The Effectiveness of Training in Task Switching:

New Insights and Open Issues from a Lifespan View

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In this chapter we will review new insights about the effectiveness of training in task switching from a lifespan perspective, considering the challenges outlined in Chapter x (see Diamond & Ling, this volume). This chapter is divided into five parts: In the first part, we will briefly summarize the empirical evidence about lifespan changes in task switching. In the second part, we will introduce and rely on a theoretical framework highlighting that an imbalance between environmental demands and brain supply is critical for inducing practice- and training-related changes, again taking a lifespan perspective on task switching. In the third part, we will review empirical findings on the effectiveness of task-switching training considering age-sensitive effects in training and transfer gains under various training conditions. The fourth part is focused on individual differences that might influence training effectiveness. Finally, we will summarize new insights on the effectiveness of task-switching interventions and discuss open issues and fundamental unanswered questions for designing an optimal training intervention across the lifespan.

1. Lifespan Changes in Task Switching

As already outlined in chapter x (see Diamond & Ling, this volume) the ability to flexibly switch between task rules and mental sets is seen as a fundamental component of cognitive control (Diamond, 2013; Miyake, et al., 2000) and is known to be associated with fluid intelligence (e.g., Duncan, Burgess, & Emslie, 1995). While researchers focusing on developmental changes of cognitive flexibility in early and middle childhood have mainly applied a specific variant of task switching, the DCCS (for a review, see Zelazo, 2006), lifespan researchers have mainly used variants of the task-switching paradigm (for recent reviews on childhood development, see Kray & Ferdinand, 2013, and on adult development, see Kray & Ferdinand, 2014).
The advantage of the task-switching paradigm is that it allows to separately measure different cognitive control processes, such as task preparation, interference and switching processes within the same experimental paradigm (for a review, see Kiesel et al., 2010). Although there exists now quite a number of different variants of the task-switching paradigm, a majority of studies apply an experimental design in which participants have to switch between two tasks A and B within the same block of trials (i.e., mixed-task blocks) as well as to perform only one of the two tasks A or B within a block (i.e., single-task blocks). This allows to determine two types of costs: Mixing costs are usually defined as difference between performance in mixed-task blocks versus single-task blocks (also termed global or general switch costs; cf. Kray & Lindenberger, 2000; Mayr, 2001), and switching costs are defined as difference between performance on switch trials (a change of task A to B or B to A) and on nonswitch trials (a repetition of the same task A) within mixed-task blocks (also termed local or specific switch costs). Mixing costs are assumed to reflect control processes that are required for maintaining multiple task sets and for selecting between them (i.e., being in a switching situation), while switching costs are associated with the reconfiguration of tasks itself (i.e., performing a task switch).

Regarding lifespan changes in task switching, it is now well documented that age differences in mixing costs show a clear u-shaped developmental curve across the lifespan that is less pronounced for switching costs. During childhood, nearly all studies investigating older children from middle childhood on, found larger age-related changes in mixing costs than in switching costs, suggesting the ability of switching between task and rules develops earlier than the ability of maintaining and selecting of task sets (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Crone et al., 2004; Dibbets & Jolles, 2006; 

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1 It should be noted that there are different definitions of mixing costs (Cragg & Chevalier, 2012; Mari-Beffa & Kirkham, 2014): Mixing costs referred to as “general” or “global” are measured as the difference in performance on single-block trials and on mixed-block trials (i.e., the latter encompassing both switch as well as nonswitch trials); Mixing costs referred to as “nonswitch-specific”, however, are measured as the difference between single-block trials and only nonswitch trials from mixed blocks.
During adulthood, the majority of task-switching studies reported substantial age differences in mixing costs, suggesting age-related impairments in maintaining and selecting between task sets (Buchler, Hoyer, & Cerella, 2008; Cepeda et al., 2001; Kray, 2006; Kray & Lindenberger, 2000; Kray et al., 2004; Kray et al., 2008; Lawo, Philipp, Schuch, & Koch, 2012; Mayr, 2001; Meiran, Gotler, & Perlman, 2001; Lien, Ruthruff, & Kuhns, 2008; Reimers & Maylor, 2005; van Asselen & Ridderinkhof, 2000; but see Kray, Li, & Lindenberger, 2002). Although some studies also found age differences in switching costs (e.g., Meiran et al., 2001), most of these studies showed smaller age differences in switching costs than in mixing costs (e.g., Karayanidis, Whitson, Heathcote, & Michie, 2011; Karayanidis, Jamadar, & Sanday, 2013; Kray & Lindenberger, 2000; Kray et al., 2004; Kray et al., 2008; Kray, Eppinger, & Mecklinger, 2005; Mayr, 2001; Mayr & Liebscher, 2001; Lien et al., 2008; Reimers & Maylor, 2005; Whitson, Karayanidis, & Michie, 2011; Whitson et al., 2014), and often age differences in switching costs fail to reach significance (e.g., Kray & Lindenberger, 2000; Hahn, Anderson, & Kramer, 2004; Salthouse et al., 1998). This indicates that older adults show less process-specific limitations in executing a task switch, but they show problems in being in a switch situation requiring the selection between tasks and their maintenance (for a meta-analysis, see Wasylyshyn, Verhaeghen, & Sliwinski, 2011). Hence, in light of these findings it seems particularly promising to foster cognitive processes required for being in a switch situation in order to reduce age-related differences in task switching.

As it has already been outlined in detail in the overview chapter, given its importance for early academic and school success as well as for cognitive functioning in old age, we
should really care to find effective ways how to improve cognitive control by optimal
cognitive intervention programs (see Diamond & Ling, this volume). In the following we will
summarize recent insights about the effectiveness of training in task switching.

2. Flexibility and Plasticity of Task-Switching Performance across the Lifespan

The possible range of practice-induced improvements in task-switching abilities
strongly depends on an individual’s potential for cognitive flexibility as well as for plasticity
(cf. Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010), both varying across the
lifespan (Mackey, Raizada, & Bunge, 2013). According to a theoretical framework of
cognitive plasticity recently suggested by Lövdén et al. (2010), the premise for the brain to
work efficiently is, on the one hand, to maintain a certain level of stability that preserves
computational resources (referred to as the brain’s dynamic equilibrium). On the other hand,
the brain demonstrates the capability to adapt to changing environmental demands. The term
plasticity refers to the actual structural constraints of the dynamic equilibrium on brain
function and performance. The term flexibility, by contrast, refers to the possible range of
changes within these structural (plastic) constraints, that is, the brain’s capacity to optimize
cognitive performance therein. If the environmental demands cause an imbalance with the
actual brain supply, the brain will react to this supply-demand mismatch with functional
(flexible) or structural (plastic) changes. While flexibility leads to an immediate response of
the behavioral system by recruitment of given cognitive functions (i.e., a primary reaction to
altered demands within the preexisting range of supply), cognitive plasticity requires a more
prolonged supply-demand mismatch to overcome the equalizing status quo (i.e., a sluggish,
secondary reaction to prolonged altered demands by changing the preexisting range of
functional supply). Within this framework, cognitive interventions may induce changes at the
level of flexibility or plasticity depending on a prolonged exposure to demand-supply
mismatches. However, such mismatches of supply and demands are a necessary but not a
sufficient condition to prompt cognitive plasticity – the individual intrinsic potential that is shaped differently throughout the lifespan by both, individual genetics as well as life experiences, determines the ultimate amount of possible plastic changes. Hence, cognitive functioning is considered to be adaptive in nature while at the same time to be restricted to an individual ultimate range of cognitive performance.

Lifespan Changes in Task-Switching Supply

The developmental changes on the flexibility to switch between task demands have been shown to be mainly related to the brain supply of the prefrontal lobe system and associated cortical and subcortical structures (Bunge & Zelazo, 2006; Bunge & Wright, 2007; Casey, Tottenham, Listen, & Durston, 2005; Enriquez-Geppert, Huster, & Herrmann, 2013; Luna et al., 2001; Luna, Padmanabhan, & O’Hearn, 2010; for recent reviews on the neural development in childhood and adolescence, see Anderson & Spencer-Smith, 2013; Giedd, Raznahan, & Lenroot, 2013; Karbach & Unger, 2014; and in old age, see Cabeza & Dennis, 2013). The prefrontal lobe shows an inverse u-shaped maturational trajectory over the lifespan, encompassing a steep structural growth in childhood, a maturational peak in young adulthood, and a steady decline in volume in older age (e.g., Blakemore, Burnett, & Dahl, 2010; Hedden & Gabrieli, 2004). Based on these neural underpinnings, Bunge and Zelazo (2006) proposed a brain-based framework to account for the functional development of rule processing depending on the maturational change of the frontal lobe. They suggest that successive changes on rule use in childhood (from using a single rule to switching between compatible rules to switching between incompatible sets of rules) emerge from age-related progress in the ability to represent increasingly complex rule hierarchies. Distinct sub-regions of the PFC may subserve these different complexity levels of rule representations due to a maturational structural differentiation that is paralleled by a functional specialization of frontal regions. Specifically, it has been demonstrated that the orbitofrontal cortex develops very early in childhood and codes simple stimulus-reward contingencies. The lateral part of
the prefrontal cortex, however, continues to develop into young adulthood, whereas different lateral networks represent, according their own specific trajectories, rules of increasingly higher complexity levels (i.e., the ventrolateral and the dorsolateral PFC both code conditional rules of medium complexity and the rostrolateral PFC, being the last to develop, codes complex higher-order rules). Hence, the conceptual understanding of the hierarchical rule system that may underlie complex task-switching abilities evolves along the (structural and functional) maturation of distinct networks of the forebrain in childhood (ibid.). At the opposite end of the lifespan, however, even the prefrontal cortex seems to be first and strongest compromised by age-related decline (Moscovitch & Winocur, 1992; West, 1996; for a recent review, see Cabeza & Dennis, 2013). This is expressed both in volume shrinkage as well as in a functional de-differentiation (Braver et al., 2001; Double et al., 1996; Raz, 2004). The neural regression may hamper the ability of complex rule switching, thus reducing the brain supply for task switching in the elderly.

According to these lifespan changes, even childhood and older age appear to be highly sensitive periods to incoming demands, as the immature or over-mature frontal supplies may lead to large mismatches. Interventions aiming at improvement of prefrontal lobe functioning within these developmental trajectories thus might accelerate its maturation in childhood development and might decelerate its decline in older age (Wass, Porayska-Pomsta, & Johnson, 2011; Watson, Lambert, Miller, & Strayer, 2011). Hence, the identification of the most effective training programs for various age ranges is essential to maximize the range of plastic modification by practice in task switching.

**Lifespan Changes in Flexible Adaptations to Task-Switching Demands**

Lifespan changes in the flexible adaptation to immediate alterations of environmental demands, that is, when individuals are required to switch back and forth between two or more tasks, will only be briefly summarized as extensive reviews have been provided recently elsewhere (e.g., Kray & Ferdinand, 2014; Peters & Crone, 2014). Age-related differences in
task-switching costs are shown to be reduced with lower demands on prefrontal lobe functioning, such as (a) with the presence of external task cues that support the maintaining and retrieving of the currently relevant task (Cepeda et al., 2001; Kray, 2006; Hahn et al., 2004), (b) with the use of internal task prompts such as task-supporting verbalizations (Kray et al., 2008; see also Kray & Ferdinand, 2014), (c) with an increase of preparation time (Crone et al., 2006; De Jong, 2001; Kray, 2006), (d) with lower interference between the involved tasks by non-overlapping task-set representations (Mayr, 2001; see also Eppinger, Kray, Mecklinger, & John, 2007), as well as by (e) task practice (Cepeda et al., 2001; Karbach & Kray, 2009). Although age-related differences can be substantially reduced by these manipulations, age differences in mixing costs are still reliable, supporting the view of age differences in structural constraints of brain supply.

Lifespan Changes in the Plasticity of Task-Switching Performance

What are the preconditions to induce plastic changes in task switching across the lifespan? Considering again the framework suggested by Lövdén et al. (2010), the training should create a mismatch between functional supply and experienced demands. Prior to a cognitive intervention, the dynamic equilibrium is determined by a relative balance between supply and demands, that is, the demand curve employs about equal proportions of negative mismatch (demand > supply) and positive mismatch (supply > demand). The training intervention ideally produces a strong mismatch between the demands of the new training condition and the current brain supply. With increasing practice (a prolonged training interval), this mismatch slowly reduces as now the brain supply adapts to the high task-demands. This is the manifestation of training-induced cognitive plasticity, and as a result, the system rebalances after training with an enlarged (plastic) range for flexible functioning. The training thus stimulates a broadening of the cognitive range so that the individual will act on a higher equilibrium level (cf. Lövdén et al., 2010).
In the previous section, we have already identified age-sensitive challenging demands of a task-switching situation that can create an initial mismatch between brain supply and task demands, such as the absence of task cues, limited preparation time, the presence of task interference, and less task practice. However, critical from a lifespan perspective is that the cognitive training intervention not only needs to evoke cognitive activity that is as far away as possible from the routine demand –the mismatch also needs to be launched relatively to the respective life period and to the intrinsic potential that presumably varies in childhood and older adulthood. Hence, assuming constraints of brain supply in children and elderly people as compared to young adult age, we rather need a moderate mismatch to induce an optimum level of requirement that is activating and challenging but not overtaxing. In order to apply cognitive interventions and to induce such a relative or optimal mismatch for different age ranges across the lifespan as well as to keep the training intervention challenging throughout a prolonged training interval, researchers have often used an adaptive training procedure that adjusts the task difficulty to individual abilities throughout the training until individuals reach an asymptotic performance level (testing-the-limits; Kliegl, Smith, & Baltes, 1989; see also Klingberg, 2010; Shipstead, Reddick, & Engle, 2012). Some researchers indeed argued and provided empirical evidence that such adaptive testing procedures lead to larger plastic changes as compared to non-adaptive testing, especially in the context of working-memory (WM) trainings (Brehm, Westerberg, & Bäckman, 2012; Dunning, Holmes, & Gathercole, 2013; Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005; but see Karbach & Verhaeghen, in press, who found no differences between benefits associated with adaptive and nonadaptive testing in a meta-analysis of executive control and WM training in older adults). For instance, Brehmer et al. (2012) investigated whether an adaptive WM training regimen would affect the training situation and promote the transfer to domains different from the trained ones, both in younger and older adults. They contrasted a group receiving an adaptive training on various spatial and verbal WM tasks, spaced over five
weeks, against an active control sample completing a non-adaptive form of training (i.e., working on the same material but with low-level task demands). Results of this study indicated that an adaptive training procedure led to larger training and transfer gains as compared to low-level practice. These gains were, partly, greater for younger than for older adults and, partly, comparable across age groups. The latter age effects are, however, surprising in respect of a lifespan interpretation of the framework by Lövdén et al. (2010), which gave reason to expect pronounced room for cognitive plasticity in older age.

3. Age Differences in the Effectiveness of Task-Switching Training Interventions:

Training, Transfer, and Maintenance Effects

As we have already learned in the overview chapter, the principles for designing a good training intervention are often violated (see Diamond & Ling, this volume). Typically a training intervention is designed as a longitudinal pretest-training-posttest experiment best with a follow-up session. The efficiency of the intervention can be measured by direct training benefits (i.e., improvements in task performance during the practice sessions), but especially by transfer and long-term maintenance effects and should optimally include an active control group. Transfer refers to indirect training gains in similar or different task domains from those performed in the training sessions, whereby long-term maintenance relates to the lastingness or stability of the attained effects. Transfer is often assessed by various tasks that differ from the trained ones and are performed prior to and after extensive intervention (i.e., at pre- and posttest) in order to determine whether the training had tapped generalizable processes. We distinguish between two transfer scopes: By near transfer we mean the generalization of training-induced improvements to a new but structurally very similar task to the trained one, while by far transfer we mean a broader generalization of training-induced benefits to dissimilar task domains or theoretical constructs (cf. Karbach & Kray, 2009). In the following we will discuss recent findings on the plasticity of task switching by describing two main
approaches on cognitive interventions in the field, at first, the effectiveness of different process-based interventions, and then strategy-based interventions.

**Process-Based Task-Switching Interventions**

The general idea of process-based interventions is that the intensive practice of switching between tasks and their underlying cognitive-control processes will result in a positive transfer to those cognitive tasks that also partly rely on the same cognitive-control processes. In order to prove the effectiveness of a task-switching training, researchers have used as active control group a group that performs exactly the same tasks as the treatment group but practices the tasks in single-task block conditions instead of mixed-block conditions (see Minear & Shah, 2008).

*Training gains.* There is ample evidence that task-switching trainings produce robust gains on training-task performance at different life ages (e.g., Karbach & Kray, 2009; Kray, Karbach, Haenig, & Freitag, 2012). For example, Karbach and Kray (2009) showed that specific switch costs were substantially reduced as a function of practice in switching (for the different task-switching conditions, net effects ranged from 0.85 SD to 1.88 SD). The amount of this reduction was similar across age groups but was modulated by the specific training condition (see The Role of Training Variability). Zinke, Einert, Pfennig, and Kliegel (2012) trained a sample of adolescents (10-14 years) with a similar training setting by further considering the moderating influence of physical exercise: They compared three conditions, one group performing task switching in combination with physical exercise; one group performing task switching without physical exercise; and one passive control group. They found a reduction of latencies for switch trials of about 25 % and of latencies for nonswitch trials of about 18 % after task-switching training. Improvements thus were larger for switch than for nonswitch trials, indicating an increase in the ability to meet the requirements of the training task (i.e., improvements in switch costs). In addition, Strobach, Liepelt, Schubert, and Kiesel (2012) investigated practice-induced changes of an alternating-run paradigm on mixing
and switching costs by varying stimulus and response interference in young adults between the ages of 21 and 30 years. Results of their study revealed larger reductions on mixing than on switching costs. Importantly, mixing costs were eliminated after training, while switching costs were still existent. Training gains were independent of stimulus or response valence (see also Kray & Fehér, 2014). Hence, it seems that the overlap between stimulus and response valence during task-switching training is not sufficient to create the necessary mismatch between environmental demands and brain supply in younger adults. A recent meta-analysis of Karbach and Verhaeghen (in press) examined the effects of executive-function trainings including task switching on the training and transfer in older adults. Results on training improvement indicated clear benefits in old age, with raw gains of about 0.9 SD and net gains (after subtracting the effects of active controls) of about 0.5 SD. They report a net treatment effect of about 1.1 SD. These robust effect sizes point to consistent gains from a task-switching training on latency switch costs even though it should be noted that on error costs, effects were rather mixed (e.g., Karbach, 2008; Zinke et al., 2012).

Near transfer. Numerous studies have shown that practicing task switching indeed induces near transfer to similar switching settings in different age groups. For instance, Kray et al. (2012) showed that a task-switching training (with alternating runs and no task cues) led to substantial reduction of task-switching costs (mixing and switching costs) in middle-aged children (7-12 years) with attention deficit/hyperactivity disorder, yielding a net effect on mixing costs of about 1.3 SD. The results of Zinke et al. (2012) on adolescents indicated near transfer for both switching groups to a similar switching task, but this transfer was limited to global mixing costs, that is, the ability to maintain and to select between different task sets. However, this exclusive change of the maintenance abilities might be related to the higher developmental plasticity (and thus the wider room for improvement) for mixing costs than for switching costs between the ages of 11 and 15 years (cf. Huizinga & van der Molen, 2007). Minear and Shah (2008) investigated undergraduates comparing transfer gains in an
alternating-run task-switching setting without tasks cues and a task-switching setting with task cues. Interestingly, in line with Zinke et al. (2012), they only obtained near transfer gains on mixing costs but only in the uncued training condition. These findings support the theoretical considerations about a considerable supply-demand mismatch in order to induce plasticity in task-switching performance in adolescence and in young adults.

In the lifespan study of Karbach and Kray (2009), younger adults also attained near-transfer gains on mixing and switching costs by using an uncued alternating-run task-switching setting. Karbach and Kray (2009) compared benefits in healthy children (8-10 years) with the ones obtained in young adults (18-26 years) and older adults (62-79 years) and found even larger near transfer gains for children and older adults than for younger adults on switching tasks that were different from the trained ones (in all age groups, effects on the reduction of mixing costs were substantially larger for task-switching training groups, ranging from 0.98 SD to 2.15 SD, than for single-task training groups, ranging from 0.11 SD to -55 SD). Notably here is that the task-switching training was not adaptive in this study so that the larger mismatch induced by the training task in children and older adults resulted in larger transfer effects, although practice gains were comparable across the three age groups. In the meta-analysis of Karbach and Verhaeghen (in press) clear near-transfer effects of executive-functions training were shown for older adults (net gain score after subtracting controls of about 0.5 SD), supporting the effectiveness of interventions aimed at improving latent cognitive control.

Far transfer. Results on far transfer effects due to a task-switching training, however, are somewhat heterogeneous: In one of our first task-switching training studies (Karbach & Kray, 2009), we found substantial far transfer to measures of inhibition, working memory, and even to fluid intelligence for all age groups (with most effect sizes after task-switching training > 0.70 SD for children, > 0.60 for younger adults, and > 0.40 for older adults as compared to low or negative effects after single-task training). Children with ADHD showed
Far transfer benefit from an alternating-run task-switching training on inhibition (effect sizes up to 1.6 SD after switching training) and verbal working memory (effects up to 0.9 SD after switching training), but not on fluid intelligence (Kray et al., 2012). In contrast, adolescents did not show any clear far transfer to other task domains (Zinke et al., 2012): they indeed benefitted from switching training on their reaction dynamics in a choice reaction time task and (by tendency) in an updating task, but not on inhibitory ability. However, the training dose in this study was somewhat smaller than in the one of Karbach and Kray (2009), and the duration of the training regimen may play a crucial role for training effects, whereby even the optimal spacing of training is still an open question (see The Role of Training Intensity and Duration).

Far transfer effects were also scarce in a study by von Bastian and Oberauer (2013). They trained three groups of young adults (age range: 18 – 36 years) in different facets of working memory whereby they defined the ability of task-set switching to be a subordinated facet (termed “supervision”) of a three-componential functional working-memory model (see also Oberauer, Süß, Wilhelm, & Wittmann, 2003). The supervision group trained on a switching paradigm while the other groups performed training tasks with regard to other functional categories of working memory (storage and processing, relational integration). The switching training was adapted from Karbach and Kray (2009) with an alternating-run setting and ambiguous stimuli. Performance of each training group was compared against the one of an active control group that practiced unrelated perceptual-matching tasks. Results indicated, similar to the study of Karbach and Kray (2009), that the supervision training led to substantial near transfer to a similar switching task as well as to far transfer effects to reasoning (fluid intelligence). It did, however, not generalize to inhibition or working memory.

Pereg, Shahar, and Meiran (2013) tried to directly replicate the results of the study of Karbach and Kray (2009) by investigating a group of undergraduate students of about 24
years of age. Yet, they only found near transfer to a very similar switching task, and found no far transfer to working memory or inhibition. Similarly, in one of our recent studies we also tried to replicate our previous results and to further examine which kind of cognitive-control processes (switching, interference control, updating), contributed to the training success of task-switching training in younger and older adults (Kray & Fehér, 2014). To this end we systematically varied demands on switching (single task vs. mixed task blocks), interference control (univalent or bivalent stimuli), and updating (memory) demands (with or without task cues) across the training groups. Interestingly, for younger adults training and transfer gains did not vary across the training groups (see also Strobach et al., 2012), but for the elderly. Groups that were trained in resolving task interference (bivalent groups) showed larger (near) transfer gains than the other two groups, while these gains did not differ across groups that were trained under different memory demands during task switching (with or without task cues). However, we did not find evidence for broad far transfer to untrained cognitive control tasks in this study. Hence, the type of stimuli and interference induced by the involved training tasks may is more important than we first thought (cf. Karbach & Kray, 2009).

In line with these findings are results of a recent study of Anguera et al. (2013) who applied a multitasking training to determine cognitive plasticity in older age. They found considerable near-transfer gains of the training and argued that especially the practice in resolving task interference required in multitasking situations is critical for inducing cognitive plasticity in the elderly. Moreover, they also reported far transfer of the dual-tasking training to sustained attention as well as working-memory tasks, and this with medium to large effect sizes for far transfer (all effect sizes > 0.5 – 1.0 SD). Importantly, this study also revealed first robust correlations between behavioral improvement and changes on neural signatures of

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2 We would like to insert that dual-tasking is not to be confused with task switching because dual-tasking is considered to be a separate component of the executive functions cluster with idiosyncratic properties (Strobach, Salminen, Karbach & Schuchter, 2014). However, in respect of the similarity of performance costs that result from coordinating two task sets in both paradigms, we will present the very promising study of Anguera et al. (2013) on dual-tasking as well.
cognitive control, the latter being indicated by enhanced midline frontal theta power and long-range coherence (e.g., neural-behavioral correlations of the change in spectral power with the multitasking behavioral gain preservation in the training task after 6 months, \( r = .76 \), and with the behavioral improvement on a vigilance transfer task, \( r = .56 \)). In contrast, Karbach and Verhaeghen (in press) found in their recent meta analysis of executive-control training in older adults the existence of indeed clear but rather small far-transfer gains across training studies (the net gain after subtracting the effects of control treatments remaining at about 0.2 SD).

_The Role of Training Variability._ Only very few studies examined whether the variability of training conditions influence practice and transfer gains of a (task-switching) training. In light of theoretical considerations of the supply-demand mismatch model, the variation of task-specific processes practiced through the training should lead to reduced practice gains, as in each of the training sessions individuals are confronted with a new task situation so that the mismatch is constantly high throughout the intervention. For instance in the study by Karbach and Kray (2009) participants received new sets of stimuli and tasks in each of the four training sessions. Indeed, in contrast to the other task-switching training groups that received the same sets of stimuli and tasks in all four sessions, practice gains were nearly absent in this group (cf. Karbach, 2008). Most interestingly from a lifespan view is that transfer gains to a new switching task were substantially larger for younger and older adults after the variable training but strongly reduced in children.\(^3\) Hence, the prolonged mismatch was promoting the plasticity of task-switching performance in adults while it hampered it in children. This further underlines that only an optimal level of mismatch in each age group results in positive plasticity.

\(^3\) It should be noted that in this training condition participants were also required to verbalize the task goals so that it is not fully clear whether the variability or the increased dual-task demands reduced the transfer gains in the children group.
The Role of Training Intensity and Duration. There is an open question how much practice is really necessary to obtain far-reaching effects of a task-switching training. To date, no study engaged in systematic measurement of the optimum session length, the optimum session number, and the optimum spacing of an intervention. Former training regimens vary considerably in the amount of training according to their protocols, where yet 3 weekly sessions à 25min (total amount: 75min; Zinke et al., 2012) led to satisfying results on training benefit or near transfer, and 4 weekly sessions à 35 min (total amount: 140min; Karbach & Kray, 2009) even to bright effects on far transfer as well (see above). In general, short-time interventions dominate the area since they are of high importance from an applied perspective, that is, they might be easier to implement in real-life contexts (cf. Zinke, 2012). The optimum intensity has, however, not been stated yet, as previous short-time results still vary in their effectiveness (see also Oberauer et al., 2013; Pereg et al., 2013). An important extension should further be to adapt the total duration and the spacing of trainings to the life age as different lifespan periods might require different amounts of practice to receive the optimum impetus for change.

Long-term Maintenance Effects. The training effectiveness is especially measured by the stability of the revealed effects. To date, there are very few studies that specifically examined long-term effects of a task-switching training regimen. For instance, van der Oord, Ponsioen, Geurts, Ten Brink, & Prins (2012) investigated in a pilot study the short- and long-term effects of an executive-function remediation training for children with ADHD (age range: 8-12 years) with a 9-weeks follow-up session. The training battery consisted of a combined working memory, inhibition, and cognitive-flexibility training, whereas the latter was again adapted from Karbach and Kray (2009). Long-term effects on executive functioning and on symptom relief were, however, only assessed by parent- and teacher-rated questionnaire data. These were indeed positive for the total executive-functioning score. Nonetheless, we cannot draw clear conclusions from this result as, first, it was derived from
mere subjective ratings, and second, we have no reliable index of whether it was in fact the
task-switching training that led to long-term improvement, or whether it was rather the
specific working-memory or the inhibition training, or even the joint latent share of all three
interventions.

**Strategy-Based Interventions**

Another way to improve task-switching performance by cognitive interventions is to
instruct individuals to apply specific strategies how to best handle the switching situation and
to train them in using these strategies in the hope that they transfer these strategies also to
similar task situations. One prominent intervention that has been investigated a lot in task-
switching studies is the potential beneficial role of verbal processes by instructing individuals
to apply task-supporting verbalizations (for reviews, see Cragg & Nation, 2010; Kray &
Ferdinand, 2013, 2014). A number of studies have shown that individuals indeed use inner
speech processes in order to maintain and update the currently relevant tasks especially when
they have to internally keep track the task sequence and external task cues are missing as in
the alternating-run task-switching setting (Bryck & Mayr, 2005; Cragg & Nation, 2010). To
demonstrate the use of inner speech processes researchers have used either articulatory
suppression in which subjects were instructed to verbalize aloud an overlearned sequences of
words while switching between tasks (Miyake, Emerson, Padilla, & Ahn, 2004; Saeki &
Saito, 2004; Saeki, Saito, & Kawaguchi, 2006; Weywadt & Butler, 2013) or by verbalizing
task-irrelevant words during task preparation (Kray et al., 2008; Karbach, Kray, & Hommel,
2011) in a switching situation. Results indicated that, compared to a secondary non-verbal
task, mixing costs were substantially increased under articulatory suppression conditions (e.g.,
Baddeley, Chincotta, & Adlam, 2001; Emerson & Miyake, 2003). Moreover, developmental
researchers found evidence for the view that children and older adults profit a lot from such
verbal self-instruction strategies (e.g., Kray et al., 2008; Kray, Gaspard, Karbach & Blayé,
2013; Lucenet, Blaye, Chevalier, & Kray, 2014; for recent reviews, see Cragg & Nation, 2010;
Kray & Ferdinand, 2014). For instance, Kray et al. (2008) investigated groups of children (age range: 7-13 years), younger (20-27 years) and older adults (66-77 years) in three different switching conditions, one with task-relevant verbalizing, one with task-irrelevant verbalizing, and one without verbalizing (control condition). Results revealed that mixing costs substantially decreased in groups with task-relevant verbalizing, and increased in groups with irrelevant verbalizing. Furthermore, age differences therein were also reduced in the task-relevant verbalizing condition, pointing to promising reductions of action-control deficits in children and older adults by verbal labeling. Hence, verbal labeling the task goals seems to be a valuable tool to optimize task-switching performance during lifespan development, as it supports the engagement in task maintenance and task preparation in task-switching situations (e.g., Kray et al., 2010). Moreover, it seems that older adults and children use such verbal strategies less spontaneously than younger adults, but are able to benefit from those when they are instructed to apply them (cf. Kray & Ferdinand, 2013). Therefore, the critical question here is to what extent such verbal strategies are even useful after practice and whether they can be transferred to new task-switching situations.

Training Effects. Empirical evidence so far suggests at first that verbalization benefits on mixing costs are strongly reduced after three sessions of practice, especially in younger children and older adults but age differences in task-switching performance are still reliable after practice and use of task-supporting verbalization (Kray et al., 2008). This finding further underlines that verbal processes are not only supportive during the implementation of the task representations but are still needed for the engagement in task preparation. Second, for verbal labeling being effective, children as well as adults need some practice in the primary task alone (here task switching) before verbal labeling becomes beneficial (see also Kray, Blaye, & Lucenet, 2010).

Transfer Effects. Given that verbal labeling the next task is such a beneficial strategy, especially for children and older adults, we were also interested whether training such a
strategy in combination with task switching lead to stronger transfer effects than training in task switching alone, assuming that a similar strategy is also applied in a new switching situation. Therefore we compared transfer effects of a task-switching training group (see above) with a group that also applied the verbal labeling (Karbach & Kray, 2009). Although the reduction of mixing costs was larger as compared to an active control group, we found no differences in transfer gains between these two training conditions. However, subjects were not instructed to use verbal labeling at posttest that may explain the lack of transfer to a new switching situation. Therefore, we ran a further study in which we compared four training conditions in a group of elderly adults between the ages of 56 and 78 years in order to determine whether transfer occurs when the training and the transfer situation are more similar to each other and involve overlapping strategy use (Karbach, Mang, & Kray, 2010). In a pretest-training-posttest design in which all group were trained in an alternating-run switching setting, we systematically varied the use of verbal task labeling during training and at posttest. One group did not verbalize the task goals neither in the training session nor at posttest; the second group only used verbal labeling in the training sessions; the third group in the training and at posttest, and finally the fourth group only verbalized at posttest. Results indicated that in line with our assumption transfer effects were larger in the third group than in the first two groups. However, the largest transfer effects (reduction in mixing costs) were found in the fourth group that received no practice in verbal labeling only in task switching. These findings again suggest that verbal labeling is a powerful cognitive intervention in a given situation and after some practice in task switching alone but is not easily being transferred to new situation. Moreover, practice in a specific task-labeling strategy can even result in negative transfer (smaller transfer) (cf. Karbach et al., 2010).

4. The Role of Inter-individual Differences on Training and Transfer of Task Switching
As we outlined in the beginning of the chapter, the maximum range for plasticity in task-switching performance will not only depend on the optimal mismatch between environmental demands and brain supply but also on the individual intrinsic potential. In this section, we will focus on two sources of influences emerging from inter-individual differences: first, we will discuss the role of inter-individual differences in initial task performance (i.e., baseline performance), and second, we will discuss the role of motivation.

*Inter-individual Differences in Baseline Performance*

There are two major models of inter-individual differences in training gains depending on baseline performance, namely the amplification and the compensation model. Both models assume interactions between the initial aptitude and the range of practice-induced cognitive plasticity. The amplification model posits that those individuals gain the most from an intervention that are already performing well at the beginning. This relation also referred to as Matthew effect (by the allegory “the rich get richer and the poor get poorer”) describes an accumulation of the initial advantages or disadvantages. In the context of lifespan, we would predict from this model that children and older adults with initially poorer performances would profit less from training, and as a consequence, age differences would be magnified as a result of practice. In contrast, the compensation model assumes that a cognitive intervention would specifically enhance the abilities of those who are performing low at the beginning, while the well-performing individuals would not record noticeable profit. Hence, children and older adults would gain substantially more than younger adults from a training intervention, and as a consequence, age differences would be reduced as a result of practice.

Empirical evidence from task-switching studies suggest for comparisons at the group level larger training and transfer gains after a task-switching training for children and elderly people as compared to younger adults supporting the compensation account (e.g., Kray & Fehér, 2014; Cepeda et al., 2001; Karbach & Kray, 2009; for a recent meta-analysis, see also Karbach & Verhaeghen, in press). However, training studies on age differences in episodic
memory show that age differences between younger and older adults are increased after practice in applying a mnemonic strategy (Lindenberger, Kliegl, & Baltes, 1992) while younger adults benefitted more from the strategy training in line with an amplification model (see also Lövdén, Brehmer, Li, & Lindenberger, 2012; Verhaeghen & Marcoen, 1996).

Studies that examined the individual status-benefit correlations on task switching found strong negative correlations between initial baseline performance and transfer gains. For instance, Karbach (2008) found that the pretest performance (status) seemed to be a reliable predictor for training and transfer benefits in a task-switching training: poorer performance at the beginning was associated with larger training gains (correlations ranging from $r = -.66$ to $r = -.83$) and greater transfer benefit (correlations ranging from $r = -.19$ to $r = -.72$), pointing to compensatory rather than Matthew effects. However, whether those correlations are mediated by initial brain supply or other intrinsic factors like motivation and personality, or interaction between them is largely unknown so far and remains an open question for future research. In the following section, we will introduce two of such potential motivational modifiers in the context of cognitive control.

**Motivational Influences**

Motivation is assumed to be integrally linked to cognitive control (evidence comes from the field of cognitive neuroscience; e.g., Kouneiher, Charron, & Koechlin, 2009; Zelazo, Qu, & Kesek, 2010) and seems to affect specifically the outcomes of a task-switching setting (e.g., Kleinsorge and Rinkenauer, 2012). Motivated behavior becomes apparent in the interplay of personal traits and environmental determinants. We will first provide insights into an influential trait concept, and second, describe an important environment variable that may tap into the cognitive training success.

Powerful motivational variables at the trait level that might affect intervention outcomes are self-regulatory beliefs, such as self-efficacy (Bandura, 1993; 1997). One’s self-efficacy beliefs describe judgments of the own capabilities to perform successfully on a given
domain, for example, on memory tasks (Bandura, 1986). Schunk (1981) demonstrated a particular sensitivity of self-efficacy to instructional interventions (see also Zimmerman, 2000). In the educational context, efficacy beliefs have been proven to mediate achievement outcomes, that is, to directly link learning environments to learning outcomes (Liem, Lau, & Nie, 2008; Moriarty, Douglas, Punch, & Hattie, 1995; Schunk, 1981; Zimmerman, 2000). Of particular interest from a lifespan perspective, elderly people seem to dispose of poorer self-efficacy resources than younger adults, leading to less effort spent on demanding cognitive tasks (Bruce, Coyne, & Botwinick, 1982; Lachman & Jelalian, 1984; Murphy, Sanders, Gabriesheski, & Schmitt, 1981; Valentijn et al., 2006; Wells & Esopenko, 2008; West, Bagwell, & Dark-Freudemann, 2008).

The influence of self-efficacy on cognitive trainings and age effects therein has been investigated especially for strategy trainings on episodic memory (e.g., West et al., 2008). Several studies showed that initial memory efficacy beliefs explained a considerable amount of the variability in training outcomes, pointing to self-efficacy and cognition being interrelated at the latent level (Carretti, Borella, Zavagnin, & De Beni, 2011; Valentijn et al., 2006; West et al., 2008; West & Hastings, 2011). There is further compelling evidence that a combined training of both memory as well as efficacy-enhancing strategies led to higher gains on cognitive memorizing than an isolated memory training (West et al., 2008). Moreover, a recent study first addressed the role of memory self-efficacy for process-specific cognitive interventions (Payne et al., 2011): The researchers examined the relation of efficacy beliefs with individual differences on an inductive reasoning training in older adults. They found that efficacy beliefs seem to be positively related to the degree to which elderly people can gain from a training on fluid abilities. Yet, to our best knowledge no published study so far has investigated the impact of such self-efficacy beliefs on training in a task-switching setting, which may also varies across the lifespan. Given their importance for explaining individual
differences in intellectual abilities in older age, we are currently investigating and including such self-regulation traits in our ongoing training studies.

A growing body of research has used another approach to keep the training motivation and willingness high, that is, the provision of a motivational training setting with video-game elements (for reviews on video-game playing, see Bavelier et al., 2012; Green and Bavelier, 2006; see also the commentary of Karbach, in press). Ryan and colleagues (2006) highlight a motivational pull emerging from video games that satisfies one’s need for self-determination (Ryan & Deci, 2000) along relatedness, autonomy, and competency. In the narrow context of computerized games, they describe relatedness as presence, that is, the sense of being completely taken in the game or being a part thereof. Autonomy refers to provisions of choice, informational feedback by means of rewards, and non-controlling instructions. Competency nurtures one’s need for challenge in terms of opportunities to acquire new skills for being successful in playing the game. All factors in sum might enhance the intrinsic interest in the game content.

Although these different factors have not been systematically investigated yet, there is some evidence that cognitive control functioning and task-switching performance can be enhanced by training with video games in younger adults (Glass, Maddox, & Love, 2013) as well as in older adults (Basak, Boot, Voss, & Kramer, 2008). For instance, recently Anguera et al. (2013) investigated the trainability of multitasking in older adults by embedding the training in a custom-designed game simulation, called NeuroRacer, in which elderly participants had, in the one task, to adapt the driving behavior of a vehicle on a winding road (drive task) and, in the other task, to respond to road signs (sign task). They determined training and transfer gains between three training conditions, that is, participants either were to perform both tasks simultaneously (multi-tasking condition), to complete each task separately (single-task condition/ active control group), or to perform none of the tasks (passive control group). Of most importance from our lifespan focus, they compared the
training benefits from the multi-tasking condition between a group of younger adults at about 20 years and a group of older adults between the ages of 60 and 85 years. Results indicated that (1) older adults in the multi-tasking condition substantially reduced their multitasking costs as compared to the active or passive control condition, and (2) the elderly reached performance levels that were even beyond the ones of untrained younger adults. Hence, embedding the training in a game setting is a promising approach to maintain motivation and training willingness throughout the cognitive intervention and by this may also promote transfer to untrained tasks.

However, the direct effects of a game setting have rarely been investigated yet (e.g., in the context of WM, see Prins et al., 2011). In one of our recent training studies, we investigated systematically the impact of a motivating game setting on a task-switching training in healthy middle-aged children (8-11 years; Dörrenbächer, Müller, Tröger, & Kray, under review). In a pretest-training-posttest design we included two active control groups (single-task training) and two task-switching groups that varied in the training setting and either contained game elements (high-motivational training setting) or no game elements (low-motivational training setting). More specifically, in the high-motivational conditions, we embedded the training procedure in the frame of an adventure game, presenting challenging monster battles on a foreign planet. Accordingly, the stimuli, the task labels, the goal instructions as well as the feedback were presented in a manner reflecting the game universe. The low-motivational conditions instead received the standard single- or task-switching setting, containing no elements of a game world: That is to say, children here were confronted with scrambled stimuli lacking the sensation of animated characters, with neutral task labels and simple feedback texts. As a manipulation check of our motivational variation, five times per session, we asked children for their willingness to perform voluntarily additional training blocks. Training motivation was then scored by the total number of additional blocks per training session. Importantly, we ensured that this score was not confounded with the training
experience by determining that all children performed in fact the same number of training blocks, irrespectively of their actual choice to play additional ones. This was covered by presenting the willingness questions at random positions during the training session. Results of this study showed that (1) a high-motivational setting indeed enhanced children’s training willingness; (b) children benefitted on their task and switching performance on latencies after a task-switching as compared to a single-task training, and especially when this switching training was embedded in a high-motivational environment; (c) near transfer was obtainable for all training groups, while the group that had received a high-motivational switching training achieved largest effect sizes on switching and mixing costs at near-transfer assessment; and (d) training gains did not consistently propagate to far transfer measures. In general, the motivational setting primarily influenced the processing speed but did not generalize to specific control processes required by the untrained cognitive-control tasks. This means that in children, video-game elements seem to facilitate specifically the response energy invested in task processing. As far as higher-order control is concerned, the presence of such high-motivational settings appears to interfere with the problem-solving behavior, maybe by eliciting approach tendencies that overshadow goal-directed control (see also Zelazo et al., 2010). This may account for the lack of far transfer in our game study. The control of individual differences at the trait level or of age differences in the sensitivity to different variations of the setting should, however, expand current insights into the nature of the interplay between motivation and cognition.

**Summary and Conclusions**

What are the new insights about the effectiveness of task-switching training programs for enhancing cognitive control processes to date? At first empirical evidence on lifespan changes in task switching has been shown that especially cognitive-control processes required for being in a switching situation, such as task maintenance and selection processes, but not
the switching process itself, are highly age sensitive. These cognitive processes mature relatively late during childhood and decline relatively early in older age. Lifespan changes in these processes have been attributed to lifespan changes in brain supply in particular in prefrontal lobe networks. Researchers also have identified several environmental demands in task-switching situations that induce a stronger mismatch with the brain supply, especially in childhood and old age, such as the absence of environmental prompts (task cues), less preparation time and task practice, and interference between the involved tasks by overlapping task representations (stimulus and response ambiguity).

Hence, these environmental demands should be challenging and thereby, considering the theoretical framework by Lövdén et al. (2010), be suitable to induce plasticity in task-switching performance across the lifespan. The findings on the effectiveness of training in task switching are generally in line with these theoretical considerations. Training conditions that produce a larger mismatch indeed result in larger transfer gains: (1) Under identical training conditions (no adaptive training), those age groups show larger transfer gains who showed the largest mixing costs at the beginning of the training, probably because the relative mismatch between demands and brain supply was larger in children and older adults than in younger adults; (2) transfer gains (reduction in mixing costs) are larger for uncued than cued task-switching conditions; (3) and also larger for variable training conditions in which task demands change in every training session than for constant training conditions at least in adulthood; (4) and finally for older adults, transfer gains are larger under training conditions that practice the resolving of task interference. (5) Moreover, depending on the brain supply in specific age ranges, training conditions can be too challenging, for instance, children did not show transfer gains to a new switching situation if they received a variable training in which they had to verbalize the task goals in addition. (6) Training conditions which result in a reduced mismatch as they support task-switching performance, such as applying verbal
strategies as well as motivational influences like a game setting, seem to be effective in the training situation but are less suitable to produce transfer gains to a new switching situation.

In contrast, the boundary conditions for the generalization of training in task switching are less clear and more heterogeneous. Training studies either found relative broad transfer of the task-switching training or nearly no transfer, relatively independent of the training conditions and age groups, may also because of a lack in statistical power due to small sample sizes in the training groups. The occurrence of far transfer is not only dependent on the amount of overlapping cognitive-control processes but also on the overlap of task domains, on reliability of measurement as well as on initial baseline task performance.

Open Issues for Designing Cognitive Intervention across the Lifespan

Although recent research has identified some age-sensitive task-switching training conditions that lead to larger transfer gains in various age ranges, there are a number of unsolved issues that could be addressed in future training studies.

Finding the Optimal Balance between Intensity, Duration, and Variability of the Training. Most training studies on the plasticity of task switching only practice a relatively short time between three and four sessions on a weekly basis with an intensity of less than 1 h. Although nearly all the training studies obtained near transfer effects to an untrained new switching task, results on far transfer gains vary considerably. Hence, it is an open question how much practice is really necessary to obtain the largest effects of a task-switching training. An important extension should be to adapt the total duration and weekly distribution of trainings to the life age as different lifespan periods might require different amounts of practice to receive the adequate impetus for change. Furthermore, the optimal balance of training duration, weekly intensity, and variability might also strongly depend on the demand-supply mismatch induced at the beginning of training.
Finding the Optimal Balance between Generality and Specificity of Training

**Interventions.** While most training studies so far used different types of a specific task-switching training, other studies trained this ability in combination with other cognitive control processes. The advantage of using more specific task-switching interventions is that it allows the better explanation what kind of processes have contributed to the transfer gains at the expense of generality of training effects. By contrast, the advantage of using combined cognitive control training interventions is that they may produce more general effects at the expense of an understanding which component has caused these effects. However, on the basis of published training studies, there is no clear pattern that supports these considerations: more specific task-switching training studies reported relatively broad transfer and more general cognitive-control training interventions reported relatively narrow transfer to other cognitive tasks. Finding the optimal balance between generality and specificity is also related to the previous point and its impact for lifespan changes in the plasticity in cognitive control is also an important issue to consider in future training studies.

**Process-Based versus Strategy-Based Interventions.** Only a handful of studies examined a potential positive transfer of instructed verbal strategies to untrained new switching situations and found the transfer of those strategies to be rather limited in contrast to process-based training interventions. However, so far only the effectiveness of verbal strategies have been investigated in training studies so it remains fully open whether other strategies are better suitable to be transferred to new switching situations.

**Motivational and Emotional Influences.** A number of training researchers have argued that motivational factors play a crucial role for the training effectiveness. However, the role of individual differences in motivation at the trait level (e.g., self-efficacy beliefs), especially for different age brackets, is fully neglected in interpreting current training results and age effects therein. Future research should therefore include such motivational determinants to achieve a broader rationale of cognitive plasticity. Furthermore, the moderating impact of the
instructional training context on cognitive performance changes should be considered in detail for different life ages: Indeed there is a large body of evidence showing that cognitive-control trainings with video-game elements lead to training and transfer effects in various age ranges. However, only recently, researchers have tried to show whether a video-game training setting indeed results in larger training and transfer benefits compared with a training setting without game elements. At least in children, it seems that video-game elements primarily have an impact on the training willingness and task performance in the training situation but less influence in the generalization of training effects. However, whether different age groups vary in their sensitivity to different kinds of training settings as well as to different motivational aspects, such as autonomy and competency, as well as different kinds and magnitudes of rewards is fully unknown so far and an inspiring avenue to create new training studies and interventions on the basis of the already known insights about the effectiveness of task-switching trainings.
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