1999). Yet, so far, all available evidence is purely correlational. Thus, in an ongoing study, we directly train the executive functions assumed to underlie prospective memory over four weeks using established training procedures for working memory, inhibition, and task switching and compare their relevance for prospective memory development. In a classical pre- post randomized controlled trial (RCT) design, we test for transfer effects on different markers of prospective memory functioning across childhood. Initial evidence suggests an important effect of especially inhibitory control and task switching training for age-related prospective memory performance. It supports evidence from studies using structural equation modelling that suggest these executive processes to be particularly related to prospective memory development (Schnitzspahn et al., 2013).

3. Young adulthood

The majority of studies on executive functioning training has been conducted in young adults and trained mainly working memory. In general, these studies reported improvements for the trained tasks (typically n-back training tasks; see e.g. Enriquez-Geppert, Huster, & Herrmann, 2013; Klingberg, 2010; Morrison & Chein, 2011; Strobach, Salminen, Karbach, & Schubert, 2014, for overviews); yet, as in children, results regarding possible transfer effects to untrained tasks are mixed. For example, studies using extensive training procedures (usually including eight to twenty sessions) revealed transfer effects to untrained working memory tasks (near transfer) as well as to other tasks of cognitive domains (far transfer) such as fluid intelligence and task switching (e.g., Dahlin, Nyberg, Bäckman, & Neely, 2008; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Salminen, Strobach, & Schubert, 2012), while other studies did not find far transfer effects (see e.g. Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012). However, Au et al. (2015) recently conducted a meta-analysis on n-back trainings in young adults and found small but significant far transfer effects to fluid intelligence. Melby-Lervag and Hulme (2016) raised methodological issues on this meta-analysis (i.e., not accounting for baseline differences and failing to emphasize the difference between studies with treated versus untreated control groups) and instead reported an absence of transfer effects in their own meta-analysis (see also Melby-Lervag & Hulme, 2013). In response to that, Au, Buschkuehl, Duncan, and Jaeggi (2016) meta-analytically demonstrated that the type of control group per se does not moderate observed transfer effects of working memory training on measures of fluid intelligence and thereby reaffirm the initial conclusions of Au et al. (2015; see also Bogg & Lasecki, 2015). This debate underlines the requirement for more systematic studies on potential moderators such as intensity, duration, or adaptivity of the training procedure (Enriquez-Geppert et al., 2013; Schwaighofer, Fischer, & Buhner, 2015). Likewise, further research is needed to disentangle different possible mechanisms underlying transfer effects, for example in the case of working memory training whether the training enhances working memory capacity (training-related increase of amount that can be held in working memory) and/or efficiency to better use the available working memory capacity (e.g., von Bastian & Oberauer, 2014).

While training of working memory has been extensively evaluated, experimental studies investigating the trainability of other executive functioning, are relatively sparse (see e.g. Enriquez-Geppert et al., 2013, for an overview). For inhibition, most studies focused on the

Stroop effect (i.e., a reduced difference between congruent and incongruent trial response times; e.g. Davidson, Zacks, & Williams, 2003; Dotson, Sozda, Marsiske, & Perlstein, 2013) and showed a reduced Stroop effect with more pronounced practice-related gains on incongruent compared to congruent trials, which is consistent with the view that training enhances interference processing by improving the suppression of reading processes in the Stroop task (e.g., Dulaney & Rogers, 1994; MacLeod, 1998; see e.g. Strobach et al., 2014, for an overview). Besides the Stroop task, there are a few studies that investigated trainability of inhibition with other tasks in young adults such as the Stop-Signal training by Noel et al. (2016). The authors found that stop performance improved if stimuli were consistently associated with the need to stop (in contrast to stop stimuli without consistent association). Furthermore, trainings effects in inhibition were observed for Go/No-Go trainings (e.g., Manuel, Grivel, Bernasconi, Murray, & Spierer, 2010). Notably, while these studies showed inhibition of irrelevant stimuli may be enhanced in the trained task, Strobach et al. (2014) concluded that there is no convincing evidence yet for near or far transfer. For example, in one of our own studies, Enge et al. (2014) trained inhibitory control using the Go/No-Go and Stop-Signal task, but did not find evidence for near transfer to an untrained Stroop task nor far transfer to measures of fluid intelligence.

For task switching, evidence showed that already relatively short task switching trainings (e.g., six practice sessions) can produce a reduction of switch costs (e.g., Buchler, Hoyer, & Cerella, 2008; Cepeda, Kramer, & Gonzalez de Sather, 2001; Karbach & Kray, 2009; Kray & Eppinger, 2006; Kray & Lindenberger, 2000; Minear & Shah, 2008; Tayeb & Lavidor, 2016). In addition, there is evidence suggesting that a task switching training can lead to performance improvements in new (untrained) task switching tasks and thus evoke near transfer (e.g., Karbach & Kray, 2009; Pereg, Shahar, & Meiran, 2013). There is also evidence of far transfer with enhanced performance in other tasks of cognitive functioning such as working memory, inhibition, and fluid intelligence (e.g., Karbach & Kray, 2009; see also e.g. Enriquez-Geppert et al., 2013; Strobach et al., 2014, for overviews).

Thus, while the trainability of different executive functions seems indeed promising, far transfer may become evident only on specific conditions. In general, it has been discussed that the prerequisites for transfer effects of executive functioning trainings may be an overlap of neural and cognitive processes involved in the trained task and in the transfer tasks (see e.g. Enriquez-Geppert et al., 2013, for an overview). Yet, albeit growing efforts to experimentally evaluate the trainability of executive functioning in younger adults during the last decade--particularly for inhibition and task switching--research is still in its infancy and detailed investigations are needed to help understanding the mechanisms underlying the observed outcomes of different training procedures for executive functions (see e.g. Enriquez-Geppert et al., 2013; Hsu, Novick, & Jaeggi, 2014; Strobach et al., 2014, for overviews). In this avenue, investigating training-related neural activation changes (e.g., Li et al., 2015) and intraindividual fluctuations during training (Könen & Karbach, 2015) may be fruitful methodological advances.

4. Late adulthood

Based on the promising patterns of early studies suggesting the possibility of enhancing efficiency in executive functions, older adults have very soon become an important target in this training literature because decline of executive functions is one of the first cognitive losses in late adulthood (see Li, Vadaga, Bruce & Lai, Chapter 4, this volume; McFall, Sapkota, Thibeau

& Dixon, Chapter 17, this volume; West, Chapter 6, this volume). As with children or younger adults, training studies in older adults have focused on the full spectrum of executive functions such as working memory, inhibition and task switching and examined both training and transfer effects.

Again, early studies in this literature have reported very promising results. For example, Borella, Carretti, Riboldi, and De Beni (2010) trained healthy older adults on a working memory training for three sessions and showed that the training group clearly benefited from the verbal working memory training. Trained participants improved in working memory, fluid intelligence, short-term memory and inhibition compared to the control group. Furthermore, the training gains and the improvement in the fluid intelligence measure were maintained even eight months after the training. The results of this study are impressive and show the usefulness of cognitive trainings in promoting older adults' executive functioning. Considering the evidence from meta-analyses, the efficiency of cognitive trainings in older adults has received further support (but see Melby-Lervag & Hulme, 2015 for a contradictory view). Karbach and Verhaeghen (2014) compared 49 different studies on working memory and executive function trainings in older adults. They showed large improvements in performance of the trained tasks as well as large near transfer effects for tasks of the same cognitive domain as the trained task. Furthermore, Karbach and Verhaeghen (2014) found small but significant far transfer effects for task performance in cognitive domains others than the trained one (e.g., reasoning for a working memory training). In older adults, similarly to research on clinical populations such as children with ADHD, transfer of working memory or executive functions training to markers of everyday life functioning are considered to be especially crucial. Yet, so far, only a few studies have targeted this topic and found transfer to real-world tasks such as instrumental activities of daily living, everyday-like multi-tasking scenarios, reading comprehension or self-reports on everyday functioning (e.g., Brehmer, Westerberg, & Backman, 2012; Carretti, Borella, Zavagnin, & de Beni, 2013; McDaniel et al., 2014; Rose et al., 2015).

To better understand which cognitive trainings promote executive functions and are in fact beneficial for older adults also gerontological training research has started to systematically examine moderators that influence the training efficacy. In late adulthood, age seems to play an especially important role. There is a differentiation between young-olds aged 60 to 75 years and old-olds aged 75 years and above. Whereas cognitive trainings benefit working memory and executive functions as reported in the meta-analyses of Karbach and Verhaeghen (2014), the picture is less clear in old-old adults. There exist only a few studies investigating this age group (e.g., Buschkuehl et al., 2008; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012). For example, the two mentioned studies used both a working memory training in old-old adults aged 80 years and above. Buschkuehl et al. (2008) found not only training gains but also near transfer effects. Only the training group improved in a not-trained working memory task. In a study from our own group, Zinke et al. (2012) investigated the impact of a working memory training on executive functions. Her, we showed clear training improvements but did not find any transfer effects to executive functions. Furthermore, we differentiated the training group according to their working memory capacity at the beginning of the training into high performer versus low performer. Separate analyses for each group revealed that the low capacity training group benefited the most from the working memory training. In a follow up working memory study from our group on young-olds and old-olds, Zinke et al. (2014)

confirmed their previous finding and showed again that baseline performance, that is performance before the training in the training tasks, impacts training gains. Specifically, we trained old adults in four different working memory tasks for nine sessions over three weeks and tested for transfer to executive functions such as inhibition and reasoning. Old adults with lower performance at the beginning improved more over the course of the training. Additionally, we showed that age and the actual training gains influenced the transfer to executive functions. Transfer effects decreased with increasing age but participants with higher training gains also showed higher transfer effects.

Although these studies considered already important influencing factors for cognitive trainings, there are still lots of open questions on other mediating or moderating factors such as motivation, lifestyle differences and leisure activities. In the same context of discovering mechanisms of training and transfer effects in old age, more and more studies on neural changes due to cognitive interventions have emerged. Studies using neuroscientific methods such as neuroimaging techniques (fMRI) or electroencephalography (EEG) to evaluate the influence of training gains on the brain reported in general more efficient neural processing. For example, Heinzel et al. (2014) found a more "youth-like" brain response in older adults after their working memory training. Gajewski and Falkenstein (2012) used a cognitive training to promote task switching performance. As neural indicators they assessed specific event-related potentials for maintaining and coordinating multiple tasks (e.g., N2, P3b) and could show that after the cognitive training these indicators were enhanced indicating better response selection.

Overall, there is a significant potential in cognitive training to promote older adults executive functioning. Behavioral training studies show training gains and some transfer effects in young-olds and old-olds. However, there are also important factors that critically influence the efficacy of a cognitive training such as age of participants with increasing age reducing the training gains and transfer effects.

5. Conclusions

Taken together, across all age groups and across healthy and clinical populations, first results on cognitive training to promote executive functions across the lifespan, indeed, appeared promising as they (i) revealed plasticity in trained tasks from childhood into old age. Moreover, (ii) some of those interventions also revealed transfer to non-trained tasks in the laboratory. More recently, however, the initial enthusiasm has been challenged by several studies not or only marginally revealing training effects for some domains, failing to generally find far transfer at all or suggesting partly limited benefits for non-trained tasks. Moreover, evidence on possible effects in everyday life is virtually non-existing. Thus, as of today, three core conclusions seem to be justified: (a) executive functions can be trained, (b) training and even more so transfer effects are critically moderated, and (c) those moderators are largely unknown. In consequence, further systematic research is urgently needed to test possible moderators of training and transfer effects in cognitive functioning across the lifespan – given the heterogeneity of study protocols and populations included a coordinated effort across research groups and traditions seems more than warranted.

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