Enhancing cognition across the lifespan

Transfer effects of task-switching training in young and old adults

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“Theories are nets cast to catch what we call 'the world': to rationalize, to explain, and to master it. We endeavor to make the mesh ever finer and finer.”

KARL POPPER

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Aging is characterized by a decline of performance in many measures of cognitive functioning such as working-memory, inhibition, and reasoning. A previous training study (Karbach & Kray, 2009) indicated that task-switching training might improve crucial cognitive processes which are affected by aging, leading to broad transfer effects in both old and young adults. The present study aimed to identify exactly which processes to train in order to facilitate transfer across task domains with cognitive control training. To this end we manipulated memory-load and inhibition-load in a task-switching paradigm, as we expected these processes to be the important variables affecting training scope. We compared performance improvements in four task-switching groups and an active control group in a pretest-training-posttest design with young and old adults. High inhibition-load seems to be crucial during training, as near-transfer in old adults was evident only in this condition. However, we did not find far-transfer effects, which we attribute to the sparse training material and relatively low cognitive control demands during training. In summary, our near-transfer results, together with the latest developments in the literature, suggest that transfer scope might be maximized through high inhibition training conditions in old adults.

Table of Contents

List of Tables

List of Figures

Introduction

What is going to be investigated in the present work in short is how people's cognitive abilities can be improved in younger and older age. Our life expectancy during the last century has increased significantly and this trend is expected to continue in the future (Vaupel, 2010). As a result, we are now facing the problem that our societies are rapidly ageing, especially in the developed countries. Unfortunately, we also know that aging is associated with a decline in many areas of cognitive functioning (for reviews, see Bishop, Lu, & Yankner, 2010; Craik & Salthouse, 2000; Hedden & Gabrieli, 2004; Lindenberger & Mayr, 2013; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Reuter-Lorenz, 2002).

The human mind is an evolving entity that undergoes continuous transformation during development. This transformation is reflected in the functional and structural changes that take place in the nervous system during an individual's lifespan. On the one hand, these changes are the consequences of unfolding biological processes that underlie the maturation and decline of the human brain. On the other hand, the human brain is capable of undergoing substantial experience dependent changes, a phenomenon which is referred to as cognitive plasticity.

Cognitive plasticity refers to the ability of the brain to reorganize, change, and improve cognitive processes in order to deal more effectively with problems or to achieve aims more efficaciously. These cognitive changes are also reflected in the structural and functional changes of the nervous system. Traditionally, cognitive plasticity has been studied through examining the neural changes that take place in the brain of laboratory animals, for example, as result of enriched environment. With the development of non-invasive neuroimaging methods it became possible to study, how different types of training such as motor skill acquisition, lead to neural changes in human subjects as well. In the clinical context, cognitive training has been successfully used even before these developments. There is evidence that training interventions can be effective to counteract adverse conditions that arise after brain lesions. These findings point to substantial and often surprising plasticity of the human brain.

From a developmental perspective there is evidence showing cognitive plasticity throughout the adult lifespan (for reviews see Burke & Barnes, 2006; Greenwood, 2007). The reserved cognitive plasticity in older adults can be measured as changes in the structure and function of the human brain. For example, a magnetic resonance imaging (MRI) study has shown that three months of training in juggling leads to an expansion of grey matter in specific areas of the brain in younger adults (Draganski et al., 2004). A similar study has shown that older adults could also learn juggling, although with somewhat less proficiency, and that similar areas undergo change as a result of the training (Boyke, Driemeyer, Gaser, Büchel, & May, 2008). Moreover, it has been shown that changes can be observed as a result of training in white matter structure (Scholz, Klein, Behrens, & Johansen-Berg, 2009), but this malleability might be limited with increasing age (Bengtsson et al., 2005). Hence, improvements in cognitive functioning might be expected even at old age.

Apart from the questions regarding the range of plastic capacity of the brain throughout the lifespan, another important issue in cognitive aging research is the question of whether cognitive decline can be reversed through training (Baltes & Lindenberger, 1988; Mayr, 2008). To be more precise the question revolves around finding out *what* processes should be trained and *how*, so that cognitive decline is reversed effectively. This requires that the training does not remain specific to the trained task, but that it generalizes to a wide range of other tasks. This transferability of training gains should be an essential consideration in any cognitive training program.

However, it has been difficult to find transfer of training to tasks that are not very similar to the trained task itself (for reviews see Green & Bavelier, 2008; and Noack, Lövdén, Schmiedek, & Lindenberger, 2009). One explanation for the limited scope of transfer effects is that only task-specific processes were trained, limiting the transfer to tasks relying on the same processes. Recent findings, however, point to the feasibility of cognitive interventions with a wider range of transfer (Anguera et al., 2013; Schmiedek, Lövdén, & Lindenberger, 2010).

In the field of cognitive aging, past research investigating the reserve capacity of older adults focused on improving episodic memory through mnemonic techniques and improving reasoning (Baltes & Kliegl, 1992; Baltes, Sowarka, & Kliegl, 1989; Singer, Lindenberger, & Baltes, 2003; Verhaeghen, Marcoen, & Goossens, 1992; Zehnder, Altgassen, Martin, & Clare, 2009). Recently, however, a different approach has been studied that might prove to be more effective: instead of training explicit strategies, a number of studies investigated the training of more general processes, such as executive functions (Bherer et al., 2005; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Dahlin, Nyberg, Bäckman, & Neely, 2008; Karbach & Kray, 2009; Karbach, Mang, & Kray, 2010; Kramer, Larish, & Strayer, 1995; Kray, Karbach, Haenig, & Freitag, 2012; Li et al., 2008). Executive functions cover a range of cognitive processes that are necessary for higher-level cognitive functions, such as problem solving (Miller, 2000), and can be differentiated into several components, such as updating, inhibition and shifting (Miyake et al., 2000).

Previous research by Karbach and Kray (2009) has demonstrated the efficacy of training executive functions by means of a task-switching paradigm. In four sessions, children, younger adults, and older adults were trained in task-switching that heavily relies on executive functions, such as updating, inhibition and shifting. The training has demonstrated broad transfer effects beyond the trained tasks as measured by pretest to posttest performance improvements in inhibition, working-memory, and even in fluid intelligence in all age groups. These findings seem promising, nevertheless, the question remains regarding what processes are actually trained and facilitate transfer across task domains when participants take part in a task-switching training. The primary focus of the present dissertation is to determine the relative importance of executive components to the transfer effects in younger and older adults. Therefore, different training conditions were created that differed in cuing-type and inhibition-load. Performance improvements were compared in a pretest-training-posttest design to an active control group in younger and older adults. With this setup we intended to uncover whether during task-switching training improvements in *interference control*, *updating*, or merely more efficient *shifting* are responsible for improvements as evidenced by far-transfer effects.

The dissertation is divided into three parts. Firstly, I will present a review of the relevant literature, giving an overview about the concepts of executive functions, cognitive training, and transfer. I will also present the main findings regarding aging and training effects in the task switching paradigm. Based on this overview I will point out the specific question which this study is intended to answer. Secondly, in the empirical part, I will present the methods and results of my study. And thirdly, the last part comprises a critical discussion of the results and provides an outlook for future directions in research on this topic.

Review of the literature

The review of the literature is separated into three parts. In the first part, theoretical models and empirical findings will be reviewed regarding executive control, the relation of executive functions to higher intellectual abilities, and age differences in executive functions. In the second part, theoretical concepts and empirical findings regarding cognitive plasticity and training interventions will be reviewed. In the third part, the focus will be on cognitive plasticity in older age primarily in relation with task-switching training. In addition, the transferability of training gains in cognitive interventions will be considered in this last part, along with an overview of measuring and evaluating transfer effects.

DEFINITIONS, MODELS, AND MEASUREMENT OF EXECUTIVE CONTROL

Definitions of Executive Control

In everyday life we often face situations, in which we cannot depend on automatic behavioral patterns but have to regulate our behavior according to unexpected changes in the environment. Imagine walking down the street listening to music while crossing the road at the sign of the green light. Suddenly a car wants to cross your way seemingly unaware of you. In such cases you have to exert control over what features of the environment you attend to (approaching car rather than music), how to respond to different stimuli from the environment (does it blink?), and to select what behaviors are most relevant in the given situation (stop, walk back, or walk faster). The execution of such actions requires many separate mechanisms. With the term “executive functions”, we are referring to several sub-processes that are important in regulating goal-directed behavior when circumstances change and control is required. In the present dissertation, I will use the terms executive control and cognitive control interchangeably. Cognitive control can also be defined as “the ability to regulate, coordinate, and sequence thoughts and actions in accordance with internally maintained behavioral goals” (cf. Braver, 2012).

Although there is lack of consensus about a taxonomy of executive processes, there is general agreement that they include at least the following three components: working-memory operations including updating and maintenance of relevant information (‘updating’), inhibition of irrelevant information (‘inhibition’), and shifting between multiple tasks or mental sets (‘shifting’). In addition, it is also postulated that some forms of ‘supervising’ or ‘monitoring’ processes are also crucial in ensuring that goal oriented behaviors succeed. There are different hypotheses of how this monitoring process might take place. Some imagine a system in which errors during task execution are reported, which subsequently leads to adjustments in cognitive control (Gehring, Goss, Coles, Meyer, & Donchin, 1993). Some suggest a mechanism which reports whenever there is a higher level of conflict during task execution, which again leads to subsequent adjustment of cognitive control (Cohen, Botvinick, & Carter, 2000). Although there are more detailed classifications of executive functions (e.g. Jurado & Rosselli, 2007), for the present considerations the above description will suffice (for a recent review, see Hofmann, Schmeichel, & Baddeley, 2012).

Models of Executive Control

Early cognitive models of executive control postulated a unified central executive system, such as the central executive in Baddeley’s working-memory model (for a review see Baddeley, 2003) and the supervisory attention system in Shallice’s Supervisory Attention System model (Norman & Shallice, 1980). In Baddeley’s original model, the central executive was not well specified. In Shallice’s model, attentional control is dived into two processes, one of which controls behavior according to habitual patterns or schemas, guided by cues from the environment, and one attentionally limited control system, the supervisory attentional system (SAS), which intervenes whenever habitual response is insufficient. In both models, the executive system has been related to frontal lobe functioning (Miller & Cohen, 2001; on the relationship between frontal lobe and cognitive control see Miller, 2000).

Presently, although the exact specification and the interrelation of the processes underlying cognitive control are still debated, the idea of a strictly unified cognitive control system has been abandoned on the basis of a number of empirical findings coming from different fields in cognitive psychology. The first argument against a unified executive system stemmed from clinical observations, suggesting that executive functions are selectively impaired (e.g. Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux, 1999). For instance, patients with posterior lobe damage exhibit impaired short-term memory, while some patients with frontal damage exhibit impaired inhibitory function. Neuroimaging studies also support the idea of separable processes in cognitive control (e.g., Collette et al., 2005; Dreher & Berman, 2002; MacDonald, Cohen, Stenger, & Carter, 2000; Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004; E. E. Smith & Jonides, 1999).

A second line of argument came from psychometric studies examining correlations between performances on different executive control tests. One study by Miyake and colleagues (Miyake et al., 2000) assessed in a large sample of younger participants several tests related with the three broad areas of executive control (inhibition, shifting, and updating) and found in a latent variable analysis that these processes are in fact separable. Fisk and Sharp (Fisk & Sharp, 2004), investigating individuals aged between 20 and 81 years, have also found three separate factors of executive control, and showed that all of them exhibit significant decline with ageing. A general consensus emerged among the researchers in this field that these processes – inhibition, shifting, and updating - are indeed core components of executive functions (Bialystok & Craik, 2006 p. 70-95; Hofmann et al., 2012).

Thirdly, there is evidence for differential age-related changes in executive control. There are studies indicating that executive functions show differential developmental trajectories (Cepeda, Kramer, & Gonzalez de Sather, 2001; Garon, Bryson, & Smith, 2008; Hughes, 2011; Williams, Ponesse, Schachar, Logan, & Tannock, 1999), but the general structure of executive control is the same for childhood and adulthood. A study for instance (Huizinga, Dolan, & van der Molen, 2006) investigated participants 7 to 21 years old, and showed that 'working-memory' and 'shifting' developed at different rates, with 'shifting' performance attaining adult levels during adolescence and 'working-memory' continuing to develop during young adulthood.

Cognitive development and its relation to executive control

One influential theoretical model describing intellectual development is the 'two component model' initially proposed by Baltes (for a review, see Baltes, Lindenberger, & Staudinger, 2006; Baltes, 1987). It suggests that lifespan intellectual development can be characterized by the development of two components of intellectual functioning. The first is the so called 'mechanics' component, that refers to basic processes that are biologically based, such as speed, accuracy, and coordination of elementary processes. It rapidly develops during childhood through young adulthood, but then already starts to show decline in middle adulthood. It can be said that it is strictly based on the biological development of the nervous system. The other component is called 'pragmatics' component not strictly related with the architecture of the nervous system, but it is the abstract knowledge base that the individual is endowed with, and which can grow by the influence of culture. This component does not show decline until very old age.

The ‘mechanics’ component is the means to gain knowledge, while ‘pragmatics’ component is the abstract knowledge gained, or that is being 'crystallized'. Evidence for this two-component model comes from multiple sources (see Baltes et al., 2006; p. 598-600.), including longitudinal studies (e.g. Seattle Longitudinal Study) indicating that cognitive abilities related with the ‘mechanic’ component (i.e. reasoning, memory, perceptual speed, spatial orientation) follow a nearly linear decline throughout adulthood, while cognitive abilities related with the ‘pragmatics’ component (i.e. verbal ability, numeric ability) does not show decline until very old age (see Figure 1).

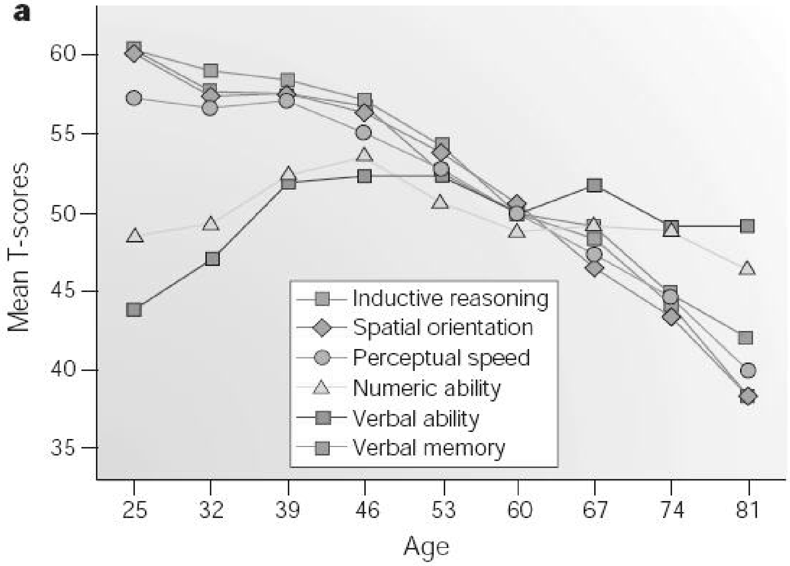

Figure 1 Cross-sectional data from the Seattle Longitudinal Study (image from Hedden & Gabrieli, 2004)

Causes of Age-Related Changes in Cognition

In this section different approaches to explain age-related changes in cognition will be outlined, along with empirical findings. The first of these is the 'general slowing' hypothesis, which mainly explains age-related changes in intellectual fluid abilities as a function of a general slowing of processes (T. Salthouse, 1996). According to this theory, the slowing down of executing processes leads to impaired cognitive performance in most cognitive tasks. While the general slowing hypothesis is still an integral theory for explaining age-related decline in many areas, it is not adequate to explain age-differences in conditions with high cognitive control demands (Mayr & Kliegl, 1993; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003).

Age-related changes in intellectual abilities can also be explained as a function of changes in inhibitory processes. An early study (Kramer, Humphrey, Larish, & Logan, 1994) for instance, found little evidence for age-related deficits in inhibitory processes, however older adults had more difficulty than younger adults to abort an action (in a stop signal paradigm where participants are asked to respond to a visual stimuli unless they hear an auditory signal), and it also proved more difficult for older adults to learn new rules in a categorization task. Also, comparing younger and older adults, inhibition related processes were found to be delayed in the elderly as evidenced by delayed inhibition-related ERPs (event related potentials, recorded with electroencephalogram) (Falkenstein, Hoormann, & Hohnsbein, 2002).

It is also possible to attribute age-related differences in intellectual abilities to changes in working-memory performance. Recent studies have demonstrated that older adults show deficits in suppressing task-irrelevant information during working-memory performance whereas their ability to enhance task-relevant information is intact (Gazzaley, Cooney, Rissman, & D’Esposito, 2005). Furthermore, it has been shown that an interruption during task maintenance distracts both younger and older adults, however while younger adults quickly disengage from the task-irrelevant disruptor and reestablish task-relevant functional networks, older adults are impaired in dynamic shifting between competing representations (Clapp, Rubens, Sabharwal, & Gazzaley, 2011). Similar findings came also from a study employing an inhibition of return paradigm (Wascher, Falkenstein, & Wild-Wall, 2011) and another study using a dual task paradigm (Hahn, Wild-Wall, & Falkenstein, 2011) suggesting that older adults process irrelevant information similarly as relevant information, and this leads to impairments in working-memory performance.

We can also approach to explain age-related differences in intellectual abilities in terms of biological changes in the nervous system. Some decades ago large scale general neuron loss was suggested to be the main reason for age-related cognitive decline (Ball, 1977; Coleman & Flood, 1987). However, recently it became evident that general neuron loss in most areas does not contribute significantly to age-related cognitive decline (Burke & Barnes, 2006) but rather there are specific areas such as the prefrontal cortex (PFC) in which neuron loss is related to cognitive decline. A study, for example, with aged monkeys have found an approximately 30 percent reduction of neurons compared to younger animals in the dorsolateral PFC area 8A, and this reduction correlated with impaired performance in a working-memory task, but at the same time other areas related to working-memory (such as area 46) were well preserved (Smith, Rapp, McKay, Roberts, & Tuszynski, 2004). Less age-related change has been reported for many electrophysiological properties of neurons in the hippocampus and the PFC, such as resting membrane potential, membrane time constant, threshold to elicit an action potential, and rise time and duration of an action potential (Burke & Barnes, 2006). However, reduced synapse number in older animals might be related with cognitive decline. It has been found in rats, that synapse number per neuron diminishes during aging in the dentate gyrus, which is a hippocampal sub-region that is important in spatial memory (Geinisman, Toledo-Morrell, & Morrell, 1986).

Previously, I have mentioned that there is a close connection between executive control and functioning of the prefrontal cortex (Miller, 2000).The frontal lobes develop more slowly than other brain areas, and many attribute the development of executive functioning during childhood and adolescents to the maturation of the frontal lobes (Casey, Tottenham, Liston, & Durston, 2005). We also know that the frontal lobes are also among the first areas that show deterioration during aging (Hedden & Gabrieli, 2004). A cross-sectional neuroimaging study for instance, estimating volumetric changes of different areas of the brain across the lifespan, has revealed a steady linear decline of the lateral prefrontal cortex from age 20, while other areas like primary visual cortex showed only slight age-related decline in volume (Raz et al., 2004). For a review on the relationship between prefrontal cortex function and cognitive aging, see West (1996).

Measurement and Development of Executive Control Components

We were interested in training related improvements in executive functions which were measured with a wide array of tests in the present study. An overview of the operationalization of these constructs will be given below. The specific tests within each domain will be described in the method section.

Task Switching

Shifting is measured by paradigms in which participants have to switch regularly between multiple task sets (for a recent review, see Kiesel et al., 2010; Grange & Houghton, in press). Each event from the environment affords a range of possible set of responses, and the appropriate response varies as a function of the task. In an experimental setting, task sets can be specified by instruction (e.g., categorizing colors, or shape).

The first description and use of the task-switching paradigm can be traced back to Jersild's early paper from 1927 (Jersild, 1927). He conducted a series of experiments with students who had to work through a list of items, either repeating one task or alternating between two (Monsell, 2003). Comparing the time needed to finish the single-task list with the time needed to finish the alternating-task list was used as an indicator of the time needed to switch between task sets. Later Jersild's paradigm was reinvented by Biedermann and Spector (1976) using discrete reaction time measures. Nowadays researchers mostly use computerized tests to measure task-switching performance. Participants are usually instructed first to perform a simple categorization task by pressing one of two response buttons for a set of stimuli according to a simple rule, for example, deciding whether a picture is colored or black and white (task A). Then with the same set of stimuli or another set of stimuli they are instructed to perform another categorization task often by using the same response buttons, for example, deciding whether a picture depicts animals or flowers (task B). We call these blocks in which participants perform only one categorization task *single-task blocks*. The blocks in which tasks need to be shifted are called *mixed-task blocks*. Moreover, in *alternating-runs paradigm*, participants are instructed to alternate between two tasks within a block, according to a predefined sequence, such as to switch the task on every second trial. Finally, in *task cuing paradigms*, participants are instructed to switch tasks according to a cue that is presented before the stimulus appears. If we use the same stimulus set for both tasks, we say that the stimuli is *bivalent* (or ambiguous on the stimulus level). Bivalent stimulus affords responses for both tasks in which case cognitive control demands are higher and costs are more substantial (Jersild, 1927; Rogers & Monsell, 1995). A univalent stimulus on the other hand affords only one task set. Ambiguity can also arise on the response level, when the same stimulus in different task sets requires different responses. In the mixed-task blocks two trial types can be separated. On so called non-switch trials the same task has to be performed as in the previous trial (AA or BB) and on so-called switch trials one has to switch from one task to the other task (AB or BA).

By registering performance on both single blocks and mixed blocks, two kinds of task-switching costs can be calculated (cf. Kray & Lindenberger, 2000). We can either calculate the performance difference between performing single-task blocks and mixed-task blocks (termed mixing cost in the following), or we can calculate the performance difference between switch and non-switch trials *within* mixed-task blocks (termed switch cost in the following). In the early studies with the task-switching paradigm, performance costs were calculated only as the difference between single and mixed blocks (e.g. Allport, Styles, & Hsieh, 1994; Jersild, 1927). However, it is assumed that this comparison reflects not purely the additional demand to perform a task switch in mixed task blocks compared to single task blocks, but also the additional demand to keep multiple task sets in an active state (cf. Rogers & Monsell, 1995). To have a more precise estimation of the performance cost resulting from switching between the task sets per se, Rogers and Monsell (1995) proposed to compare the performance on switch and non-switch trials within mixed-task blocks. Mixing costs are thought to reflect an additional memory demand, while switch costs are thought to reflect the switching process per se. The terminology regarding these performance costs is not unitary among researchers. For instance, switch costs have been also termed specific or local switch cost and mixing cost as general or global switch cost.

Both switch and mixing costs are robust, they can be found with different types of tasks even after extensive practice (Kray & Lindenberger, 2000), and they have been found repeatedly in task-switching studies (for a review, see Kiesel et al., 2010). Given their interrelatedness one might ask whether mixing and switch costs are separable. Is it true that mixing cost reflects mainly working-memory demands, while switch costs reflect mainly shifting demands? By applying confirmatory factor analysis, Kray and Lindenberger (2000) have demonstrated that the two types of costs are indeed separable and that they are domain general latent factors of cognitive control. This is in line with the previously presented models of cognitive control by Miyake and colleagues (2000; see page 69-72.), showing that the executive functions, ‘updating’ and ‘shifting’ are distinguishable constructs. Neuroimaging findings by Crone and colleagues (2006), also support that task-rule *representation* (i.e. retrieving, maintaining and implementing relevant rules) and task-set *reconfiguration* are separable, showing different activation patterns in the lateral and medial prefrontal cortex respectively.

There are also alternative task-switching paradigms (see Grange & Houghton, 2014), such as (a) task-cuing paradigm where unpredictable cues dictate which task to perform, (b) intermittent instructions paradigm where repeated performance on a single task is occasionally changed by a cue to continue with another single task, and (c) voluntary task-selection paradigm where participants decide themselves which task to perform.

Task switching costs and their explanation

The task-switching paradigm has become an extensively used paradigm in the last decade in order to understand executive control functions. The primary goal of most task-switching studies was to elucidate the underlying causes of the switch costs. It has been attempted to explain the phenomena of the switch costs from different angles with multiple methods including computational, neuroscientific, and behavioral methods. In the following, I will mainly discuss empirical evidence from behavioral studies.

Switch costs has been proved to be a robust phenomenon found across different task-switching paradigms (alternating runs paradigm, task-cuing paradigm, intermittent instructions paradigm, voluntary task selection paradigm). Here, I shall briefly introduce two competing models that initially tried to explain the source of the observed task-switching costs in task-switching paradigms. The first model was originally proposed by Rogers and Monsell (1995), while the second by Allport (1994). According to the first model, there are two components that contribute to the existence of switch costs. The first is an *endogenous component* related with top-down reconfiguration of task-sets prior to stimulus presentation. It has been observed that if the cue-stimulus interval in the task-cuing paradigm (Meiran, 1996) or the response-stimulus interval in alternating runs paradigm (Rogers & Monsell, 1995) is increased, then this prolonged period to prepare for the next trial results in reduced switch costs. However, even with very long preparation time switch costs do not disappear entirely. These observations led to the proposal that there is a further task-set reconfiguration process, dependent on the actual presentation of the stimuli, termed as the *exogenous component* of task-set reconfiguration. According to the second model proposed by Allport (1994), switch costs are explained as a result of interference between the competing task sets (for a review of findings, see Kiesel et al., 2010; p. 861-868.). This interference can arise either as a result of persisting activation of currently irrelevant task-sets, or as a result of persisting inhibition of the currently relevant task-set.

Age-related changes in task-switching abilities

While most of the studies on task-switching focused on younger adults, there have been a number of studies investigating age differences in task-switching performance as well (for a review, see Grange & Houghton, 2014, pp. 350–371). In this section, I will provide an overview of the extant empirical findings on age differences in task-switching.

It is now well documented that cognitive aging is associated with a decline in dual-task performance and also with an increase in mixing costs in the task-switching paradigm, but there are no such age-related changes with regard to switch costs (Kray, Eber, & Lindenberger, 2004; Wasylyshyn, Verhaeghen, & Sliwinski, 2011). In one study, a large sample of 5271 participants from age 10 to 66 took part in an internet based task-switching study (Reimers & Maylor, 2005). The results of this study indicated that while mixing costs decreased from 10 to 18 years old, and then showed an almost linear decline, switch costs remained relatively stable. Similarly, comparing younger and older adults Kray and Lindenberger (2000) found a more pronounced difference in mixing costs than in switch costs. They suggested that this means that advancing age negatively influences the ability to maintain and coordinate multiple task sets in working-memory but not shifting itself.

There has been some concern whether the theory of general slowing can account for the age differences in both mixing costs and switch costs. In a meta-analysis Wasylyshyn and colleagues (2011) concluded that with regard to the explanation of mixing costs there is a genuine age difference not accounted for by general slowing, whereas switch costs can be accounted for by it.

In summary, only processes related with the maintenance and coordination of multiple task-sets seems impaired in the elderly, but not shifting itself. The magnitude of these age differences, however, depends on a number of factors, such as cuing type, task ambiguity, and preparation time. As the factors of cuing type and task ambiguity were manipulated in the present study, empirical findings regarding these effects will be presented next.

The effects of cuing in task-switching

As previously mentioned, in a task-switching study with younger and older adults, Kramer and colleagues (Kramer, Hahn, & Gopher, 1999) demonstrated that older adults achieved age equivalence with regard to switch costs after a small amount of practice. However their study also showed that older adults were unable to improve their switch performance through training under high memory-load conditions.

Furthermore, according to a meta-analytic study, cuing and task predictability do not affect age differences with regard to task-switching costs such that there is a reliable difference between younger and older adults with respect to mixing costs, and there is no difference with regard to switch costs, independent of whether cues are provided or not or whether task sequences are predictable or not (Wasylyshyn et al., 2011).

The effects of task ambiguity in task-switching

I have argued previously that there is little age-related change with respect to ‘shifting’ as evidenced by task-switching studies, whereas the ‘updating’ and ‘inhibition’ components (presumably related with mixing costs) seem to be impaired with progressive aging. Mayr (2001) suggested that increased mixing costs might reflect a decreased ability to maintain reliable representations of currently relevant task sets in the face of ambiguous stimulus information. One might argue that this could stem from a decreased ability to inhibit currently task-irrelevant information, which might then interfere with currently task-relevant information. However, this explanation has been ruled out (Mayr, 2001; Experiment 1.), as the inhibition of recently activated task-sets is even larger in older adults then younger adults. Importantly, in a further study Mayr (2001; Experiment 2) found that mixing costs are only different between younger and older adults if stimuli are ambiguous (affording multiple task-sets) and response sets are overlapping (responses are mapped onto the same response options, i.e. same buttons). Thus, Mayr suggested that, as a result of less reliable task-set representations, older adults might need to rely more extensively on set-updating processes, which results in larger mixing costs in older adults. According to this, while younger adults update only on switch trials, older adults update on both switch and non-switch trials. This is in line with theoretical models suggesting a larger reliance on external information in older adults than in younger adults to guide action, which is probably due to difficulties in selecting and maintaining cognitive representations in older age (for a review, see Lindenberger & Mayr, 2013).

Inhibition

Inhibition is measured most frequently by the Stroop task (Stroop, 1935) which has several versions (e.g. color, number) but what is common is that a prepotent response has to be inhibited in favor of another response. We choose this type of inhibition task for the reason that it has similar executive control demands as the task-switching training applied in our study, namely, inhibition of currently irrelevant information and maintenance of currently relevant information. In a typical Stroop task, participants are presented with words (‘red’, ‘green’, ‘house’, ‘shoe’ etc.) in different colors. The task of the participants is to name the color of the ink the words are printed with. In this way, we get three different conditions: color words printed in the same color (congruent condition) to which response is fastest; non-color words (neutral condition) which serves as a baseline; color words printed in a different color (incongruent condition) to which response is slowest. The reason for these latency effects is that there are activations on different levels for color representations (color of stimulus; color concept associated with word), and these can facilitate each other (congruent condition) or get into conflict (incongruent condition) (for a review on the Stroop paradigm, see MacLeod, 1991).

Working-memory

With the term working-memory we refer to the process of continuously maintaining a trace of information in a temporary active state, updating it when necessary, and to use it according to specific goals (Baddeley, 2003). Working-memory allows us to keep relevant information in an active, retrievable state when the information is no longer directly accessible from the environment. It is important not only in short-term buffering of information, that is no longer directly accessible, but also in shielding that information from disruptions by irrelevant information.

Cognitive control is involved in the regulation of the contents stored in working-memory (Smith & Jonides, 1999) for which updating, maintenance, inhibition and shifting are essential ingredients. Maintenance also requires inhibition, which makes it possible to suppress task-irrelevant information and automatic impulsive responses. Inhibitory processes contribute to working-memory performance in the suppression of task-irrelevant information.

There are different types of working-memory tests that can be divided according to what type of information participants have to maintain throughout the task. This way we can speak of visual working-memory tests and verbal working-memory tasks. Verbal working-memory measures include operation span tasks, such as reading or counting span, in which relevant information have to be maintained in an active state while executing a secondary task. In the present study, we used operation span tasks. According to a model by Miyake and colleagues (Miyake et al., 2000), operation span tasks primarily require updating ability but not shifting or inhibition.

Updating can also be measured by n-back tasks in which participants are presented with a train of stimuli and the task is to indicate if the stimulus is the same as the one presented *n* previously. For example, in a 2-back task participants have to press a response button if the present stimulus is the same as the one before the last stimulus. Performing this task requires the continuous updating of information stored in working-memory.

Intelligence

The terms intelligence, general cognitive ability, intelligence quotient (i.e. IQ) are used interchangeably (cf. Deary, Penke, & Johnson, 2010). A broad definition of intelligence can be given as the following (cf. Gottfredson, 1997, p. 13): “Intelligence is a very general capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test‑taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—‘catching on’, ‘making sense’ of things, or ‘figuring out’ what to do. Intelligence, so defined, can be measured, and intelligence tests measure it well.”

It has been found that the performance on fluid intelligence tests predict well how participants perform on other cognitive tasks. One of the models of intelligence by Cattell and Horn (see Linn, 1989, pp. 29–73) distinguishes fluid intelligence (intelligence as ‘process’) and crystallized intelligence (intelligence as ‘product’). Fluid intelligence is typically assessed by tests that require new knowledge creation. Crystallized intelligence on the other hand is typically assessed by tests that require already stored knowledge (about facts, etc.).

As mentioned in the introduction, our ability to organize complex actions is intimately related to intelligent behavior and crucially dependent on executive functions. We know that there is a high correlation between fluid intelligence and working-memory but they are not identical (Conway, Kane, & Engle, 2003). It has been shown that a child’s working-memory capacity at 5 years old is a better predictor of academic achievement than IQ (Alloway & Alloway, 2010). However it is not clear what links together working-memory and fluid intelligence. One study (Friedman et al., 2006), examining the relationship between the three main executive control components – inhibition, shifting, and updating – and fluid intelligence, has shown that updating is highly correlated with intelligence but shifting and inhibition are not. Another study has indicated that cognitive flexibility as indexed by the efficiency to update task-sets is correlated with fluid intelligence as measured by the Raven test (Colzato, Wouwe, Lavender, & Hommel, 2006). Others have linked the ability to suppress task-irrelevant information in working-memory to fluid intelligence (Burgess, Gray, A, & Braver, 2011). Although there is no agreement between different studies regarding the specific contribution of different executive functions to fluid intelligence, they indicate that executive functions are closely related with fluid intelligence.

Summary

Executive functions show decline during aging and this decline is associated with impaired cognitive functioning. I have presented that executive functioning is not a unitary construct, but can be separated into at least three different components (inhibition, shifting, and updating). The task-switching paradigm allows the calculation of switch costs and mixing costs, which are psychometrically distinguishable and presumably related with the components of shifting and inhibition/updating respectively. Task-switching studies suggest that age-related decline in executive functioning does not primarily affect the ability of shifting. According to one theory, in the face of ambiguous situations older adults might rely on excessive set-updating processes in order to solve tasks more efficiently.

COGNITIVE PLASTICITY AND TRAINING INTERVENTIONS

Learning and Transfer

In this section, I will present theoretical concepts and empirical findings in connection with learning or skill acquisition that will be important in understanding how general and enduring training benefits might be achieved.

Skill learning can be defined as a change (i.e. improvement) in perceptual, cognitive, or motor performance that is elicited by training and lasts for an extended time period (weeks or months), thereby differing from mere adaptation or other short-term effects (Green & Bavelier, 2008). Thus, in the context of cognitive training, we can differentiate between an early stage of learning that takes place within minutes related to the familiarization with the task, and a later stage of learning that requires training for a longer period of time (Green & Bavelier, 2008). Here, we are interested in the latter type of learning. More specifically, we are interested in training with generalizable *transfer* effects.

Broadly speaking, by *transfer* we refer to situations in which training in one task leads to performance improvement on another non-trained task (for a taxonomy of transfer distance see Noack et al., 2009 p. 446-448.). Researchers often differentiate between *near transfer* and *far transfer*. By near transfer we mean that the transfer is restricted to structurally similar tasks which share similar stimuli characteristics, response rules and requirements, etc. By far transfer we mean that the transfer is not restricted to similar tasks but leads to performance improvement on structurally dissimilar tasks as well (for a critical review on the concept of far transfer, see: Barnett & Ceci, 2002).

The first hurdle for cognitive interventions came from observations indicating that despite the plasticity of perceptual and motor skills, effects of training are mostly task specific. A lack of transfer effects would be problematic for cognitive interventions, as the aim of these interventions should be to reach beyond the trained context and mitigate age-related cognitive decline that hinders individuals in their daily lives.

Thus, the question arises whether anything can be trained beyond task-specific processes which are related to a given paradigm. As suggested by Klingberg (2010), a distinction can be made between explicit and implicit learning. Explicit learning is the process when performance improvement (for example in working-memory tasks) is initiated by learning new strategies for encoding and handling information by rehearsing techniques, chunking or meta-cognitive strategies. An example for explicit learning is when participants learn a strategy to chunk long series of digits into smaller meaningful units, thereby extending effective recall length (e.g., although short-term storage of information is restricted to 7 ± 2 items (Miller, 1956), by chunking participants has been shown to be able to recall up to 79 digits (Ericcson, Chase, & Faloon, 1980)). Given that explicit learning usually only work with trained material (i.e. it does not transfer to other tasks; for example learning how to memorize digits does not help memorizing letters) the question remains as to what extent can implicit learning be exploited to facilitate broad general improvement.

It has been suggested that in order to show transfer effects from one task to another the two tasks should share some common underlying processes. As a general principle, it can be assumed that by training one task, certain processes and functions are strengthened, which, if relevant to another task, will enhance performance on that other task as well. As an example, there is evidence that updating training shows transfer only if underlying brain structures and functioning is shared with the target test (Dahlin, Neely, et al., 2008).

Principles to enhance training and transfer effects

What are the optimal conditions for training-related improvements (e.g. time, frequency, motivation, intensity), and what are limiting factors (upper boundaries on plastic changes, process specific limits, and so forth)? Factors that modify training outcomes include task difficulty and motivation. According to Vygotsky's ‘zone of proximal development’ model (Vygotsky, 1980), learning is most efficient when tasks to be solved are close to the upper limits of the participants’ current abilities. The reason for this is that in cases where task difficulty is too high or too low, it leads to a decrease in motivation and thereby reduced learning. Hence many cognitive interventions apply *adaptive training* procedures in which task difficulty is changing according to the improving performance of the individual (i.e. if participants get better during training the task becomes more demanding, if participants get worse during training the task becomes less demanding).

How to quantify transfer?

There are some essential requirements that should be followed at the design of training studies, therefore these criteria will be reviewed here briefly.

Usually, assessing the effectiveness of a training one has to measure baseline performance on the tests of interest before the training and then after the training. As in most cases we expect improvements on tests at posttest, we shall make sure that the effects that we see are not merely retest effects (i.e. performance improves by repeated encounter with the same test). One thing that we can do is to use modified tests at the posttest, so that they are not exactly the same as at the pretest. The tests should ideally be counterbalanced, so that half the participants use the original and half the modified version at pretest, and at posttest the other way around.

Another important aspect for evaluating training related improvements is that we should make sure that participants improved as a result of gaining skills specifically related to the training and not some other trivial factors. For example, repeated visit to the lab can make participants more comfortable, so that they might perform better because of that circumstance in comparison to a no contact control group which does not visit the lab in between pretest and posttest sessions. In order to avoid this problem one can use active control groups. These groups also spend the same time in the lab, performing a test which is similar to the training task, but which differs in some crucial aspect. For instance, we used an active control group that practiced no switching between trials, but only single-task blocks. In this way the task-switching training groups and the active control group conditions were almost similar, except for one crucial difference: the task-switching training groups alternated between tasks while single-task groups did not.

In general, participants can be assigned to training groups based on their pretest performance on the tests of interest, so that baseline differences do not make it problematic to interpret changes at posttest. One scenario could be where one group has already high performance at pretest while another group does not, and after training at the posttest assessment the high performance groups do not show any further improvement while the initially lower performing group reaches the level of the high performing. In this case one might interpret wrongly that only one of the groups improved. Whereas, it might be equally valid to interpret that there was no more room for improvement in the initially high performing group which is commonly referred to as a *ceiling effect*. The details of the matching procedure of the present study will be described in the method section.

When evaluating training interventions, apart from statistical testing for significance (i.e. between pre- and posttest measures), it is recommended to also report effect sizes (Wilkinson, 1999). Effect sizes quantify the magnitude of the training effects, that is, the pretest-posttest improvement. It also makes possible to compare studies with different designs, samples and analyses (Wilkinson, 1999). It has been suggested that to qualify for successful training effect size should be at least 0.30 (Klauer, 2001), or alternatively the proportion of participants showing improvement after training should be higher than 50 percent (Derwinger, Neely, Persson, Hill, & Bäckman, 2003). According to Cohen (1988) effect sizes using Cohen's *d* between 0.2 – 0.3 should count as "small", around 0.5 as "medium", and above 0.8 as "large". Also, ideally, long-term maintenance of training benefits should be assessed. Thus, inspection of effect sizes, proportion of participants showing transfer, long-term stability of improvements, and individual differences in relative improvements should ideally be investigated for the evaluation of cognitive interventions.

One further difficulty in evaluating cognitive interventions is, however, how to quantify transfer scope. Noack and colleagues (Noack et al., 2009) suggests that mere improvement on individual tests in itself might not reflect improvement on the level of general cognitive abilities, instead, one should look for improvements on the latent variable level by measuring multiple tests in a given domain. Thus, *effect range* should be assessed by a wide range of cognitive tests. Showing transfer of training on the latent variable level might provide stronger evidence for the effectiveness of a given cognitive intervention.

COGNITIVE TRAINING IN OLDER AGE

Investigating the possibility of cognitive plasticity through cognitive interventions in older age is a relatively new research area. There has been substantial progress in cognitive aging research for several decades, but the focus shifted only recently (see

Kramer & Willis, 2002; Mayr, 2008) to what can be actually done in order to slow down or even to reverse cognitive decline observed in the many cognitive abilities affected by aging, which has been well documented through longitudinal and cross sectional studies. Most early studies on cognitive training focused on memory training with explicit strategies, such as the *method of loci* (Baltes & Kliegl, 1992; Verhaeghen et al., 1992), and training on fluid intelligence (Baltes, Kliegl, & Dittmann-Kohli, 1988; Baltes et al., 1989; Blieszner, Willis, & Baltes, 1981). The interventions using the method of loci, a mnemonic technique to improve memory performance, in younger and older adults generally indicated that younger as well as older adults were able to improve their memory performance, although younger adults were better able to do so. In addition it was also found that training gains were maintained for months or even years (Brehmer et al., 2008).

There is also evidence for plasticity with regard to executive functions, even in older age. A study for example by Dahlin and colleagues (Dahlin, Nyberg, et al., 2008) investigated the plasticity of executive functions in younger and older adults. They trained participants for 5 weeks in updating information in working-memory, and found that compared to a control group, both younger and older adults improved their performance on updating. Moreover, the training-induced improvements were maintained for a period of 18 months after training. In younger adults, the training also led to improvements on an untrained task that also required updating. However, even after five weeks of training older adults remained below the level of performance reached by younger adults after two weeks, and they did not show transfer to a 3-back task. This suggests that there might be limits on how much older adults can gain through training with regard to updating processes.

A recent study by Anguera and colleagues (Anguera et al., 2013) measured multitasking with participants aged 20 to 79 years in a three dimensional video game and showed a linear decline in performance with aging. However, training older adults (60 to 85 years) in an adaptive version of the video game for a period of one month showed marked improvements (compared to an active and a no-contact control group) in multitasking, reaching better performance than untrained 20-year-olds. Furthermore, this improvement in multitasking was still observable after six months. The training also led to improvements on untrained cognitive abilities, such as enhanced sustained attention and enhanced working-memory. Furthermore, both the single-task-training and the multitask-training led to similar improvements in single task components, but only the multitask-training led to enhanced multitasking, sustained attention and working memory performance. This indicates that the mechanism that drives the training effects is the improved interference resolution resulting from overlapping cognitive control processes during task execution in the multitask-setting.

These findings point to the preserved plasticity of executive functions, such as updating and multitasking even in older age, although there might be limitations regarding the possible level of performance that can be achieved by older adults (i.e. in certain facets of executive functions older adults might not reach performance levels of younger adults, as suggests the updating training by Dahlin (2008); not so for multitasking (Anguera et al., 2013)). Also, there has been a number of recent reviews on working-memory training (Melby-Lervag & Hulme, 2013; Morrison & Chein, 2011; e.g. Shipstead, Redick, & Engle, 2012). These reviews indicated that although there have been a number of studies showing reliable short-term improvements of working-memory, the improvements were rather task-specific, and there is little evidence for generalization of working-memory training to other skills (Melby-Lervaag & Hulme, 2013). Also, many studies used only single tasks to assess whether there was change in executive functions following training, whereby improvements can be explained as task-specific learning (Shipstead et al., 2012). Finally, it has been suggested that working-memory training regimens can be differentiated as *strategy* training (training specific strategies to improve memory performance) and *core* training (training of core cognitive processes needed for successful memory performance), and that a greater generalizability might be expected from core working-memory trainings (Morrison & Chein, 2011). This is a similar idea to what has been said above regarding explicit and implicit learning. The next section will provide an overview about the training with task-switching in older age, the cognitive intervention that is being applied in this study.

Training with task-switching

In this section, empirical findings regarding the plasticity of task-switching abilities will be overviewed. As mentioned earlier, there are two performance costs that can be differentiated in relation to task-switching: mixing and switch costs. Mixing costs reflect the ability to *maintain and coordinate* multiple task sets in mind. Switch costs reflect more directly the ability to *switch* task sets. By examining the results of extensive practice on these two performance costs in task-switching, inferences regarding the degree of plasticity in *maintenance/coordination* and *shifting* can be drawn. As mentioned previously in the presentation of the task-switching paradigm, many studies have shown that by training it is possible to reduce switch costs (e.g. Cepeda et al., 2001; Rogers & Monsell, 1995) as well as mixing costs (e.g. Gajewski & Falkenstein, 2012; Minear & Shah, 2008; Salminen, Strobach, & Schubert, 2012). With regard to age differences in task-switching costs and training, in a task-switching study with younger and older adults Kramer and colleagues (Kramer et al., 1999) demonstrated that after a small amount of practice, older adults achieved equivalent switch costs to younger adults. Another study by Kray and Lindenberger (2000) investigated switch and mixing costs in participants aged 20 to 80 years. After participants underwent four sessions of training in a set of task-switching tasks, pretest to posttest changes were examined in switch and mixing costs across age groups. The results indicated significant practice effects, with both switch and mixing costs being reduced through practice. Also, older adults showed more reduction in mixing costs than younger adults. However, both switch and mixing costs were still reliable at posttest, and older adults still showed larger mixing costs than younger adults. These findings point to the plasticity of executive functioning as reflected in the training-related reductions of both types of task-switching costs even in older age, but they also suggest that even after extensive practice both switch and mixing costs are still observable.

Are training gains generalizable?

Although, as we have seen, there is ample evidence for plastic capacity even in older age, an important question concerning cognitive interventions is not merely whether a specific task can be trained but whether generalizable skills can be obtained by completing the intervention. The limitations of training studies became apparent in early studies in that they usually did not show substantial transfer to other untrained tasks (for a review on the training literature, see e.g., Green & Bavelier, 2008). There are plenty of commercial products that claim to improve cognitive functioning. However, their generalizability to other tasks above the tasks that are actually trained is still ambiguous. One influential large scale online experiment testing 11,430 participants for six weeks (for an average 26 hours) has shown that there were no differences in improvement between two experimental groups (experimental group 1 practicing tasks emphasizing reasoning, planning, and problem solving; experimental group 2 practicing tasks of short-term memory, attention, visuospatial processing and mathematics) and an active control group (answering general knowledge questions through the internet) on benchmark tests (reasoning, verbal short-term memory, spatial working-memory and paired-associates learning) that were assessed at pretest and posttest (Owen et al., 2010). Recent reviews of cognitive intervention studies also suggest that effect sizes are usually small and that training usually does not generalize to untrained tasks (Noack et al., 2009). Nevertheless, one should keep in mind that much depends on the kind of training applied in training studies. For example, there have been a number of studies showing the beneficial effects playing video games on a variety of cognitive abilities (e.g., Boot et al., 2010; Castel, Pratt, & Drummond, 2005; Green & Bavelier, 2008). It has been shown that playing action video games can enhance visual selective attention in younger adults, improving attentional capacity, the spatial distribution of attention, and also that it reduces attentional bottlenecks in sequential processing (Green & Bavelier, 2003). Moreover, some studies found that video games improve not only selective attention but executive functions as well, such as shifting (e.g., Green, Sugarman, Medford, Klobusicky, & Bavelier, 2012; Strobach, Frensch, & Schubert, 2012).

Furthermore, studies also found that reversing age-related decline in executive functions through video game training might be possible even in older age (Basak, Boot, Voss, & Kramer, 2008). In a study of Basak and colleagues (2008), older adults were training in a real-time strategy video game to improve executive functions. Relative to a control group, trainees improved in executive functions, such as shifting, working-memory, and visual short-term memory. In another online game-training experiment, van Muijden, Band, and Hommel (2012) also investigated whether cognitive control can be trained in older adults. One group practiced with alternating between five different videogames, which presumably taxed cognitive control, as participants were required to select and integrate information, manipulate working-memory representations, and switch between task sets (cf. van Muijden et al., 2012). This group practiced for seven weeks while an active control group answered quiz questions for the same period of time. Transfer effects included improvement of inhibition (stop-signal task) for the training group and improvement of selective attention for the control group. However, as several other tests (e.g., Stroop task, counting span, task-switching) did not show transfer effects, this study indicated only limited plasticity of cognitive control in older adults.

An elusive goal of cognitive training studies is to achieve improvements in general intelligence. After a long history of failure to achieve improvements in reasoning through training (Sternberg, 2008), there has been some empirical support that after all it might be possible (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Klingberg et al., 2005; Schmiedek et al., 2010). In a seminal study, Jaeggi and colleagues (2008) trained participants on an adaptive dual n-back task, and showed for the first time that far transfer to fluid intelligence might be possible. Moreover, they also showed that improvements on fluid intelligence were dependent on training dosage. However, the results should be viewed critically (see, Sternberg, 2008). One of the criticisms of the study was that to measure fluid intelligence they used a shorter, speeded version of the BOMAT (a commonly used test measuring fluid intelligence) (Moody, 2009). The problem was that whereas this test contains 29 items and is supposed to be solved within 45 minutes, participants were allowed only 10 minutes to solve the task in the study by Jaeggi and colleagues (2008), and therefore, given that task sequence follows increasing difficulty, only the easiest items could be tested. Thus, it is conceivable that dual n-back tasks do not train executive functions per se, but attention (see for example: Oelhafen et al., 2013), which might lead to better performance in speeded measures of fluid intelligence.

Since then, many studies tried to replicate the findings of improving fluid intelligence by n-back training, some with success (e.g. Jaeggi et al., 2010; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Jaeggi, Buschkuehl, Shah, & Jonides, 2014) some without success (e.g., Colom et al., 2013; Heinzel et al., 2014; Oelhafen et al., 2013; Redick et al., 2013; Salminen et al., 2012; Thompson et al., 2013). Although the empirical findings with n-back training are still controversial, the results indicate that generalizable skills might indeed be possible to achieve through cognitive training. In the next section the transfer effects of task-switching training will be considered.

Transfer effects with task-switching training

There has been a number of studies investigating training and transfer effects in task-switching and dual-task performance in both younger and older age, suggesting that there are significant age-related deficits (Hahn et al., 2011; Verhaeghen et al., 2003), but also that cognitive plasticity is preserved in older adults and that they can improve by training (e.g., Bherer et al., 2005; Kramer et al., 1995; Lussier, Gagnon, & Bherer, 2012). It has been presented above that we can differentiate between two types of task-switching costs, switch and mixing costs. If task-switching costs are reduced during training as a result of enhanced efficiency in the ability to coordinate and reconfigure competing task sets, then transfer to other similar task-switching situations and to other tasks relying on shared control processes should show improvements as well.

One of the first studies examining transfer effects with a task-switching paradigm was a study done by Minear and Shah (2008). They investigated the extent to which task-switching training transfers to non-trained switching tasks (i.e. near transfer). Participants were trained in either an unpredictable cued paradigm or a predictable alternating runs paradigm with run length two in a pretest-training-posttest design. Near transfer effects at posttest were assessed on both a predictable and an unpredictable task-switching paradigm. In a first experiment, transfer was only evident for mixing costs in the unpredictable training groups. However, this transfer was constrained to a similar unpredictable task-switching paradigm at posttest and not to a predictable task-switching paradigm. There were no difference between the transfer effects of a control group and a predictable switching group. Reaction times got significantly faster for the unpredictable switching group after training for both switch and nonswitch trials compared to the control group which resulted in differences in the mixing costs but not in the switch costs, as both switch and nonswitch trials became faster. If we assume that predictable and unpredictable switching requires the same control processes, then if shifting related control processes in general were really improved in the unpredictable task-switching group it should have actually been easier for them to perform a predictable switching paradigm - which was not the case. In a second modified experiment (by inserting a 200 ms cue stimulus interval) the findings were replicated. Nevertheless, all groups improved performance from pretest to posttest on the predictable task-switching. In a third experiment (with varying cues), comparing control group to the unpredictable task-switching group similar transfer effects were found for mixing costs in the unpredictable paradigm. Most importantly, a further analysis showed that the source of transfer was the improvement in the ability for recovery from an unexpected switch.

In summary, this study has shown that with an unpredictable task-switching training the ability to recover from an unexpected switch can be improved, but this improvement does not show up in a predictable task-switching paradigm because unexpected switches are not present there. On the other hand, control groups and task-switching groups (either predictable or unpredictable) did not show difference in transfer to a predictable task-switching paradigm.

As for today, only a few studies investigated the trainability of cognitive control processes from a lifespan perspective. Even less used the task-switching paradigm to investigate whether training generalizes to other tasks. The most important of those studies for the present study is a training study of Karbach and Kray (2009), therefore, it will be presented next.

In comparison to the study by Minear and Shah (2008), in the study of Karbach and Kray (2009) a different paradigm was used, and participants trained for a longer duration. The main goal of the study was to investigate lifespan differences in near and far transfer effects in three age groups (children 8-10, younger adults 18-26, older adults 62-76) and the modulation of the transfer effects by the employment of *verbal self-instructions* (i.e. naming the upcoming task goal in the preparation interval, supposedly facilitating task maintenance and selection) and also by the introduction of *variability in the training* (i.e. training with different tasks and stimuli in each training sessions, supposedly supporting transfer effects). They used a pretest-training-posttest design, with three task-switching training groups and an active control group. The task-switching paradigm used was an alternate runs paradigm, with a run-length of two (i.e. tasks switched every second trial). At pretest there were two tasks (Task A and Task B), with responses assigned to the same response button in both task sets. Stimuli comprised of 16 fruit and 16 vegetable pictures, either in small or large size. In Task A participants had to decide whether the picture was fruit or vegetable; in Task B participants had to decide whether the picture was small or large. There were four training sessions. The task-switching training groups practiced mixed blocks, with new tasks (Task C: transportation task, decide whether picture shows planes or cars; Task D: number task, decide whether one or two planes/cars are presented). The task-switching training group with variable training had in addition six other tasks (Tasks E-J). The active control group practiced the single tasks, C or D, in separate blocks. Each session started with two practice blocks followed by 24 experimental blocks (17 trials each), resulting in a total of 1768 trials throughout the four sessions. At pretest and posttest a cognitive test battery assessed participants task-switching ability (single task and mixed task performance), inhibitory control (color stroop and number stroop), verbal working-memory (reading span and counting span) spatial working-memory, and fluid intelligence (figural reasoning/letter series, Raven's Standard Progressive Matrices). The task-switching task at pretest and posttest consisted of 2 practice blocks, followed by 20 experimental blocks (8 single and 12 mixed blocks).

The main findings of the study were the following: (a) near transfer was found for both mixing and switch costs; (b) near transfer for mixing costs was most pronounced for older adults and children; (c) verbal self-instructions alone not but (d) verbal self-instructions with variable training modulated near transfer effects; (e) far transfer effects were found in several areas, like interference control, spatial and verbal working-memory as well as fluid intelligence; and (f) far transfer effects were not modulated by either age or type of task-switching training.

Effect sizes were larger for near transfer than for far transfer. With regard to mixing costs, effect sizes were larger in all age groups for task-switching groups (d' = 0.98 – 2.15) than for single-task groups (d' = 0.11 - 0.55). The results were similar regarding switch costs: effect sizes were larger in all age groups for task-switching groups (d' = 0.88 – 1.14) than single-task groups (d' = 0.22 - 0.60). For task-switching groups, effect sizes were relatively large even for far transfer (younger adults d' > .60, older adults d' > .40 in most cases).Compared to the task-switching training groups the single-task groups showed only small effect sizes in far transfer, most values of d' were smaller than 0.30 for both younger and older adults.

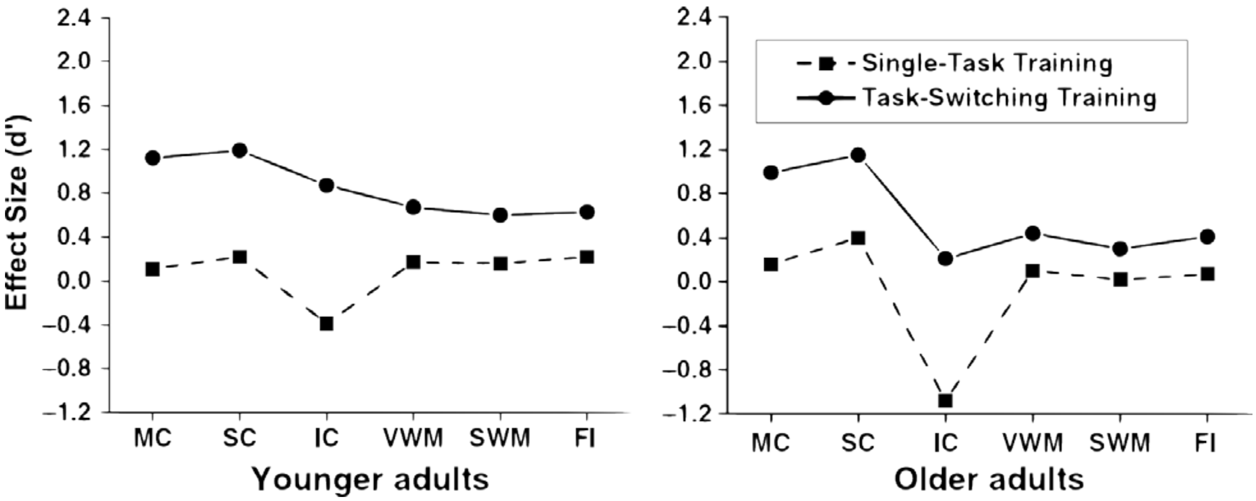

Figure 2 Karbach & Kray (2009): Effect size d' for near and far transfer as a function of training (single-task, task-switching), transfer measure (MC = mixing costs; SC = switch costs; IC = interference control; VWM = verbal working-memory; SWM = spatial working-memory; FI = fluid intelligence), and age (younger adults, older adults).

Since then, far transfer effects of task-switching training to interference control and working-memory have been replicated with ADHD children as well (Kray et al., 2012). However, it should be noted that effect sizes have been on medium levels for single-task groups as well. This has been attributed to improved ability of focusing attention to the task in general.

Another study (Zinke, Einert, Pfennig, & Kliegel, 2012), investigating near and far transfer effects of task-switching training in *adolescents* (aged 10-14 years) have found near transfer effects for mixing costs but far transfer effects were restricted to improvements in a choice reaction time task and faster reaction times on a 2-back task. However, this study involved only three sessions of training which might have been not sufficient to show broader effects of the training.

Given the broad transfer effects of the study by Karbach and Kray (2009), it seems to be important to further investigate the paradigm, as if it indeed turns out to be effective, it could guide the development of cognitive interventions to ameliorate age-related cognitive decline. However, in order to better optimize task-switching training programs, the question remains as to exactly what the transfer effects can be attributed to. There are multiple factors that could have contributed to the observed transfer effects but the most prominent among those might probably be inhibition demands, memory demands, and shifting demands.

In the present study we will use similar dependent variables at pretest and posttest as in the study done by Karbach and Kray (2009), but during the training we will use a different task-switching paradigm in which we will manipulate the level of interference and memory load. Furthermore, we will only focus on younger and older adults.

GENERAL SUMMARY

Cognitive control is necessary to set up, manage, and coordinate goal-directed behavior. There are several components of cognitive control that can be separated as indicated by psychometric studies (Miyake & Friedman, 2012; Miyake et al., 2000) and neuroimaging studies (Collette et al., 2005; E. E. Smith & Jonides, 1999). A frequently adopted taxonomy takes inhibition, shifting, and updating as key components of cognitive control (Hofmann et al., 2012; Miyake & Friedman, 2012). Cognitive control is assumed to be closely related to higher-level cognitive abilities, such as fluid intelligence, which is also evidenced by similar developmental trajectories across the lifespan (Craik & Bialystok, 2006).

One of the commonly used paradigms to measure executive functions is the task-switching paradigm (Monsell, 2003). It requires participants to switch regularly between two or more task sets related with simple categorization tasks. By registering performance on single blocks, in which only one task is repeated continuously, and mixed blocks, which involve task-switching and task repetition trials, two comparisons are usually made to measure different aspects of executive functions. Switch costs measure the shifting ability, which is assumed to require the inhibition of irrelevant task sets and activation of relevant task sets. Mixing costs give a measure related to the efficiency of keeping and coordinating multiple task sets in mind. Studies investigating age differences in these two components of task-switching generally indicated that while mixing costs are increased in older age, switch costs stay on the same level in older age (if general slowing is taken into account), indicating intact abilities to switch between task sets (Wasylyshyn et al., 2011).

One of the main questions of the present work is whether cognitive decline can be remedied by cognitive intervention, and related with that, the question of how to do this effectively. There is a growing body of empirical evidence suggesting that even in older age there is hope for plastic changes to be brought forth by cognitive interventions. However, mere reserved plasticity to improve through training is not sufficient in itself. If training effects are strictly task specific then there is little point in training. This has been a problem, as many studies indicated that the transfer scope of cognitive trainings might be limited to tasks very similar in structure to the trained task (Green & Bavelier, 2008; Owen et al., 2010).

In recent years, however, a number of training studies demonstrated generalizable transfer effects with different training regimens. For example, intensive practice of working-memory is suggested to improve fluid intelligence (Jaeggi et al., 2008). Another example is multitask training, which demonstrated transfer to untrained cognitive control abilities in older adults, improving sustained attention and working-memory (Anguera et al., 2013).

The present work focuses on the beneficial effects of a task-switching training paradigm and the mechanisms mediating transfer effects to untrained cognitive abilities in younger and older adults. A study conducted by Karbach and Kray (2009) showed evidence for far transfer effects of task-switching training. After four sessions of training in task-switching, older and younger adults showed broad transfer to measures of inhibition, working-memory and fluid intelligence (compared to an active control group). However, it remained unclear as to what processes were actually trained during task-switching.

Statement of problem and research predictions

In the previous parts age-related changes in cognitive control have been outlined, as well as age-related differences in task-switching costs. Although, as we could see above, considerable research is trying to elucidate the necessary conditions and kinds of trainings for successful transfer, there are still many open questions. One approach to facilitate the effectiveness and transfer of cognitive training has been based on the idea that there is a possibility for plastic change in basic cognitive control processes, and given that higher level cognitive abilities are based on these basic processes (such as inhibition, shifting, and updating) the training of them should lead to broad transfer. However, one problem is that we do not know the precise kind of training to bring forth substantial and long lasting changes in basic cognitive control processes. The present study examined the applicability of a task-switching approach to elicit such changes following a previous task-switching training study.

In addition, by creating training conditions with different levels of demands in inhibition and updating, the aim of the present study was also to disentangle what processes are actually trained during task-switching. The knowledge gained through this study regarding the transfer effects in different training conditions might have practical relevance for designing optimal training programs for the elderly. The core question that the study is intended to answer is the following: *what components of cognitive control trained by the task-switching paradigm are the most important in eliciting transfer effects*? And a further sub-question stemming from the main question can be stated as follows: *are there age-differences with that regard (i.e., are the same components of cognitive control important in eliciting transfer effects in both younger and older adults)*?

OVERVIEW OF STUDY DESIGN

The specific design of the present training study was based largely on a previous task-switching training study by Karbach and Kray (2009). Most importantly we used the same amount of training (i.e. same amount of practice trials). The differences between the two studies were the specific tasks used, and related to that, the change in the nature of the stimuli (pictures in the previous study; characters in the present study).

Solving task-switching tasks requires cognitive control that can be separated into three main components, as mentioned in the theoretical introduction: ‘updating’, ‘inhibition’ and ‘shifting. To disentangle the relative involvement of these different cognitive control components in task-switching we had to use a design in which we could separately manipulate demands on these three components.

‘Updating’, demands were manipulated by the presence or absence of a task cue. The reason for this is that without a task cue participants had to continually update which task to perform during the task-switching paradigm. Therefore, in the absence of a cue, demands on ‘updating’ were high, whereas if task cues were present throughout the task, demands on ‘updating’ could be kept low.

With regard to ‘inhibition’, demands were manipulated by combining stimuli which were either task specific or neutral. During task execution, if participants were presented with a bivalent stimuli (i.e. containing two different task specific stimuli), then response to the currently irrelevant stimuli had to be suppressed; therefore demands for ‘inhibition’ were high. Whereas, if participants were presented with a univalent stimuli (i.e. containing a task specific stimuli and a neutral stimuli), then demands for ‘inhibition’ were low, as no competing responses had to be suppressed.

By the combination of these manipulations, four different task-switching training groups were created in which participants had to switch between two tasks on every second trial within each block. In addition, we had a single-task training group, which practiced the same two tasks, but in isolation. Therefore, they did not have to switch tasks within blocks. It was assumed that if the ‘updating’ and ‘inhibition’ manipulations would not yield any difference in transfer effects between the task-switching training groups, but at the same time all task-switching training groups would show transfer effects relative to the single task training group, then the ‘shifting’ component is mostly responsible for the observed transfer effects.

As it will be described in the method section, near transfer was measured at pretest, posttest, and at the follow-up sessions with a task-switching paradigm different from the ones used during training. Far transfer was also assessed in these three occasions. Measures for far transfer consisted of a battery of cognitive tests assessing verbal working memory (reading span, counting span), interference control (color stroop, number stroop), updating (digit backwards; 2-back, 3-back), and reasoning (Raven Standard Progressive Matrices, BOMAT). As mentioned previously, we used multiple indicators for each construct to assess whether improvements are present on the latent variable level. This decreases the likelihood that transfer effects are task specific. The specific details of the training groups and the tasks at pretest and posttest are presented in the method section.

RESEARCH PREDICTIONS

This part is divided into four parts. The specific research predictions are outlined (1) with regard to the task-switching training sessions, (2) with regard to near transfer effects to a similar untrained switching task, and (3) with regard to far transfer effects to other executive control tasks, and (4) long-term maintenance of the task-switching training. Each section begins with a brief summary of the relevant theoretical considerations, followed by the predictions.

Task-Switching Training Sessions

The main interests of this study are the near and far transfer effects of the training. Nevertheless, examining the training effects during the four training sessions will help us to better understand the near and far transfer effects. This will be done by examining age differences in the training benefits of the groups that practiced task-switching. The four different task-switching conditions are: 1) with task cues (low updating) and univalent stimuli (low inhibition); 2) with task cues and bivalent stimuli (high inhibition); 3) without task cues (high updating) and univalent stimuli; and 4) without task cues and bivalent stimuli.

Age differences in the reduction of switching costs

As previously presented, switch costs can be reduced through practice in both younger and older adults, but there are no differences in the rate of reduction between younger and older adults (Bherer et al., 2005; Karbach & Kray, 2009; Kramer et al., 1999; Kray & Lindenberger, 2000). Therefore, we expect that: switch costs will be reduced throughout the four training sessions (prediction 1); there will be no differences in reduction between younger and older adults (prediction 2); switch costs will still be found at the fourth training session (prediction 3).

The impact of inhibition demands

Performance costs in task-switching and especially switch costs are sensitive to whether the stimuli are bivalent or univalent (affording multiple or single task sets respectively). Switch costs are greater in bivalent conditions (e.g., Allport et al., 1994; Jersild, 1927; Rogers & Monsell, 1995; Spector & Biederman, 1976). Therefore, we expect that switch costs will be greater in bivalent groups (prediction 4).

Previous studies indicated that older adults have more difficulties than younger adults when there is an ambiguity in the stimuli to respond to (i.e. when stimuli are bivalent) (Mayr, 2001). Therefore, we expect that switch costs will be larger for older adults than for younger adults in the task-switching groups with bivalent stimuli (prediction 5).

The impact of updating demands

Previous studies indicated that older adults have more difficulties than younger adults when there is a higher demand on updating internal representations of upcoming task goals (i.e. when task cues are not provided) (Lindenberger & Mayr, 2013). Furthermore, previous studies have indicated that older adults can use task cues to prepare for an upcoming task in a similar way as younger adults, leading to a similar amount of reduction of mixing and switch costs (Cepeda et al., 2001; Kramer et al., 1999; Kray, 2006). Therefore, we expect that switch costs will be larger in older adults than in younger adults in the uncued task-switching groups (prediction 6).

There is evidence suggesting that older adults have difficulties when task uncertainty increases. In a study by Kray and colleagues (2002), using an externally cued task-switching paradigm, age-related differences in mixing costs disappeared when task cues were provided. Also, Kramer and colleagues (Kramer et al., 1999) demonstrated that in an alternate runs task-switching paradigm if memory demands are increased then older adults are less able to reduce switch costs through training. Therefore, we expect that older adults will show less reduction through training in uncued task-switching groups (prediction 7).

Near Transfer Effects

In general, we expect larger reduction in switch costs for task-switching groups relative to the control group from pretest to posttest (prediction 8), as well as larger reduction in mixing costs for task-switching groups relative to the control (prediction 9).

The impact of inhibition demands

We expect larger transfer (i.e. larger reduction in switch and mixing costs) from the more demanding conditions to the less demanding conditions, therefore larger transfer from high inhibition demand training to low inhibition demand conditions (prediction 10).

The impact of updating demands

Similar to our expectation regarding inhibition demands, we expect larger transfer from the more demanding conditions to the less demanding conditions, therefore larger transfer from high memory demand training to low memory demand conditions (prediction 11).

Age differences in the reduction of switching costs

There is evidence that older adults show a greater impairment with regard to mixing costs, whereas on the level of switch costs there is not much difference between younger and older adults (Karbach & Kray, 2009; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Wasylyshyn et al., 2011). Therefore, we expect: larger mixing costs in older adults than in younger adults at pretest (prediction 12); and no difference in switch costs between younger adults and older adults at pretest (prediction 13). We also expect more substantial reduction in mixing costs for older adults from pretest to posttest than for younger adults (prediction 14).

Far Transfer Effects

The main interest of this study is to investigate the mechanisms mediating transfer effects of a task-switching training paradigm to untrained cognitive abilities in younger and older adults. As mentioned above, evidence for far transfer effects of task-switching training comes from a study conducted by Karbach and Kray (2009), which showed broad transfer effects to measures of inhibition, working-memory and fluid intelligence. However, this previous study did not give an answer regarding which processes were actually trained during task-switching. We are interested in how manipulating demands on inhibition and updating affects transfer effects, and whether there are age-related differences in the transfer effects.

With respect to Interference Control we have the following predictions:

Prediction 15: larger reduction with respect to interference costs in those groups that trained with bivalent task-switching condition as compared to those groups that trained with univalent task-switching.

With respect to Verbal Working-memory we have the following predictions:

Prediction 16: larger improvements in verbal working-memory in those groups that trained with uncued task-switching condition as compared to those groups that trained with cued task-switching.

Prediction 17: larger improvements in verbal working-memory in those groups that trained with bivalent task-switching condition as compared to those groups that trained with univalent task-switching.

With respect to Updating we have the following predictions:

Prediction 18: larger improvements in those groups that trained with uncued task-switching condition as compared to those groups that trained with cued task-switching; as well as larger improvements in those groups that trained with bivalent task-switching condition as compared to those groups that trained with univalent task-switching (prediction 19).

With respect to Fluid Intelligence we have the following predictions:

Prediction 20: larger improvements in task switching groups than single-task groups.

Predictions to long-term maintenance of task-switching training

There are previous results indicating long term maintenance of training in the domain of working memory (Dahlin, Nyberg, et al., 2008). Similarly, we also expect that training effects will be maintained after six months in task switching. Furthermore, previous training studies with younger and older adults indicated a larger drop in performance for older adults at follow up sessions (Brehmer et al., 2008; Li et al., 2008). Similarly, we expect that relative to younger adults, older adults will show a larger drop in performance from posttest to follow up.

Method

PARTICIPANTS

Overall 176 participants were recruited for the study. Thirteen participants had to be excluded from the analysis either because they did not want to finish the study (n = 9), because of health problems (n = 3) or because of mixing up training groups during training sessions (n = 1). The final sample consisted of 81 young adults (mean age = 21.9 years; age range = 19-25 years) and 82 older adults (mean age = 70.8 years; age range 65-85 years). They were recruited from a subject pool at Saarland University, and were paid 56 and 64 Euros, for younger and older adults respectively, to participate in the six sessions of the study, plus 20 Euros for a follow up assessment. Table 1 provides some of the descriptive statistics of the study sample.

Table 1 Descriptive Statistics of the Effective Sample for Age, Gender Distribution

	Younger Adults	Older Adults
N	81	82
Mean age	21.9	70.8
Age range	19-25	65-85
Female	40	43
Years of education	15	14

MATERIALS AND PROCEDURE

Paper pencil tests as well as computerized tests were registered during the study. The computerized tests were presented with E-Prime software package. Manual responses were registered with a standard desktop keyboard.

The effectiveness of different types of task-switching training conditions was assessed by a pretest-training-posttest-follow-up design. To examine near- and far-transfer as well as the maintenance of transfer effects, the pretest session included baseline measurements of a single-task and different task-switching conditions as well as a battery of comprehensive cognitive tasks. After the pretest session participants were assigned to one of five training groups and worked through four training sessions. The posttest and follow-up sessions were similar to the pretest session with parallel versions of the tests used at pretest. Participants were expected to participate in the six sessions with at least two intervening days between the sessions. Testing took approximately three weeks per person. Mean duration between last training session and posttest was 5 days. Follow up measurements took place 6 months after the pretest sessions.

MEASURES AT PRETEST, POSTTEST AND FOLLOW-UP

Table 2 gives an overview of the different psychometric tests and cognitive tasks at pretest, posttest and follow-up. The cognitive battery included tests that were used in previous dissertation study (Karbach, 2008), with slight modifications to some of the tests which will be indicated below.

Table 2 Measured constructs, items, type of tests, estimated time needed for completion of tests and sources.

Construct	Items	Type	Estimated Time (min)	Source
	Demographic Questionnaire	paper pencil	3	
	Self Efficacy Questionnaire	paper pencil	3	
Perceptual Speed	Digit Symbol	paper pencil	1,5 – 3	(Wechsler, 1982)
Shifting	Task Switching	computer	20	
Verbal Working-memory	Digit Backward	paper pencil	3	(Wechsler, 1981)
Verbal Working-memory	Reading Span	computer	5-7	(Kane et al., 2004)
Verbal Working-memory	Counting Span	computer	6	(Kane et al., 2004)
Updating	AX-CPT	computer	5	(Servan-Schreiber, Cohen, & Steingard, 1996)
Updating	2-back	computer	5	(McElree, 2001)
Updating	3-back	computer	5	(McElree, 2001)
Inhibition	Color Stroop	computer	8-11	(T A Salthouse & Meinz, 1995)
Inhibition	Number Stroop	computer	3-5	(T A Salthouse & Meinz, 1995)
Fluid Intelligence	BOMAT	paper pencil	15-18	(Hossiep & Hasella, 2010)
Fluid Intelligence	Raven	paper pencil	10-13	(Raven, 1988)

Similar to the previous Karbach study (2008) two to three different tests were used to measure each ability at a latent level to reduce measurement errors.

Verbal working-memory was assessed by Digit Backward, Reading Span, and Counting Span tests; fluid intelligence by the BOMAT and Raven's Progressive Matrices tests; updating by the 2-back, 3-back and AX-CPT tests; and inhibition by the Color Stroop and Number Stroop tests. For near transfer a task-switching task was developed which provided baseline measurements of four different kinds of task-switching conditions. In addition, a Demographic Questionnaire, a Self-Efficacy Questionnaire, and the Digit Symbol tests were also administered.

DEMOGRAPHIC QUESTIONNAIRE

The demographic questionnaire assessed basic information about the participants such as gender, handedness, highest school achievement, years of education, physical and mental health, hearing and vision. These measures were later analyzed to control for differences between training groups.

SELF-EFFICACY QUESTIONNAIRE[1]

The Self-Efficacy Questionnaire contained 20 statements (e.g.: "I believe that I can solve brainteasers easily." ["Ich bin der Meinung, dass ich Denksportaufgaben gut lösen kann."]) and participants had to indicate their agreement with a given sentence on a 7 point likert scale from -3 to 3.

COGNITIVE BATTERY

Digit Symbol

The same paper pencil version of the Digit Symbol Substitution Test was applied as in the Karbach study (2008) adapted from Wechsler's Adult Intelligence Scale (1982). The test is supposed to indicate basic processing speed. On the upper part of the test sheet

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[1] this questionnaire was included in the study as part of a separate project, and is not analyzed in the present dissertation

nine symbols were paired with nine digits. Below that 100 of the digits were presented without the symbols. The task of the participants was to fill in as many of the empty cells with the corresponding symbols in 90 seconds as they could. The test score was the sum of correctly paired symbols.

Digit Backward

In the Digit Backward test the experimenter read aloud series of numbers and the participants had to repeat the series in reverse order (cf. Wechsler, 1981). The task started with two practice trials containing two items. The next three trials contained three items, then four items, and so on. The test ended if the participant could not repeat correctly any of the three trials with a given length or continued for up to 24 trials at maximum. The test score was the number of the items in the longest correctly recalled trial, as well as the number of totally correct items.

BOMAT

The BOMAT (Bochumen Matrizentest Standard) is a non-verbal paper-pencil reasoning test (Hossiep & Hasella, 2010). On a page participants saw a matrix of 5 x 3 with figures of basic geometrical shapes in grayscale, and one of the figures was missing (see Figure 3**Error! Reference source not found.**). Below the matrix there were six figures, and the task was to find out which figure fits the matrix above. After three practice examples participants had 15 minutes to work through 28 examples. For the pretest and posttest parallel versions with different examples were available. For the follow-up test examples were taken from the pretest (even numbered) and posttest (odd numbered). The test score was the sum of correctly solved examples.

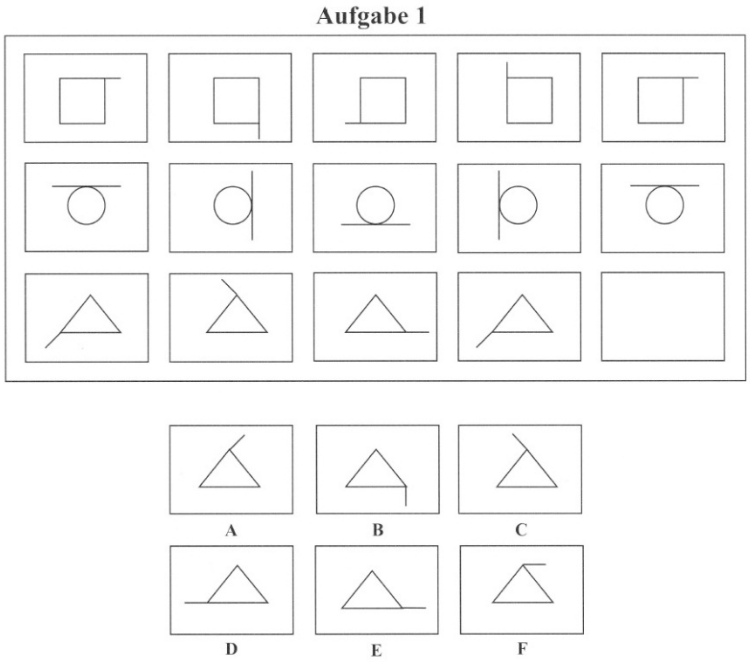


Figure 3 Example sheet from the BOMAT test

2-back

A shorter and modified version of the 2-back task was applied in the present study compared to the one used in the Karbach study (2008) (adapted from McElree, 2001). In this 2-back task participants saw in the middle of the screen a succession of numbers (from 1 to 9) presented for 1000 ms with 0 ms in between the numbers. The task was to monitor the numbers and press a button on the keyboard (P) if the given number was the same as two before, or another button (Q) in every other case. The task started with a practice block of 20 trials followed by the experimental block of 108 trials. Target probability was 25 percent. For the older participants an extra practice block (20 trials) with longer stimulus presentation time (2000 ms) was included as they had difficulties to perform this test. Then they had the normal practice block (20 trials) that the younger participants had. A further difference between the test of the younger and older adults was that the older adults only had to press a button (P) if the given number was the same as the number before the last. Due to visual problems font sizes were also enlarged for older adults (72 points instead of the 24 points used for younger adults; Courier New). The test score was hits minus false alarms.

Reading Span

The same Reading Span test with a slight modification was applied as in the Karbach study (2008), which was a shortened form of the test used by Kane and colleagues (2004) (with 8 trials instead of 12 trials). As in other operation span tasks participants had to engage in a primary task, and in the meanwhile they had to perform a secondary interfering task. In this reading span task, participants were presented with displays showing grammatically correct sentences which were either sensible or nonsense, followed by a question mark and a letter in uppercase (B, F, H, J, L, M, Q, R, X) separated by space. In the secondary task participants were to decide whether the given sentence made sense or not by saying aloud “yes” or “no” (e.g. Beim Einkaufen muss man immer darauf achten, dass das Wasser nicht zu hoch steht. ? H). The sentences consisted of 7 to 14 words, with a mean of 10.5 words. After a decision they had to read aloud a letter (in the above example H) and memorize that letter, which was the primary task. The set of letters were repeated across trials with approximately equal proportion, but they were not repeated within a given trial. Then the experimenter pressed a button and a new display was shown immediately. After that either a new display followed where the task was the same or the participant was prompted to recall the memorized items, which they had to write down on an answer sheet in the correct order starting with the first item they had to memorize. Font sizes were 28 points, white color, and Arial type on a blue background. Set sizes (i.e. the number of recalled items) of trials were between two to five. Participants received three practice trials that were followed by eight experimental trials ranging from two to five items. Each length of set size occurred twice in a random order. The test score was the number of correctly recalled trials, and the number of correctly recalled items.

Color Stroop

A computerized version of the Color Stroop task was applied (cf. Karbach, 2008). Participants were presented words (red, blue, green, yellow, hat, book, tree, flea [actually they were written in German: rot, blau, grün, gelb, Hut, Buch, Baum, Floh]) in different colors (red, blue, green, yellow). The task of the participants was to indicate the color in which the word was written with one of four buttons of the keyboard (S - red, K – blue, N -green, C - yellow) that were marked with the respective colors. The stimuli were written in 18 points, presented on a white background. The stimulus presentation time was until response but maximum 2000 ms. The inter-stimulus interval was 700 ms. The task started with two practice blocks, each containing 12 trials. That was followed by four experimental blocks, each containing 24 trials. In each block three different types of trials were intermixed: in *congruent* trials words “red”, “blue”, “green”, “yellow” are written with the same color that the word refers; in *incongruent* trials the words “red”, “blue”, “green”, “yellow” are written with different colors than to which the words refer; and in *neutral* trials the words “hat”, “book”, “tree”, “flea” are presented with any of the four colors. By subtracting from the mean reaction times of incongruent trials the mean reaction times of neutral trials we obtain a measure indicating the interference effects.

AX-CPT

In a modified AX version of the Continuous Performance Test (i.e. AX-CPT, adapted from Servan-Schreiber et al., 1996) participants first saw a cue (A, F, G, S) for

500 ms that was followed by a probe (X, C, M, U) for 500 ms. The probe was present until response (but 1300 ms maximum). Cue probe interval was 2000 ms. The task was to press a button on the keyboard (P) for an AX cue-target combination, or another button (Q) in every other cue-target combinations (that could either be an AY [that is A followed by a C, M or U], a BX [that is an F, G or S followed by an X] or a BY [that is a F, G or S followed by a C, M or U]). If participants did not answer within 1300 ms after the presentation of the probe, they were shown a display urging them to answer faster. The probability of AX trials were 70 percent, all other combinations (AY, BY, BX) were 10 percent. The task started with two practice blocks of 12 trials followed by two experimental blocks of 50 trials. Fonts were 48 points Calibri type. Dependent variables were latencies and error rates.

3-back

Only the younger adults performed the 3-back task (adapted from McElree, 2001) as it proved to be too hard to perform for the older adults. The 3-back task was similar to the 2-back task. As in the 2-back task participants saw a series of numbers (from 1 to 9) successively. The presentation time for each number was 1000 ms. The task was to monitor the numbers and press a button on the keyboard (P) if the given number was the same as the number two before the last, or another button (Q) in every other case. The task started with a practice block of 20 trials followed by an experimental block of 108 trials. Target probability was 25 percent. Font sizes were 24 points Courier New. The test score was again the percentage of the correctly answered target trials.

Counting Span

This task was adapted from Kane (2004; see also, Karbach, 2008). Participants were presented displays showing shapes of 3 to 9 dark blue circles, 1 to 5 green circles and 1, 3, 5, 7 or 9 dark blue squares on a grey background. Across displays the number of these three shapes was approximately balanced. The secondary task of the participants was to count loudly the number of dark blue circles (i.e. in the case of 3 dark blue circles for example saying aloud “one”, “two”, “three” - “three”, repeating the final number) and then to memorize that number, which was the primary task. Then the experimenter pressed a button and a new display was shown immediately, and the participants had to count again the number of dark blue circles and memorize that number as well. After a prompt they had to write down the correct numbers in order of presentation. Set sizes (i.e. the number of recalled items) of trials were between two to five. After three practice trials participants performed eight experimental trials followed (with set sizes 2*2, 2*3, 2*4 and 2*5, in a mixed order). Test score was the number of correctly recalled trials, and the number of correctly recalled items.

Number Stroop

The Number Stroop task was adapted from Salthouse and Meinz (1995). In this task participants were presented with the following characters (1, 2, 3, 4, X, M, A, H) and in a trial any of these characters could be presented 1, 2, 3 or 4 times next to each other. The task of the participants was to indicate how many characters were displayed on the screen (with the keyboard buttons S - 1, K - 2, C - 3, N - 4). Other details (stimulus size, presentation time, number of trials and blocks) were similar to that of the Color Stroop task. Similarly to the Color Stroop task, in each block three different types of trials were intermixed: in *congruent* trials the characters “1”, “2”, “3”, “4” were displayed the same number of times that the character indicated; in *incongruent* trials the characters “1”, “2”, “3”, “4” were displayed with a different number of times than to which the character referred to; and in *neutral* trials the characters “X”, “M”, “A”, “H” were presented 1, 2, 3 or 4 times next to each other. Dependent variable was again the interference effect, which was obtained by subtracting from the mean reaction times of incongruent trials the mean reaction times of neutral trials

Raven's Standard Progressive Matrices (Raven)

The Raven's Standard Progressive Matrices (Raven, 1988) is a non-verbal reasoning task. It has black and white figures which are combinations of basic geometrical shapes in matrixes of 3 x 3 with one of the figures missing (see Figure 4). The task of the participants was to find out which figure would fit best from a given array of eight figures which were displayed below the matrix. The test started with three examples, after which participants had to solve as many items as they could in 10 minutes. Parallel versions for pretest and posttest were made by separating the complete test containing 36 items into two sets, by having the odd numbered items (item 1, item 3 etc.) at pretest and the even numbered items (item 2, item 4 etc.) at posttest. For the follow-up, items from the pretest as well as the posttest version were selected, choosing every second item from them starting with the first (i.e.: item 1 from pretest, item 2 from posttest, item 5 from pretest, item 6 from posttest etc.). All in all at the pretest, at the posttest as well as at the follow-up there were 18 items in order of increasing difficulty. The test score was the sum of correctly solved items.

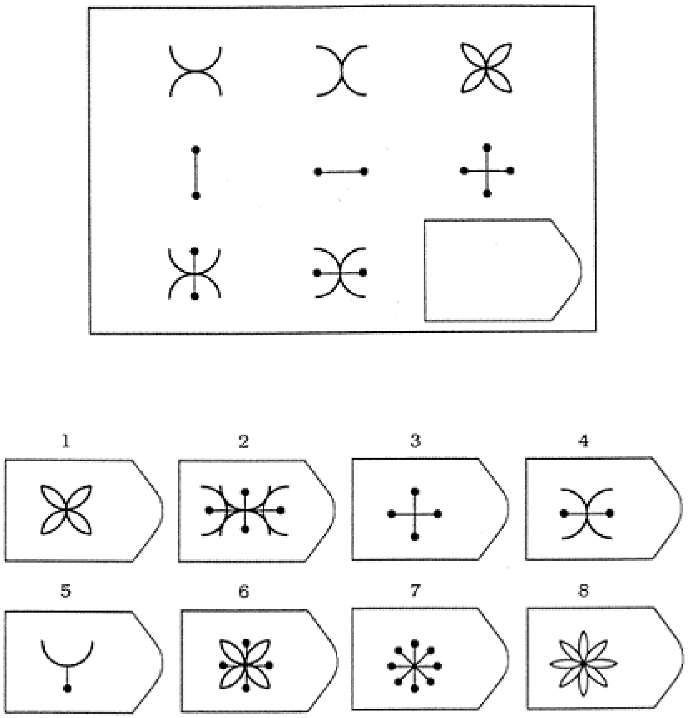


Figure 4 Example sheet from the Raven test

Measurement of Task Switching

For the purposes of the present study new task-switching programs had been developed. They were written in E-prime programming environment, and were run on lab computers with E-prime software. For studying near transfer effects different switching tasks were designed for the pretest-posttest sessions and the training sessions.

Below the specific details of the tasks at pretest and posttest and the training groups will be presented.

Pretest and Posttest

At pretest, baseline performance on five types of switch conditions were assessed. Stimuli consisted of a pair of characters presented next to each other in the middle of the screen, similar to a design be Rogers and Monsell (Rogers & Monsell, 1995) (see Figure 5).

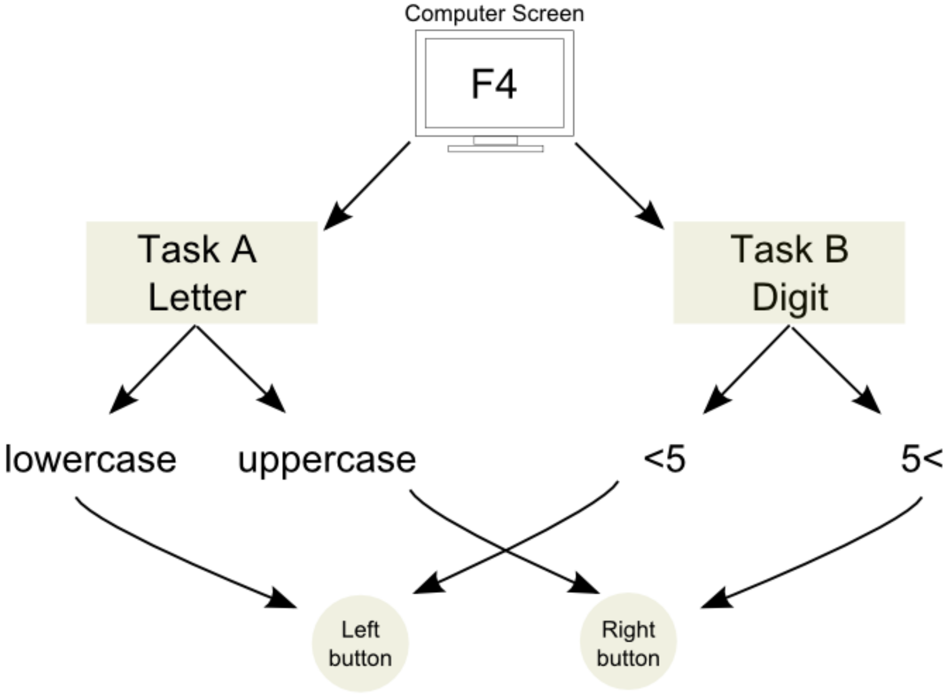


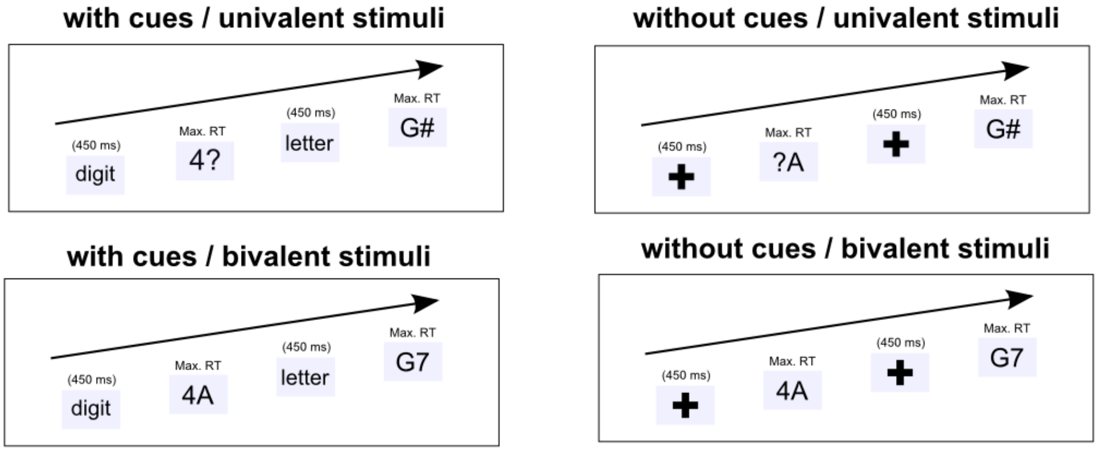
Figure 5 Schematic depiction of the task-switching paradigm used in the study

In the “digit” task (Task A) one of the characters was a number, which could be either smaller (1, 2, 3, 4) or larger (6, 7, 8, 9) than five. Task A required participants to decide whether a number is smaller or bigger than 5. In the “letter” task (Task B) one of the characters was a letter, which could be written either in lowercase (f, t, d, j) or in uppercase (F, T, D, J). In Task B participants had to decide whether a letter was uppercase or lowercase.

The relevant characters appeared randomly (balanced) at either side. In the single-task blocks the other element of the stimuli pair was always selected from the currently irrelevant set. A small diagram situated between the keyboard and the computer monitor indicated the response assignments of the two tasks. The combination of the above characters resulted in 128 stimuli combination in both Task A and Task B. The same two response keys (Q and P) were used for both tasks as well as in all other switching tasks.

In single-task blocks participants had to perform either Task A or Task B separately. In mixed-task blocks participants had to switch tasks on every second trial. There were four types of mixed-task blocks (see Figure 6):

- With cues / univalent stimuli. In this condition requirements for updating were kept low as a cue (“digit”, “letter” [“BUCH”, “ZAHL”]) always indicated which task to perform. Inhibition was also low as task-relevant stimuli were always paired with a task-irrelevant stimuli, selected from a neutral set [*,?,#,%].
- Without cues / univalent stimuli. It was similar to the first type except that the cue (“+”) did not indicate which task to perform, so that participants had to maintain the relevant task-set.
- With cues / bivalent stimuli. It was similar to the first type except that task relevant stimuli were always paired with interfering stimuli selected from the other task-set (example stimuli pair: 1F).
- Without cues / bivalent stimuli. It was similar to the third type, except that the cue (“+”) did not indicate which task to perform, so that participants had to maintain the relevant task-set.


with cues / univalent stimuli

without cues / univalent stimuli

with cues / bivalent stimuli

without cues / bivalent stimuli

Figure 6 Illustration of the four task-switching conditions

Pretest and Posttest procedure

At pretest and posttest the single-task blocks were presented first, starting with a short practice block (9 trials) of either Task A or Task B (counterbalanced), followed by 3 experimental blocks (17 trials / block). This was followed by the second single-task practice block (9 trials) (Task B or Task A), 3 experimental blocks (17 trials), and then the mixed-task blocks, 3 block / type, 17 trials / block, in the following order: with cues / univalent stimuli, with cues / bivalent stimuli , without cues / univalent stimuli, and without cues / bivalent stimuli.

During data analysis the practice blocks as well as the first trial of each block was dropped, resulting in 48 trials for each condition. Response types (left/right), stimulus types (smaller/lowercase – smaller/uppercase – larger/lowercase – larger/uppercase) as well as task types (digit/letter) were counterbalanced in each condition and block, and the sequence of stimuli was randomized for each block.

Before the participants started with the computer test the experimenter explained the tasks both visually with the help of a diagram and verbally. Instructions were also provided in the program before each type of task explaining the given task as well as a diagram (see Figure 7) with the response assignments before the ninth and fifteenth blocks.

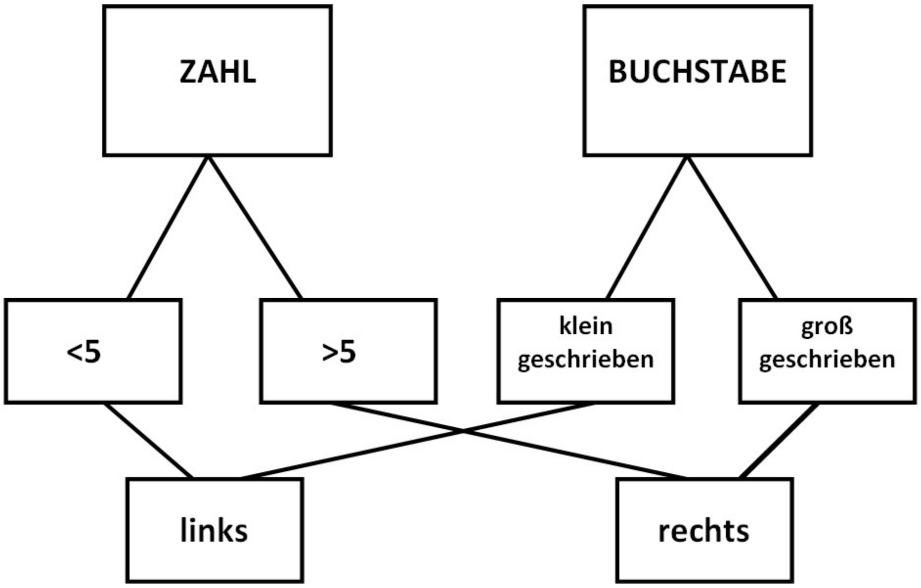


Figure 7 Schematic depiction of the task-switching paradigm showing response assignments presented in the program.

Trials started with a cue for 1000 ms, which was followed by the target until the subject responded and then 25 ms blank screen until the next cue (see Figure 8). Subjects were instructed to respond as fast and as accurate as possible. Feedback about their performance (error rate, RT) was given at the end of each block. To finish the task took approximately 20-30 minutes.

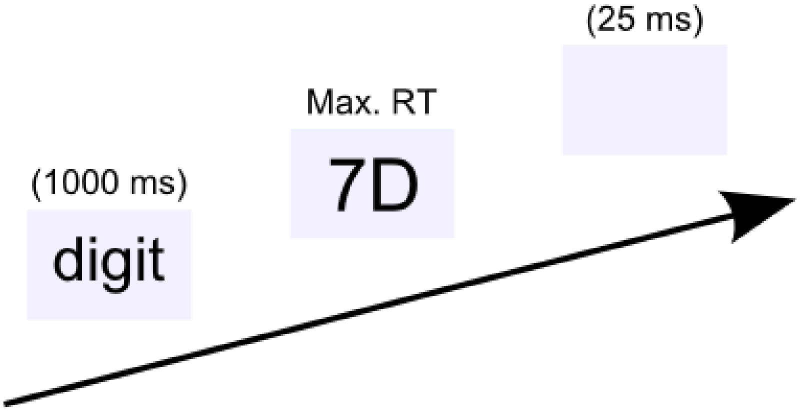


Figure 8 Schematic depiction of the trial procedure in the task-switching tasks.

Training

For the four training sessions participants were assigned to one of the following five training groups based on their pretest performance (Digit Symbol, Raven, single task mean RT, mixing costs, Color Stroop, Number Stroop, 2-back, 3-back, AX-CPT). The method for matching the participants based on these tests will be presented later.

Single-task group:

In the Single-task group participants trained with alternating single-task blocks including Task C and Task D. In Task C (’letter’ task) participants had to decide whether a letter was consonant (G, K, M, R) or vowel (A, E, U, I). In Task D (’digit’ task) participants had to decide whether a number was odd (1, 3, 5, 7) or even (2, 4, 6, 8). The presentation of the stimuli was similar to the pretest and posttest single-task blocks, which resulted in 64 stimuli combination in Task A and 64 in Task B. With regard to response assignments participants had to press (Q) for odd (‘digit’ task) and vowel (‘letter’ task) and (P) for even (‘digit’ task) and consonant (‘letter’ task). This stimulus response assignment was constant across the five groups. Before each of the sessions the experimenter reiterated the task rules. A small diagram situated between the keyboard and the computer monitor also indicated the response assignments of the two tasks for all five groups.

Task-switching groups

These mixed-task conditions were similar to their corresponding pairs at pretest and posttest, except that instead of Task A and B they practiced Task C and D. These have been described above at the Single-task group. In all conditions there were 128 stimuli combinations. As for the Single-task group the experimenter reiterated the task rules before each of the sessions. A small diagram situated between the keyboard and the computer monitor also indicated the response assignments of the two tasks, as well as the program also showed a diagram before participants started with the first block.

Training sessions for all groups consisted of 24 experimental blocks (17 trials per block) and took approximately 20-30 minutes to finish. In this way all participants had performed 1632 trials after the four sessions. After each block participants were presented with a feedback display showing the average reaction times and error rates of the previous block. Participants of the Single-task group with odd ID numbers started their first and third sessions with 12 blocks of digit tasks followed by 12 blocks of letter tasks. Their second and fourth sessions started with 12 blocks of letter tasks followed by 12 blocks of digit tasks. Participants with even ID numbers had the other way around. Participants of the four mixed task groups had only mixed blocks (alternating between Tack C and Task D as described above). Each block started with two digit tasks followed by two letter tasks, etc., with the last trial being a digit task. Testing took place in two labs with the same equipment. Each lab had three workstations so that during the training sessions (but not during pretest, posttest or follow up sessions) participants could be instructed and tested in parallel for up to three persons per lab.

FOLLOW-UP SESSION

As mentioned earlier all participants were contacted after approximately six months after their first session date and were offered 20 Euros to participate in a follow up assessment. The procedure for the follow up was identical to that of the posttest with parallel versions of the tests as indicated above.

PROCEDURE

At the beginning of the experiment all participants gave their informed consent. After a Demographic Questionnaire, at pretest, posttest, and follow-up, and a Self-Efficacy Questionnaire and the cognitive battery were assessed. An overview of the study design is provided in Table 3.

Table 3 Study design showing the tests assessed during specific phases of the study as well as different task conditions of the task-switching test and the five different training groups

Pretest Session 1	**Training** Sessions 2-5	**Posttest** Session 6	**Follow Up** Session 7
Task switching: Single task Low inhibition Low updating Low inhibition High updating High inhibition Low updating High inhibition High updating	Active control group (single task training) Low inhibition Low updating group Low inhibition High updating group High inhibition Low updating group High inhibition High updating group	Task switching: Single task Low inhibition Low updating Low inhibition High updating High inhibition Low updating High inhibition High updating	Task switching: Single task Low inhibition Low updating Low inhibition High updating High inhibition Low updating High inhibition High updating
Working-memory (reading span, counting span)		Working-memory (reading span, counting span)	Working-memory (reading span, counting span)
Interference (color stroop, number stroop)		Interference (color stroop, number stroop)	Interference (color stroop, number stroop)
Updating (2-back, 3-back, AX-CPT)		Updating (2-back, 3-back, AX-CPT)	Updating (2-back, 3-back, AX-CPT)
Reasoning (Raven, BOMAT)		Reasoning (Raven, BOMAT)	Reasoning (Raven, BOMAT)

MATCHING THE PARTICIPANTS

To make comparisons unbiased baseline differences between the five training groups on the critical measures had to be considered. Therefore after pretest we calculated the following scores for each participant. From the task-switching part we calculated Speed of Task Execution (single-task median RT) and Mixing Cost (median RT). For Interference Score we calculated interference costs by subtracting congruent trials (median RT) from incongruent trials (median RT) separately for the Color and Number Stroop, then averaged them. For Updating Score we calculated PR scores (hits - false alarms) separately for 2-back, 3-back and AX-CPT, than averaged them. For Working-memory Score we calculated correct answers on Reading Span, Counting Span and the span of the Digit Backwards task, than we averaged them. For Fluid Intelligence Score we used the Raven task scores. At last we also used the score on Digit Symbol for the matching.

The basic idea behind the matching was the following. For each age group, the first five participants were assigned randomly to the five different training groups. Then we calculated standard deviations separately for the critical test scores (Speed of Task Execution, Mixing Cost, Interference Score, Updating Score, Working-memory Score, Fluid Intelligence Score, Digit Symbol Score) of these five participants. By adding the standard deviations of these seven scores together we got an indicator of how far these five groups are from each other. Then from the sixth participant we did the following. As we wanted to get minimal difference between the groups we had to assign the participant in a group so that this indicator (defined as the sum of the SDs of the seven measures) changes always to a lowest value. Therefore we tested how the indicator would change in the five possible cases, and then we assigned the participant to the group in which, as a result of changing the average scores of the seven critical measures in the respective group, the indicator assumed the lowest value.

DATA ANALYSIS

Task switching and Stroop tasks

During data analysis practice blocks were discarded as well as the first trials of each block. Mean reaction times for correct responses were calculated for specific trial (switch, non-switch; congruent, incongruent, neutral) and block (single, mixed) types. For the analysis of training and transfer effects general and specific switch costs were defined by two orthogonal contrasts. In the first contrast performance of single task trials were compared with switch and non-switch trials in mixed blocks (i.e.: -2 1 1, general switch cost). In the second contrast performance within mixed blocks were compared between switch and non-switch trials (i.e.: 0 -1 1, specific switch cost).

Similar to other studies we also used log transformed reaction times during data analyses (e.g. Karbach, 2008; Kray & Lindenberger, 2000). The reason for using log transformed reaction times is the following. If we assume that there is a constant value with which older adults are slower than younger adults (for instance, if they are 2 times slower), than difference-scores in log transformed scores between younger and older adults will be the same. For example, if younger adults perform stay trials in 300 ms and switch trials in 350 ms, and assuming older adults are twice as slow, and they perform stay trials in 600 ms and switch trials in 700 ms, then after log transformation the difference of log(350)-log(300)=log(700)-log(600). Thus log transformation takes general slowing into account. Additional age-differences in task-switching costs should reflect genuine age-related differences in cognitive processing.

Matching

Before analyzing the training and transfer data, it was controlled whether there were baseline differences between the five training groups in the two age groups with regard to the dependent variables of interest (single trials, stay trials, switch trials, mixing costs, switch costs) (Table 4 and Table 5).

Table 4 Mean (*M*) reaction times and standard deviations (*SD*) for each trial type (single, stay, switch) as well as mixing and switch costs separately for each training group at pretest.

	Training Group				
	Group 1 single (*n*=16)	Group 2 cued/univalent *n*=(16)	Group 3 cued/bivalent *n*=(16)	Group 4 uncued/univalent *n*=(17)	Group 5 uncued/bivalent *n*=(16)
Trial Type	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
			Younger		
Single	511 (49)	519 (47)	521 (71)	513 (78)	525 (58)
Stay	597 (100)	599 (106)	590 (115)	602 (182)	599 (99)
Switch	676 (139)	676 (150)	677 (135)	695 (231)	696 (134)
Mixing cost	86 (76)	79 (77)	69 (69)	89 (116)	73 (69)
Switch cost	79 (53)	77 (63)	87 (53)	93 (61)	97 (57)
			Older		
Single	680 (68)	721 (138)	659 (102)	701 (79)	689 (64)
Stay	913 (155)	940 (231)	883 (179)	925 (176)	907 (141)
Switch	1010 (199)	1047 (292)	978 (203)	1033 (204)	1007 (151)
Mixing cost	234 (110)	219 (134)	224 (128)	224 (143)	218 (121)
Switch cost	96 (106)	106 (108)	95 (59)	108 (65)	100 (84)

Reaction Time Analysis

To assess baseline differences in mean reaction times a three-way ANOVA was conducted with the within-subjects factor Trial Type (single, stay, switch) and between-subjects factors Age Group (younger adults, older adults) and Training Group (Group 1-5). Results showed a main effect of Age Group for single trials, F (1, 153) = 188.65, $p <$ .001, stay trials, F (1, 153) = 169.36, $p < .001$, as well as for switch trials, F (1, 153) = 121.60, $p < .001$. There were no significant main effects of Training Group in any of the trial types, (all *p*s > .60), and neither were interactions between Age Group and Training Group, (all *p*s > .56).

To assess baseline differences in mixing costs and switch costs a three-way ANOVA was conducted with the within-subjects factor Trial Type (single, stay, switch) and between-subjects factors Age Group (younger adults, older adults) and Training Group (Group 1-5). We set up two orthogonal contrasts for the factor Trial Type to determine mixing and switch costs. The first contrast tested single trials against stay and switch trials (mixing cost) the second contrast tested stay trials against switch trials (switch cost). Results showed a main effect of Age Group for mixing costs, *F* (1, 153) = 72.53, *p* < .001, but not for switch costs (*p* = .22). There were no significant main effects of Training Group in either mixing or switch costs, (all *p*s > .95), nor significant interactions between Age Group and Training Group, (all *p*s > .96).

Error Rates

Table 5 Mean (*M*) percentage correct trials and standard deviations (*SD*) for each trial type (single, stay, switch) separately for each training group at pretest.

	Training Group				
	Group 1 single (*n*=33)	Group 2 cued/univalent *n*=(33)	Group 3 cued/bivalent *n*=(32)	Group 4 uncued/univalent *n*=(33)	Group 5 uncued/bivalent *n*=(32)
Trial Type	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
			Younger		
Single	95.83 (3.42)	95.18 (2.77)	96.68 (2.50)	94.91 (3.86)	96.74 (2.84)
Stay	95.96 (3.11)	95.12 (3.18)	96.09 (2.42)	95.59 (2.57)	96.61 (2.68)
Switch	93.95 (5.48)	94.14 (3.57)	92.45 (5.56)	91.12 (3.26)	94.47 (3.70)
			Older		
Single	98.35 (1.43)	96.94 (2.19)	97.20 (1.81)	98.18 (1.55)	97.79 (1.61)
Stay	96.69 (2.66)	95.71 (3.31)	96.09 (4.57)	96.16 (2.51)	96.35 (3.36)
Switch	95.10 (3.66)	93.50 (4.98)	93.62 (4.87)	94.34 (3.76)	93.95 (4.81)

To assess baseline differences in error rates a three-way ANOVA was conducted with the within-subjects factor Trial Type (single, stay, switch) and between-subjects factors Age Group (younger adults, older adults) and Training Group (single, LMLI, LMHI, HMLI, HMHI). Results showed a main effect of Age Group for single trials, *F* (1, 153) = 21.07, *p* < .001, but not for stay trials (*p* = .50) or switch trials (*p* = .21). There were no significant main effects of Training Group for any trial types (all *p*s > .32), neither any interactions between Age Group and Training Group, (all *p*s > .19).

Results

AGE-RELATED DIFFERENCES IN TASK-SWITCHING TRAINING AS A FUNCTION OF INHIBITION AND UPDATING DEMANDS

To examine practice-induced training gains the training data were analyzed separately for the single-task group and the four task-switching groups. The single-task group data were submitted to a two-way ANOVA including the within-subjects factor Session (1, 2, 3, 4) and between-subjects factor Age group (younger adults, older adults). With regard to the task-switching groups data were submitted to a four-way ANOVA including the within-subjects factors Session (1, 2, 3, 4) and Trial type (stay, switch) and the between-subjects factors Age group (younger adults, older adults) and Group (Group 2, Group 3, Group 4, Group 5). Mean reaction times and percentage of correct trials for all training groups and sessions can be found below (Figure 9 - Figure 11).

RTs and ERs Group 1

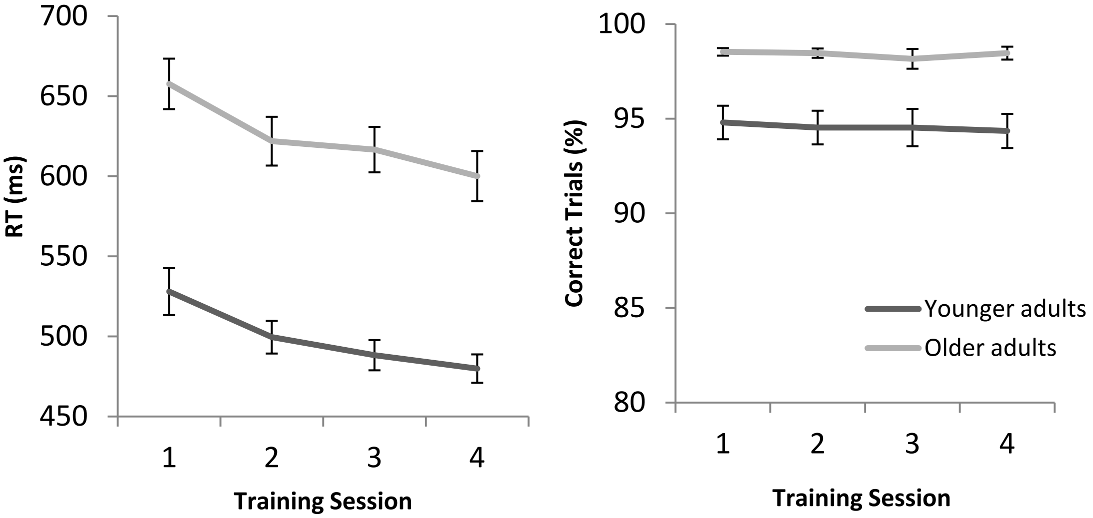


Figure 9. Mean RT (ms) and percentage of correct trials (%) as a function of Training Session (1, 2, 3, 4) and Age Group (younger adults, older adults) for Group 1 (single task – bivalent stimuli). Error bars indicate the standard error of the mean.

Latencies. Analysis of the data from Group 1 (single task – bivalent stimuli) revealed a main effect of Age group, $F(1, 31) = 55.07$, $p < .001$, $\eta^2 = .64$, indicating that older adults were generally slower than younger adults. Furthermore there was a significant main effect of Session, $F(1.85, 57.42) = 28.98$, $p < .001$, $\eta^2 = .48$, indicating a reduction in latencies from the first training session to the last training session. There was no interaction between Session and Age Group ($p = .79$)

Error rates. Analysis of error rates revealed a main of Age group, $F(1, 31) = 19.77$, $p < .001$, $\eta^2 = .39$, indicating that older adults were more accurate than younger adults.

RTs and ERs Groups 2-5

With regard to the reaction time and accuracy analysis for task-switching groups (Groups 2-5) the overall ANOVA results can be found below (Table 6). Means and error rates for all training groups and trial types can be found in the Appendices (Table 15 and Table 16).

Table 6 Overall ANOVA results for task-switching groups (Groups 2-5) based on log-transformed reaction times (Log-RT) and error rates. (ER)

	Log-RT				ER			
Effect	*df*	*F*	*p*	η^2	*df*	*F*	*p*	η^2
Age group	1, 122	128.21	<.001	.51	1, 122	30.86	<.001	.20
Group	3, 122	15.82	<.001	.28	3, 122	.52	.67	.01
Age group * Group	3, 122	1.12	.35	.03	3, 122	2.05	.11	.05
Session	2.07, 252.74	484.97	<.001	.80	1.63, 198.88	26.89	<.001	.18
Session * Age group[2]	2.07, 252.74	2.32	.10	.02	1.63, 198.88	6.53	<.05	.05
Session * Group	6.22, 252.74	1.32	.25	.03	4.89, 198.88	2.08	.07	.05
Session * Age group * Group	6.22, 252.74	1.95	.07	.05	4.89, 198.88	1.12	.35	.03
Trial type	1, 122	418.02	<.001	.77	1, 122	164.28	<.001	.57
Trial type * Age group[3]	1, 122	.02	.88	<.01	1, 122	2.20	.14	.02
Trial type * Group	3, 122	6.49	<.001	.14	3, 122	.25	.86	.01
Trial type * Age group * Group	3, 122	.93	.43	.02	3, 122	.21	.89	.01
Session * Trial type	2.38, 290.34	120.06	<.001	.50	2.80, 341.67	29.97	<.001	.20
Session * Trial type * Age group[4]	2.38, 290.34	5.65	< .05	.04	2.80, 341.67	8.90	<.001	.07
Session * Trial type * Group	7.14, 290.34	1.09	.37	.03	8.41, 341.67	1.50	.15	.04
Session * Trial type * Age group * Group	7.14, 290.34	.90	.51	.02	8.41, 341.67	.78	.63	.02

Latencies. With regard to latencies all main effects reached significance, as well as two of the two-way interactions (Trial Type * Group; Session * Trial Type) and one of the three-way interactions (Session * Trial Type * Age Group).

Error rates. With regard to error rates, with the exception of Group, all main effects reached significance, as well as two of the two-way interactions (Session * Age Group; Session * Trial Type) and one of the three-way interactions (Session * Trial Type * Age Group).

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[2] Based on mean reaction times there was an interaction between Session and Age group, $F(1.86, 227.17) = 18.37$, $p < .001$, $\eta^2 = .13$

[3] Based on mean reaction times there was an interaction between Trial type and Age group, $F(1, 122) = 9.51$, $p < .05$, $\eta^2 = .07$

[4] Based on mean reaction times this interaction was not significant ($p = .60$).

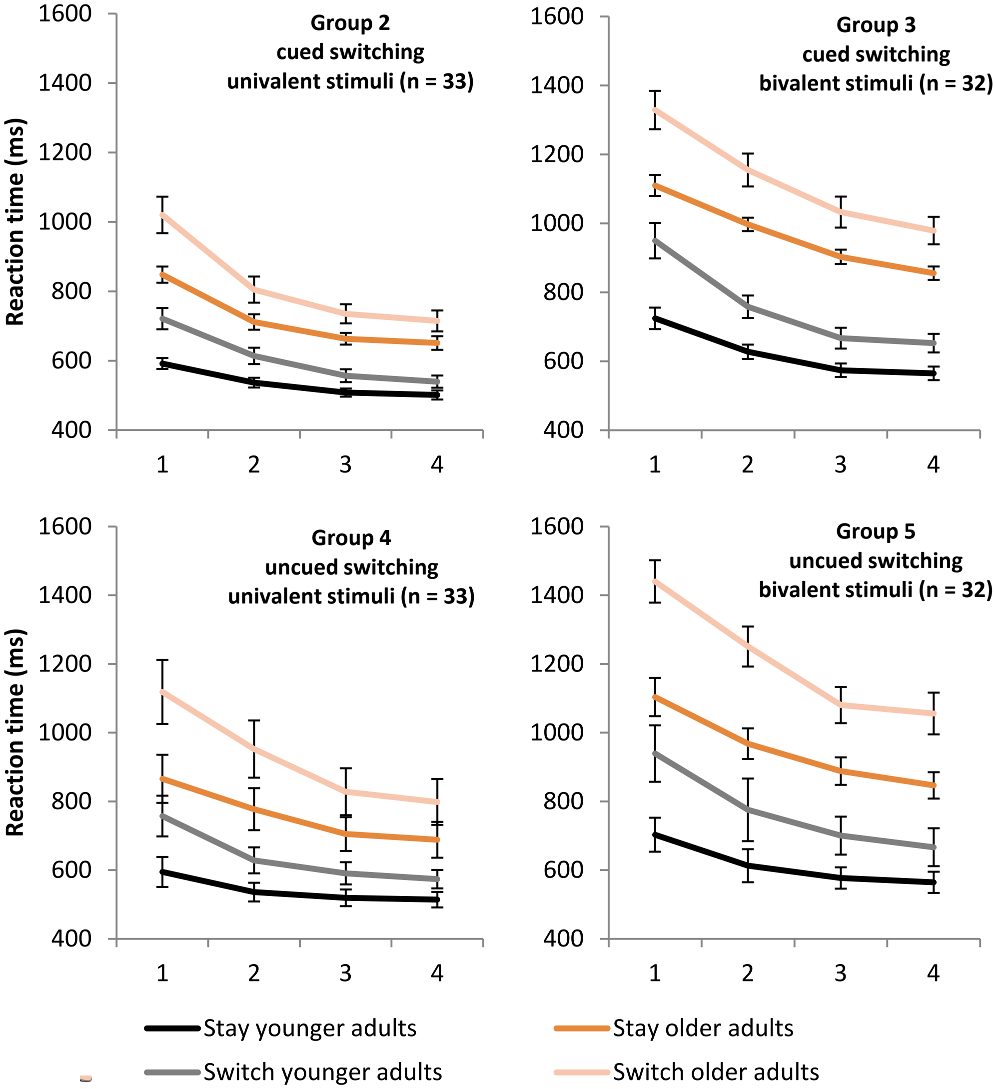
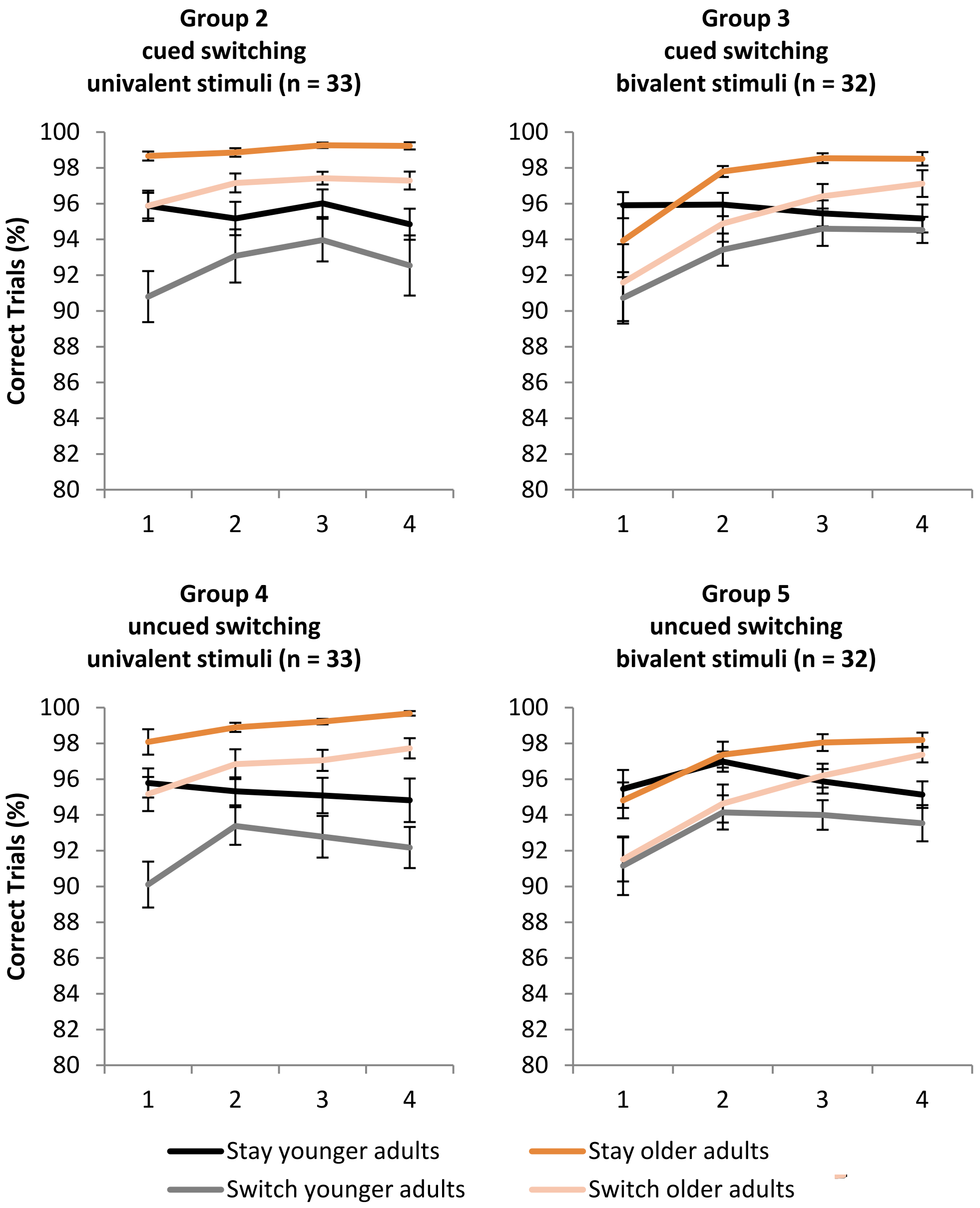


Figure 10. Mean reaction times (ms) as a function of Session (1, 2, 3, 4), Age group (younger adults, older adults), Group (Group 2, Group 3, Group 4, Group 5) and Trial type (stay, switch). Error bars refer to standard error of the mean.



Group 2
cued switching
univalent stimuli (n = 33)

Group 3
cued switching
bivalent stimuli (n = 32)

Group 4
uncued switching
univalent stimuli (n = 33)

Group 5
uncued switching
bivalent stimuli (n = 32)

Figure 11. Percentage of correct trials (%) as a function of Session (1, 2, 3, 4), Age group (younger adults, older adults), Group (Group 2, Group 3, Group 4, Group 5) and Trial type (stay, switch). Error bars refer to the standard error of the mean.

Contrasts

In the next phase follow up analyses were performed with a-priori contrasts in line with our predictions to disentangle the interactions with the factor Group. Given that no specific hypotheses were put forth with regard to the training related changes across the four training sessions analyses will concentrate on comparisons between the first and fourth training sessions. Thus, data were subjected to a four way ANOVA including the within-subjects factors Session (1, 4) and Trial Type (stay, switch) and the between-subjects factors Age Group (younger adults, older adults) and Group (Group 2, Group 3, Group 4, Group 5). As none of the comparisons yielded significant differences with regard to accuracy, only the significant results from latencies will be reported.

Contrast 1: univalent stimuli groups (Group 2 and Group 4) – bivalent stimuli groups (Group 3 and Group 5)

There was a main effect of Group, $F(1, 124) = 22.22$, $p < .001$, $\eta^2 = .15$, indicating that latencies were longer in bivalent stimuli groups than in univalent stimuli groups. Furthermore there was a significant interaction between Trial type and Group, $F(1, 124) = 8.45$, $p = .004$, $\eta^2 = .06$, indicating that the bivalent stimuli groups had larger switch costs than the univalent stimuli groups. There was also a tendency for an interaction between Session and Group, $F(1, 124) = 3.76$, $p = .055$, $\eta^2 = .03$, indicating that reaction times improved more in bivalent groups from the first session to the last. However there was no interaction between Session, Trial Type and Group ($p > .12$), indicating that switch costs reduced equally in both univalent and bivalent groups from the first session to the last session. There was also an interaction between Session, Age Group and Group, $F(1, 124) = 4.20$, $p = .042$, $\eta^2 = .03$, indicating that reaction times improved more in bivalent groups from the first session to the last session for younger adults compared to older adults. Other interactions with Age Group did not reach significance (all *p*s > .10).

Contrast 2: cued switching groups (Group 2 and Group 3) – uncued switching groups (Group 4 and Group 5)

There was a significant interaction between Trial type and Group, *F*(1, 124) = 9.70, $p = .002$, $\eta^2 = .07$, indicating that the uncued switching groups had larger switch costs than the cued switching groups. However, neither the main effect for Group nor any of the interactions reached significance (all *p*s > .10).

Contrast 3: univalent stimuli groups: cued switching group (Group 2) – uncued switching group (Group 4)

There was a tendency for an interaction between Trial type and Group, *F*(1, 124) = 3.75, $p = .055$, $\eta^2 = .03$, indicating that the uncued univalent switching groups had larger switch costs than the cued univalent switching groups. However neither the main effect for Group, nor any other interactions reached significance (all *p*s > .42).

Contrast 4: bivalent stimuli groups: cued switching group (Group 3) – uncued switching group (Group 5)

There was a significant interaction between Trial type and Group, *F*(1, 124) = 5.95, $p = .016$, $\eta^2 = .05$, indicating that the uncued bivalent switching groups had larger switch costs than the cued bivalent switching groups. However neither the main effect for Group, nor any other interactions reached significance (all *p*s > .10).

General Summary

From the above results the following conclusions can be drawn. Reaction times reduced in all training groups and older adults were generally slower than younger adults. Switching costs also reduced in all task-switching training groups. Although the amount of switch costs or its reduction from the first to the last session did not differ between younger and older adults, there was a difference in the amount of RT reduction from the first to the last session within bivalent groups, indicating a larger reduction in younger adults in those groups. Furthermore, task-switching groups with bivalent stimuli had longer latencies and larger switch costs than task-switching groups with univalent stimuli. Also, uncued switching groups had longer latencies and larger switch costs than the cued switching groups. Furthermore, uncued-univalent switching groups had larger switch costs than the cued-univalent switching groups and uncued-bivalent switching groups had larger switch costs than the cued-bivalent switching groups. Finally, the amount of reduction in switch costs did not differ between any of the groups and there were no interactions with age. With regard to error rates, we can conclude that older adults were generally more accurate than younger adults, and that in overall, accuracy improved from the first session to the fourth.

NEAR TRANSFER OF TASK-SWITCHING TRAINING

To assess near transfer to a similar switching task, data were submitted to a four-way ANOVA including the within-subjects factors Session (pretest, posttest) and Trial type (single, stay, switch) and the between-subjects factors Age group (younger adults, older adults) and Training group (Group 1, Group 2, Group 3, Group 4, Group 5). Mean reaction times and percentage of correct trials for all training groups and sessions are displayed in Table 7and Table 8. As age differences with regard to mixing and switch costs as well as speed of responding was entirely similar at posttest to that of the results at pretest, we will not report those effects again, but will focus on interactions with the factors Training group and Session.

Table 7 *Mean* (*M*) reaction times and standard deviations (*SD*) for each trial type (single, stay, switch) as well as mixing and switch costs for younger and older adults separately for each training group at pretest and posttest.

	Training group				
	Group 1 single (*n*=33)	Group 2 cued/univalent *n*=(33)	Group 3 cued/bivalent *n*=(32)	Group 4 uncued/univalent *n*=(33)	Group 5 uncued/bivalent *n*=(32)
Trial type	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Younger				
	Pretest				
Single	511 (49)	519 (47)	521 (71)	513 (78)	525 (58)
Stay	597 (100)	599 (106)	590 (115)	602 (182)	599 (99)
Switch	676 (139)	676 (150)	677 (135)	695 (231)	696 (134)
Mixing cost	125 (96)	118 (98)	113 (80)	135 (137)	122 (76)
Switching cost	79 (53)	77 (63)	87 (53)	93 (61)	97 (57)
	Posttest				
Single	469 (45)	472 (44)	474 (66)	481 (68)	480 (48)
Stay	523 (55)	509 (68)	501 (77)	526 (124)	514 (61)
Switch	582 (87)	561 (107)	566 (101)	598 (181)	574 (98)
Mixing cost	84 (50)	64 (53)	59 (50)	81 (94)	64 (49)
Switching cost	59 (46)	52 (44)	65 (35)	72 (64)	60 (42)
	Older				
	Pretest				
Single	680 (68)	721 (138)	659 (102)	701 (79)	689 (64)
Stay	913 (155)	940 (231)	883 (179)	925 (176)	907 (141)
Switch	1010 (199)	1047 (292)	978 (203)	1033 (204)	1007 (151)
Mixing cost	282 (128)	272 (144)	271 (140)	278 (149)	268 (119)
Switching cost	96 (106)	106 (108)	95 (59)	108 (65)	100 (84)
	Posttest				
Single	613 (70)	678 (108)	671 (110)	669 (84)	660 (79)
Stay	787 (128)	829 (204)	744 (159)	832 (151)	782 (132)
Switch	902 (157)	926 (236)	835 (202)	934 (194)	897 (146)
Mixing cost	231 (101)	199 (137)	118 (117)	214 (98)	180 (83)
Switching cost	115 (66)	97 (72)	91 (71)	102 (71)	115 (84)

Table 8 *Mean* (*M*) percentage correct trials and standard deviations (*SD*) for each trial type (single, stay, switch) for younger and older adults separately for each training group at pretest and posttest.

	Training group				
	Group 1 single (*n*=33)	Group 2 cued/univalent *n*=(33)	Group 3 cued/bivalent *n*=(32)	Group 4 uncued/univalent *n*=(33)	Group 5 uncued/bivalent *n*=(32)
Trial type	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
			Younger		
			Pretest		
Single	96 (3.42)	95 (2.77)	97 (2.50)	95 (3.86)	97 (2.84)
Stay	96 (3.11)	95 (3.18)	96 (2.42)	96 (2.57)	97 (2.68)
Switch	94 (5.48)	94 (3.57)	92 (5.56)	91 (3.26)	94 (3.70)
			Posttest		
Single	95 (2.87)	95 (3.76)	95 (3.77)	94 (5.12)	94 (4.18)
Stay	95 (3.12)	93 (4.14)	95 (3.32)	94 (3.63)	95 (3.41)
Switch	92 (4.88)	93 (4.53)	95 (2.90)	90 (5.87)	95 (3.54)
			Older		
			Pretest		
Single	98 (1.43)	97 (2.19)	97 (1.81)	98 (1.55)	98 (1.61)
Stay	97 (2.66)	96 (3.31)	96 (4.57)	96 (2.51)	96 (3.36)
Switch	95 (3.66)	94 (4.98)	94 (4.87)	94 (3.76)	94 (4.81)
			Posttest		
Single	99 (1.37)	99 (1.20)	97 (4.25)	98 (2.66)	99 (1.32)
Stay	98 (2.07)	96 (2.93)	98 (1.73)	97 (2.59)	98 (1.61)
Switch	96 (4.22)	95 (3.51)	97 (2.98)	96 (3.09)	98 (1.75)

Latencies. There was a significant main effect of Session, $F(1, 153) = 322.29$, $p < .001$, $\eta_p^2 = .68$. There was also an interaction between Session and Age group, $F(1, 153) = 4.72$, $p < .05$, $\eta_p^2 = .03$, indicating that the reduction in latencies from pretest to posttest was larger for younger adults than for older adults[5] (see Figure 12). Furthermore, there was also an interaction between Session and Trial type, indicating that mixing costs reduced from pretest to posttest, $F(1, 153) = 75.45$, $p < .001$, $\eta_p^2 = .33$, but switch costs did not reduce from pretest to posttest ($p = .62$).

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[5] However this interaction was not significant based on mean reaction times ($p = .29$)

More importantly we were interested in the interactions with Training group. There was neither a main effect of Training group (p = .88), nor an interaction between Session and Training group (p = .69). However there was a significant interaction between Session, Training group and Trial type, $F(8, 306) = 2.61$, $p < .05$, $\eta_p^2 = .06$, as well as a tendency for an interaction between Session, Training group, Trial type and Age group, $F(8, 306) = 1.79$, $p = .08$, $\eta_p^2 = .05$. Therefore, in the next step specific contrasts were set up to disentangle the above interactions.

Contrast 1: single-task group (Group 1) – task-switching groups (Group 2-5)

The first contrast revealed that there was a larger reduction in mixing costs from pretest to posttest in the task-switching groups than in the single-task group , $F(1, 154) = 6.33$, $p < .05$, $\eta_p^2 = .04$. However, age did not modulate this reduction (p = .27). Furthermore, there were no differences in the reduction of switch costs from pretest to posttest between the task-switching groups and the single-task group (p = .26).

Contrast 2: univalent stimuli groups (Group 2 and Group 4) – bivalent stimuli groups (Group 3 and Group 5)

The second contrast revealed that there was a larger reduction in mixing costs from pretest to posttest in the bivalent stimuli groups than in the univalent stimuli groups, $F(1, 154) = 5.10$, $p < .05$, $\eta_p^2 = .03$. Furthermore, this reduction was larger for older adults than for younger adults, $F(1, 154) = 4.02$, $p < .05$, $\eta_p^2 = .003$. However, there were no differences in the reduction of switch costs (p = .80) from pretest to posttest between the bivalent stimuli groups and the univalent stimuli groups.

Contrast 3: univalent stimuli groups: cued switching group (Group 2) – uncued switching group (Group 4)

The third contrast revealed that there was no difference in the reduction of mixing costs from pretest to posttest between the univalent cued switching group and the univalent uncued switching groups (p = .83). Furthermore, there was also no difference in the reduction of switch costs (p = .90) from pretest to posttest between the univalent cued switching group and the univalent uncued switching groups.

Contrast 4: bivalent stimuli groups: cued switching group (Group 3) – uncued switching group (Group 5)

The fourth contrast revealed that there was a tendency for a difference in the reduction of mixing costs from pretest to posttest between Group 3 and Group 5 , $F(1, 154) = 3.17$, $p = .08$, $\eta_p^2 = .02$, indicating a larger reduction of mixing costs in the bivalent-cued switching group (Group 3) than in the bivalent-uncued switching group (Group 5). Furthermore, this was modulated by age, $F(1, 154) = 4.03$, $p < .05$, $\eta_p^2 = .03$, indicating a larger reduction of mixing costs in older adults than in younger adults. However, there was no difference in the reduction of switch costs (p = .99) from pretest to posttest between the bivalent-cued switching group and the bivalent-uncued switching groups.

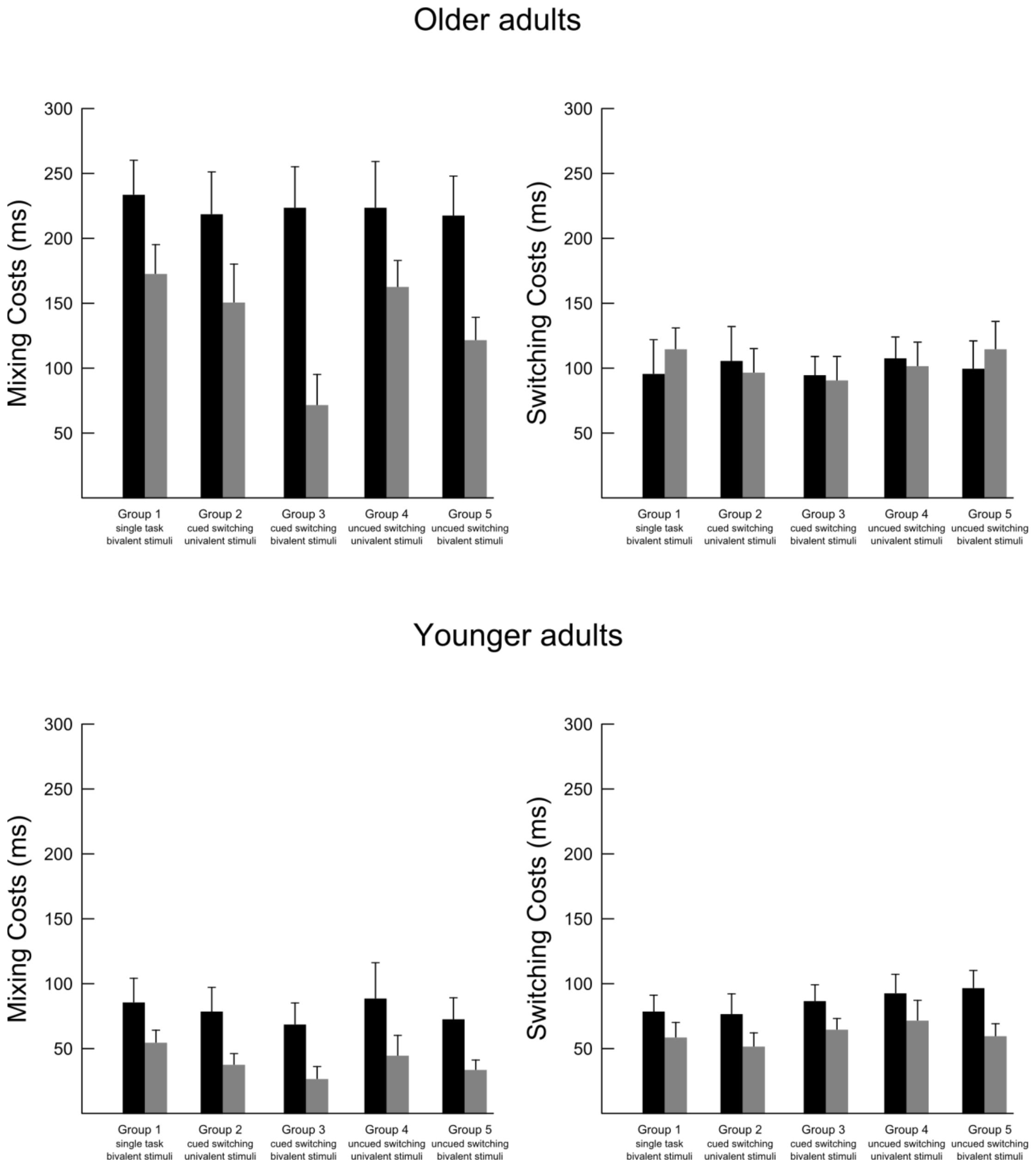

Figure 12. Mixing costs and switch costs, based on mean reaction times, in both age groups (younger adults, older adults) separately for each group (Group 1-5). Error bars refer to the standard error of the mean.

Error rates. There was a significant main effect of Age group, $F(1, 153) = 33.89$, $p < .001$, $\eta_p^2 = .18$, indicating that older adults were more accurate than younger adults.

There was also an interaction between Session and Age group, $F(1, 153) = 36.75$, $p < .001$, $\eta_p^2 = .19$, indicating that while older adults got more accurate from pretest to posttest, younger adults got less accurate. Furthermore, there was a significant main effect of Trial type, $F(2, 153) = 66.78$, $p < .001$, $\eta_p^2 = .31$, indicating that stay trials were less accurate than single trials, $F(1, 153) = 14.16$, $p < .001$, $\eta_p^2 = .09$, and switch trials were less accurate than stay trials, $F(1, 153) = 65.74$, $p < .001$, $\eta_p^2 = .30$. There was also an interaction between Session and Trial type, $F(2, 306) = 9.52$, $p < .001$, $\eta_p^2 = .06$, indicating that switch costs reduced from pretest to posttest, $F(1, 153) = 17.30$, $p < .001$, $\eta_p^2 = .10$, but mixing costs did not reduce from pretest to posttest ($p = .88$). Moreover, there was an interaction between Trial type and Age group as well, $F(2, 306) = 3.21$, $p < .05$, $\eta_p^2 = .02$. Finally, there was an interaction between Trial type, Session and Training group, indicating a larger reduction of mixing costs in bivalent groups than in univalent groups from pretest to posttest, $F(1, 156) = 8.94$, $p < .05$, $\eta_p^2 = .05$.

Summary. The results thus showed that when task-switching groups are pooled together, there was a larger reduction in mixing costs from pretest to posttest in the task-switching groups than in the single-task group. However, there were no differences in the reduction of switch costs from pretest to posttest between the task-switching groups and the single-task group.

Analyzing near-transfer effects separately for younger and older adults

In the next step the above analyses were carried out separately for younger adults and older adults. Thus data were submitted to three-way ANOVAs including the within-subjects factors Session (pretest, posttest) and Trial type (single, stay, switch) and the between-subjects factor Training group (Group 1, Group 2, Group 3, Group 4, Group 5).

Younger adults

Latencies. There was a significant main effect of Session, $F(1, 76) = 216.39$, $p < .001$, $\eta_p^2 = .74$. There were also reliable mixing costs, $F(1, 76) = 115.29$, $p < .001$, $\eta_p^2 = .60$, and switch costs, $F(1, 76) = 350.32$, $p < .001$, $\eta_p^2 = .82$. Furthermore, there was also an interaction between both contrasts, indicating that mixing costs reduced from pretest to posttest, $F(1, 76) = 25.99$, $p < .001$, $\eta_p^2 = .26$, and that switch costs also reduced from pretest to posttest $F(1, 76) = 10.98$, $p < .001$, $\eta_p^2 = .13$. There was no main effect of Training group ($p = .996$). As previously we were more interested in the interactions with Training group. However, there was neither an interaction between Session and Training group ($p = .64$), nor an interaction between Session, Training group and Trial type ($p = .95$).

Error rates. There was a significant main effect of Session, $F(1, 76) = 10.10$, $p < .05$, $\eta_p^2 = .12$. There was also a significant main effect of Trial type, $F(2, 152) = 28.24$, $p < .001$, $\eta_p^2 = .27$, indicating reliable switch costs, $F(1, 76) = 31.61$, $p < .001$, $\eta_p^2 = .29$. Furthermore, there was also an interaction between Session and Trial type, indicating a reduction in accuracy for stay trials relative to switch trials from pretest to posttest $F(1, 76) = 3.47$, $p < .05$, $\eta_p^2 = .15$. There was no main effect of Training group ($p = .33$). With regard to the interactions with Training group, there was an interaction between Trial type and Training group, $F(8, 152) = 2.33$, $p < .05$, $\eta_p^2 = .11$, and an interaction between Session, Training group and Trial type, $F(8, 152) = 2.26$, $p < .05$, $\eta_p^2 = .11$.

To disentangle the interactions with Training group we set up contrasts as before. There was a tendency for a larger switch cost reductions in task-switching groups than single-task groups $F(1, 76) = 3.48$, $p = .07$, $\eta_p^2 = .11$. There was also a tendency for univalent groups to be more accurate than bivalent groups, $F(1, 76) = 3.22$, $p = .08$, $\eta_p^2 = .04$. Also, there was larger reduction of switch costs, $F(1, 76) =5.78$, $p < .05$, $\eta_p^2 = .07$ as well as mixing costs, $F(1, 76) = 4.50$, $p < .05$, $\eta_p^2 = .05$, in bivalent groups compared to univalent groups. Furthermore, there was a tendency for larger specific switch costs in uncued groups compared to cued groups, $F(1, 76) = 3.66$, $p = .06$, $\eta_p^2 = .04$. Finally, there was also a tendency for bivalent-cued groups to be more accurate than bivalent-uncued groups, $F(1, 76) = 3.93$, $p = .05$, $\eta_p^2 = .04$, and bivalent-cued groups had lower switch costs, $F(1, 76) = 8.81$, $p < .005$, $\eta_p^2 = .10$, than bivalent-uncued groups.

Older adults

Latencies. There was a significant main effect of Session, $F(1, 77) = 117.19$, $p < .001$, $\eta_p^2 = .60$, indicating a reduction in latencies from pretest to posttest. There was also a significant main effect of Trial type, $F(2, 154) = 467.95$, $p < .001$, $\eta_p^2 = .86$, indicating reliable mixing costs, $F(1, 77) = 365.19$, $p < .001$, $\eta_p^2 = .83$, as well as switch costs, $F(1, 77) = 243.87$, $p < .001$, $\eta_p^2 = .76$. Furthermore, there was also an interaction between Session and Trial type, $F(2, 154) = 30.96$, $p < .001$, $\eta_p^2 = .29$, indicating that mixing costs reduced from pretest to posttest, $F(1, 77) = 50.01$, $p < .001$, $\eta_p^2 = .39$. There was no main effect of Training group ($p = .76$). However, there was an interaction between Session, Training group and Trial type, $F(8, 154) = 3.44$, $p = .001$, $\eta_p^2 = .15$. In order to break down the interaction with Training group for the latency data, in the next step specific contrasts were set up, similar to that of the pooled analysis.

Contrast 1: single-task group (Group 1) – task-switching groups (Group 2-5)

The first contrast revealed that there was a larger reduction in mixing costs from pretest to posttest in the task-switching groups than in the single-task group , $F(1, 77) = 5.87$, $p < .05$, $\eta_p^2 = .07$. There were no differences in the reduction of switch costs from pretest to posttest between the task-switching groups and the single-task group ($p = .32$).

Contrast 2: univalent stimuli groups (Group 2 and Group 4) – bivalent stimuli groups (Group 3 and Group 5)

The second contrast revealed that there was a larger reduction in mixing costs from pretest to posttest in the bivalent stimuli groups than in the univalent stimuli groups, $F(1, 77) = 7.89$, $p < .05$, $\eta_p^2 = .09$. There were no differences in the reduction of switch costs ($p = .53$) from pretest to posttest between the bivalent stimuli groups and the univalent stimuli groups.

Contrast 3: univalent stimuli groups: cued switching group (Group 2) – uncued switching group (Group 4)

The third contrast revealed that there was no difference in the reduction of mixing costs from pretest to posttest between the univalent cued switching group and the univalent uncued switching groups ($p = .81$). There was also no difference in the reduction of switch costs ($p = .81$) from pretest to posttest between the univalent cued switching group and the univalent uncued switching groups.

Contrast 4: bivalent stimuli groups: cued switching group (Group 3) – uncued switching group (Group 5)

The fourth contrast revealed that there was a difference in the reduction of mixing costs from pretest to posttest between Group 3 and Group 5 , $F(1, 77) = 6.19$, $p < .05$, $\eta_p^2 = .07$, indicating a larger reduction of mixing costs in the bivalent cued switching group (Group 3) than in the bivalent uncued switching group (Group 5). There was no difference in the reduction of switch costs ($p = .46$) from pretest to posttest between the bivalent cued switching group and the bivalent uncued switching groups.

Error rates. There was a significant main effect of Session, $F(1, 77) = 32.59$, $p < .001$, $\eta_p^2 = .30$, indicating an increase in accuracy from pretest to posttest. There was also a significant main effect of Trial type, $F(2, 154) = 43.38$, $p < .001$, $\eta_p^2 = .36$, indicating reliable switch costs, $F(1, 77) = 36.30$, $p < .001$, $\eta_p^2 = .32$, as well as mixing costs, F(1,

77) = 22.32, p < .001, η_p^2 = .23. Furthermore, there was also an interaction between Session and Trial type, F(1.55, 154) = 6.10, p < .005, η_p^2 = .07, indicating an increase in accuracy for switch trials relative to stay trials from pretest to posttest F(1, 77) = 11.06, p = .001, η_p^2 = .13. There was no main effect of Training group (p = .49).

Summary. The results from the separate analyses thus showed that there was a larger reduction in mixing costs from pretest to posttest in the task-switching groups relative to the single-task group only in older adults. With regard to the reduction of switch costs from pretest to posttest, there were no differences between the task-switching groups and the single-task group or between the task-switching groups in either the younger adults or in the older adults.

Furthermore, with regard to the older adults, comparing the task-switching groups to each other, the results indicated that there was a larger reduction in mixing costs from pretest to posttest in the bivalent stimuli groups than in the univalent stimuli groups. The results also indicated a larger reduction of mixing costs in the bivalent cued switching group (Group 3) than in the bivalent uncued switching group (Group 5).

FAR TRANSFER

As mentioned previously in the method section each theoretical construct was measured on multiple tests. As a more reliable assessment of far transfer effects can be achieved by using composite measures combining several tests, firstly, data from the different tests was examined whether they can be collapsed together for each construct. We performed exploratory factor analysis with the variables digit backward span, counting span, reading span, Raven, 2-back (hits-false alarms), AX-CPT updating (ER; AY vs. BXR), AX-CPT interference (ER; AX+BY vs. AY+BX), Color Stroop interference (RT and ER; incongruent - neutral), Number Stroop interference (RT and ER; incongruent - neutral). The BOMAT was not included, as due to printing error data from younger adults couldn’t be evaluated. The 3-back was also not included, as we assessed it only in younger adults. However, apart from a factor for working memory (including the variables: digit backward span, counting span, reading span), other factors couldn’t be meaningfully interpreted (Table 9 - Table 12). Therefore only these three tests were aggregated, the other tests were analyzed separately. The total variance explained by the model was 66.85%.

Table 9. Principal Component Analysis, Rotated Component Matrix.

	Component				
	1	2	3	4	5
Digit Backward	.67	.30	-.04	-.04	.12
Counting Span	.70	-.05	.28	.18	-.23
Reading Span	.85	-.02	.03	-.02	.08
Raven	.23	.70	.19	.19	.00
2-back	.11	.29	.60	.34	-.02
Color Stroop RT	.06	-.84	.01	.14	.01
Number Stroop RT	.06	.00	.04	-.03	.92
Number Stroop ER	.06	-.01	-.08	.85	-.04
Color Stroop ER	.14	.45	-.32	-.35	-.34
AX-CPT Interference	-.08	-.22	-.62	.36	.31
AX-CPT Updating	.08	-.16	.76	-.10	.22

Table 10. Correlations Between the Psychometric Tests in the Cognitive Battery for both Age Groups. Correlations marked in red refer to indicators for one factor.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Digit Backward Span	1												
2. Counting Span	.24**	1											
3. Reading Span	.37**	.45**	1										
4. Raven	.27**	.24**	.17**	1									
5. 2-back	.17*	.20*	.14	.21**	1								
6. AX-CPT Updating	.03	.18*	.07	.09	.21**	1							
7. AX-CPT Interference	-.09	-.15	-.11	-.14	-.25**	-.26**	1						
8. Color Stroop RT	-.13	-.01	.00	-.41**	-.11	.12	.20*	1					
9. Number Stroop RT	.05	-.08	.11	-.06	.02	.16*	.12	.04	1				
10. Color Stroop ER	.16*	-.04	.06	.12	-.06	-.20*	-.14	-.30**	-.18*	1			
11. Number Stroop ER	.01	.12	.06	.05	.12	-.05	.14	.12	.03	-.10	1		
12. Mixing Cost	-.22**	-.21**	-.13	-.52**	-.20**	.04	.16*	.25**	.09	-.21**	-.16*	1	
13. Switching Cost	-.05	-.03	-.01	-.08	-.12	-.04	.02	.08	.14	-.12	-.08	.43**	1

** p < .01 (two-tailed), * p < .05 (two-tailed)

Table 11. Correlations Between the Psychometric Tests in the Cognitive Battery for Younger Adults. Correlations marked in red refer to indicators for one factor.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Digit Backward Span	1												
2. Counting Span	.20	1											
3. Reading Span	.34**	.44**	1										
4. Raven	.01	.15	.20	1									
5. 2-back	.15	.22	.13	.33**	1								
6. AX-CPT Updating	.09	.19	.10	.25	.17	1							
7. AX-CPT Interference	-.10	-.25*	-.13	-.13	-.28*	-.49**	1						
8. Color Stroop RT	.09	-.03	-.03	-.17	-.10	.05	-.08	1					
9. Number Stroop RT	.02	-.10	.15	-.05	-.11	.08	-.14	-.01	1				
10. Color Stroop ER	.19	.03	.24*	-.10	.01	-.10	-.08	-.07	.11	1			
11. Number Stroop ER	-.06	-.01	.14	-.05	.22	-.03	-.08	.21	-.12	-.17	1		
12. Mixing Cost	-.03	-.14	-.04	-.01	-.29**	-.04	.23*	.04	.26*	-.13	.04	1	
13. Switching Cost	.05	-.07	.07	.07	-.11	-.01	.16	.00	.17	-.19	.08	.66**	1

** p < .01 (two-tailed), * p < .05 (two-tailed)

Table 12. Correlations Between the Psychometric Tests in the Cognitive Battery for Older Adults. Correlations marked in red refer to indicators for one factor.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Digit Backward Span	1.00												
2. Counting Span	.19	1.00											
3. Reading Span	.41**	.46**	1.00										
4. Raven	.15	.14	.23*	1.00									
5. 2-back	.19	.17	.16	.28*	1.00								
6. AX-CPT Updating	.01	.21	.05	.15	.25*	1.00							
7. AX-CPT Interference	-.08	-.10	-.10	-.21	-.26*	-.17	1.00						
8. Color Stroop RT	-.04	.17	.06	-.04	-.13	.14	.28*	1.00					
9. Number Stroop RT	.09	-.06	.10	-.03	.10	.20	.19	.03	1.00				
10. Color Stroop ER	.06	-.16	-.07	-.04	-.13	-.24*	-.15	-.29**	-.28*	1.00			
11. Number Stroop ER	.03	.20	-.02	.01	.04	-.05	.25*	.17	.11	-.09	1.00		
12. Mixing Cost	-.11	-.11	-.20	-.31**	-.17	.06	.13	-.03	-.01	-.11	-.26*	1.00	
13. Switching Cost	-.07	.03	-.05	-.06	-.13	-.06	-.03	.05	.12	-.07	-.15	.36**	1.00

** p < .01 (two-tailed), * p < .05 (two-tailed)

For analyzing far-transfer measures both reaction times and error rates were submitted to ANOVAs with the between-subjects factors Age group (younger adults, older adults) and Training group (Group 1, Group 2, Group 3, Group 4, Group 5) and the within-subject factor Session (pretest, posttest). Group contrasts were similar to that of the near transfer analyses. In the case of the Stroop and AXCPT data an additional within-subject factor for Trial Type (Stroop: neutral/congruent/incongruent; AXCPT: AX, AY, BX, BY) was added, with specified contrasts for interference costs (Stroop: -1 0 1; AXCPT: 1 -1 -1 1) and updating (AXCPT: 0 -1 1 0). Error rates and reaction times data for trial types and costs can be found in the Appendices (Table 17 - Table 28).

AX-CPT

With regard to reaction times, there was a main effect of Session, $F(1, 162) = 18.90$, $p < .001$, $\eta_p^2 = .10$, indicating better performance at posttest. Furthermore, there were significant interference costs, $F(1, 154) = 346.86$, $p < .001$, $\eta_p^2 = .68$, reflected by better performance on non-interference trials than interference trials, but it did not interact with Session, ($p > .81$). There was also a significant effect for the Updating contrast, $F(1, 154) = 370.81$, $p < .001$, $\eta_p^2 = .70$, indicating better performance on BX trials as compared to AY trials, but it also did not interact with Session, ($p > .10$). Group contrasts did not reveal differences between single and task-switching groups in any of the above comparisons, (all ps > .33), nor did the contrasts between bivalent and univalent groups, (all ps > .25), or the contrasts between cued and uncued groups, (all ps > .33). With regard to age differences, there was a tendency for larger interference effects in older adults compared to younger adults, $F(1, 161) = 2.93$, $p = .09$, $\eta_p^2 = .02$, but there were no age differences in Updating, ($p > .24$). There was no interaction of Session and

Age Group, (p > .67). Finally, there were no interactions of Age Group and Session in any of the group contrasts. (all ps > .19).

With regard to error rates, there was no main effect of Session (p = .62). There were significant interference costs, $F(1, 162) = 123.75$, $p < .001$, $\eta_p^2 = .43$, indicating higher error rates in interference trials compared to non-interference trials. There was also a significant effect for the Updating contrast, $F(1, 162) = 33.50$, $p < .001$, $\eta_p^2 = .17$, indicating higher error rates in AY trials compared to BX trials. With regard to age differences, there was an interaction of Session and Age Group, $F(1, 161) = 13.43$, $p < .001$, $\eta_p^2 = .08$, indicating that error rates decreased in older adults from pretest to posttest. Age Group also interacted with the Updating contrast, $F(1, 161) = 8.47$, $p < .005$, $\eta_p^2 = .05$, indicating higher error rates in younger adults on AY trials, and there was a tendency for an interaction of Age Group, Updating and Session, $F(1, 154) = 2.88$, $p = .09$, $\eta_p^2 = .02$, indicating that while younger adults had a decrease in AY performance, $t(80) = 4.29$, $p < .001$, older adults performance increased on AY trials from pretest to posttest, $t(81) = 2.55$, $p < .05$. Finally, there was a tendency for an interaction of Age Group, Updating and Session in the group contrast for single and task-switching group, $F(1, 154) = 2.88$, $p = .09$, $\eta_p^2 = .02$, indicating that in older adults there was a tendency for an increase in accuracy for BX trials in task-switching groups, $t(63) = 1.78$, $p = .08$.

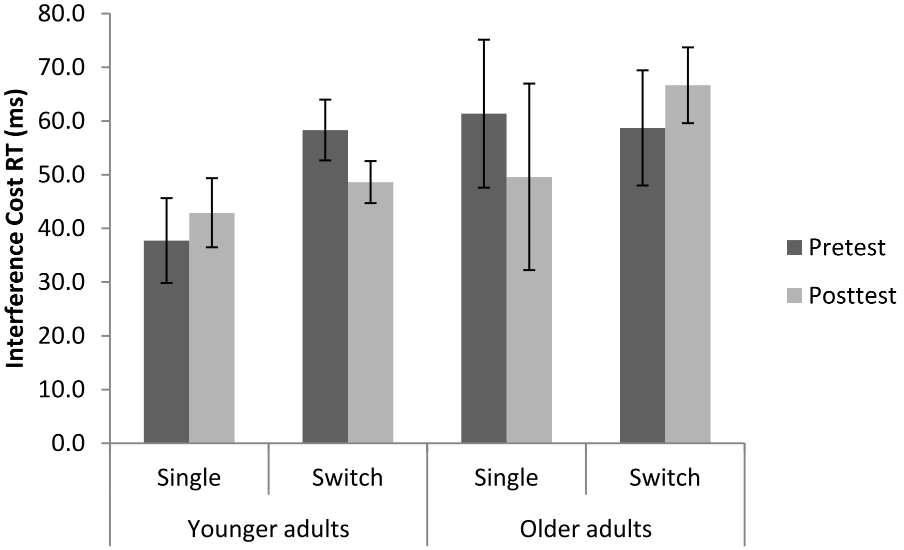

Figure 13. AX-CPT Interference costs (RT) as a function of Training group (single, switch), Age group (younger adults, older adults) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

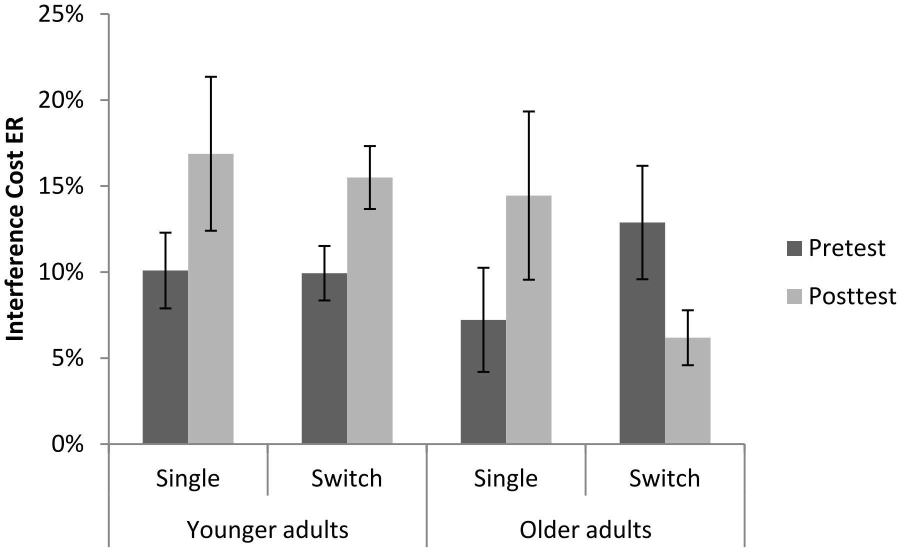

Figure 14. AX-CPT Interference costs (ER) as a function of Training group (single, switch), Age group (younger adults, older adults) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

Inhibitory Control (Color Stroop, Number Stroop)

Color Stroop

With regard to reaction times, there was a significant interference effect, $F(1, 162) = 200.87$, $p < .001$, $\eta^2 = .55$, however it did not interact with Session ($p = .81$). Group contrasts did not modulate the interactions of Trial Type and Session (all *p*s > .12). With regard to age differences, there was an interaction between Age group and Trial type, $F(1, 161) = 50.06$, $p < .001$, $\eta^2 = .24$, indicating that older adults had larger interference costs than younger adults. There was no interactions of Session, Age Group and Trial Type ($p = .63$). Group contrasts did not modulate any of the above interactions with Age Group (all *p*s > .50).

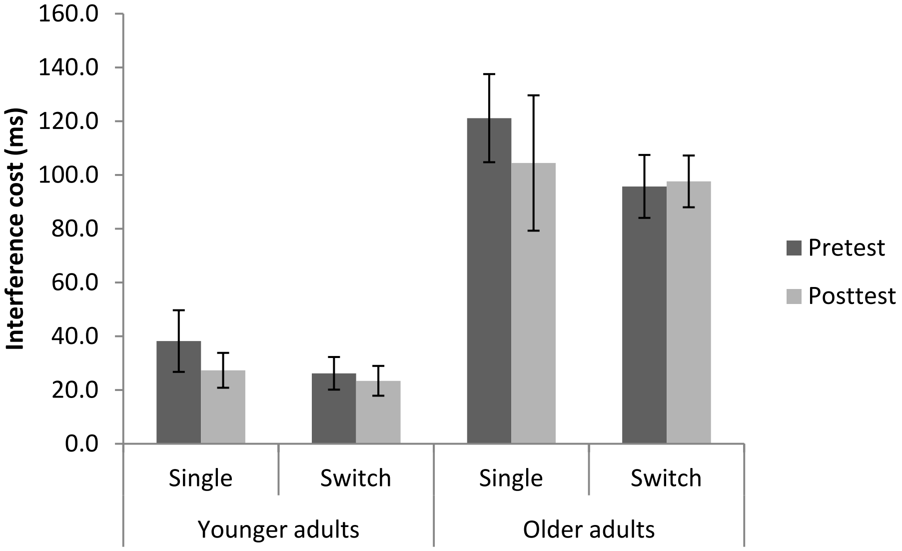

Figure 15 Color stroop mean interference costs (ms) as a function of Age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

With regard to error rates, there was a significant interference effect, $F(1, 162) = 31.55$, $p < .001$, $\eta^2 = .16$, which decreased from pretest to posttest, $F(1, 162) = 9.08$, $p < .005$, $\eta^2 < .05$. The group contrasts did not modulate the interactions of Trial Type and

Session (all *p*s > .42). With regard to age differences, there was an interaction between Age group and Trial type, $F(1, 161) = 5.95$, $p < .05$, $\eta^2 = .04$, indicating that older adults had larger interference costs than younger adults. There was no interaction of Session, Age Group and Trial Type ($p = .10$). Group contrasts did not modulate any of the above interactions with Age Group (all *p*s > .46).

Number Stroop

With regard to reaction times, there was a significant interference effect, $F(1, 162) = 60.52$, $p < .001$, $\eta^2 = .27$, however it did not interact with Session ($p = .31$). The group contrast comparing single-task and task-switching groups modulated the interaction of Trial Type and Session, $F(1, 158) = 3.89$, $p = .05$, $\eta^2 = .02$, indicating a tendency for a decrease in interference cost in task-switching groups from pretest to posttest, $t(130)=1.908$, $p = .06$. With regard to age differences, there was no interaction between Age group and Trial type ($p < .79$). There was no interactions of Session, Age Group and Trial Type ($p = .42$). Group contrasts did not modulate any of the above interactions with Age Group (all *p*s > .49).

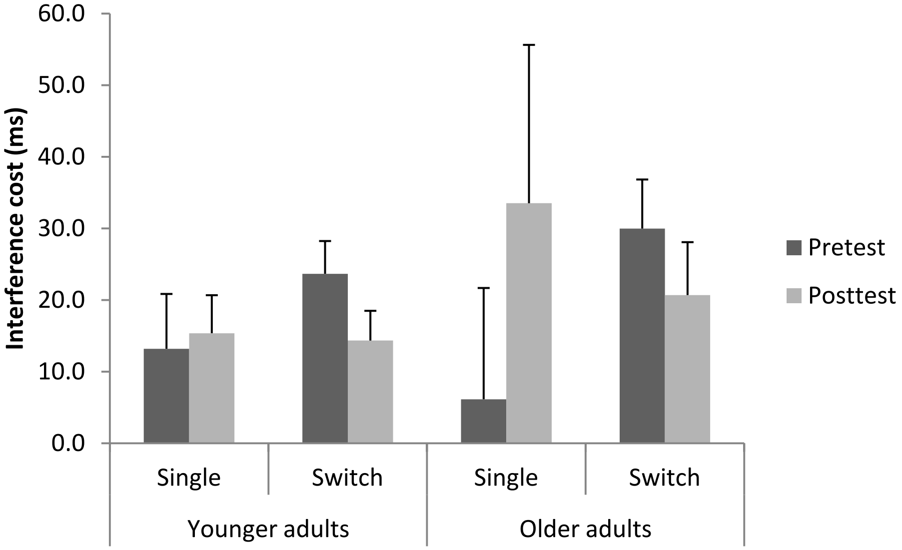

Figure 16 Number stroop mean interference costs (ms) as a function of Age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

With regard to error rates, there was a significant interference effect, $F(1, 162) = 102.91$, $p < .001$, $\eta^2 = .39$, which decreased from pretest to posttest, $F(1, 162) = 7.61$, $p < .05$, $\eta^2 < .04$. The group contrasts did not modulate the interactions of Trial Type and Session (all *p*'s > .60). With regard to age differences, there was no interaction between Age group and Trial type ($p = .46$). There was no interaction of Session, Age Group and Trial Type ($p = .50$). Group contrasts did not modulate any of the above interactions with Age Group (all *p*s > .14).

2-back

There was a main effect of Session, $F(1, 160) = 6.07$, $p < .05$, $\eta_p^2 = .04$, indicating that the groups improved from pretest to posttest, however group contrasts did not reveal differences between groups in the improvements from pretest to posttest (all *ps* > .17). With regard to age differences, there was no interaction between Age Group and Session

(p = .70). Group contrasts did not modulate the interaction of Age Group and Session (all *p*s > .60).

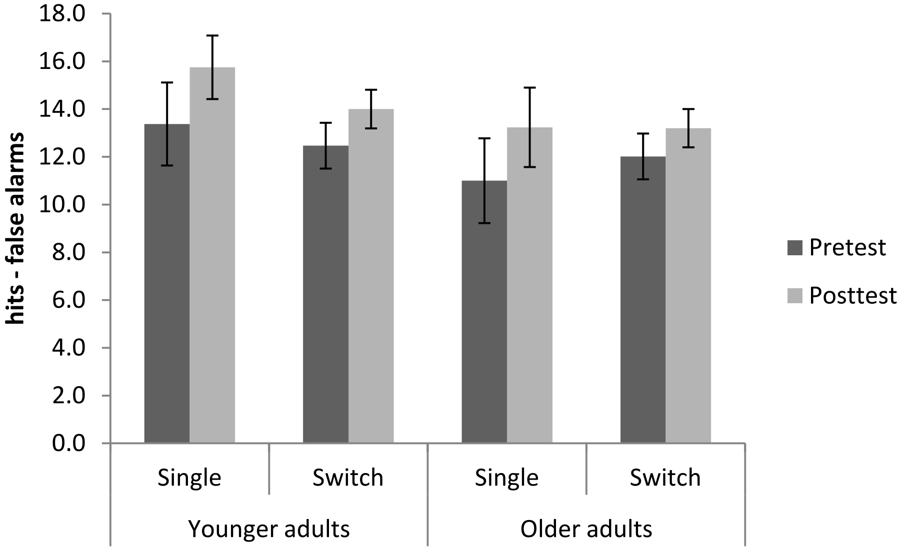

Figure 17 2-back mean performance (hits – false alarms) as a function of Training group (single, switch), Age group (younger adults, older adults) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

3-back

There was a main effect of Session, $F(1, 71) = 7.69$, $p < .05$, $\eta_p^2 = .10$, indicating that the groups improved from pretest to posttest, however group contrasts did not reveal differences between groups in the improvements from pretest to posttest (all *ps* > .26).

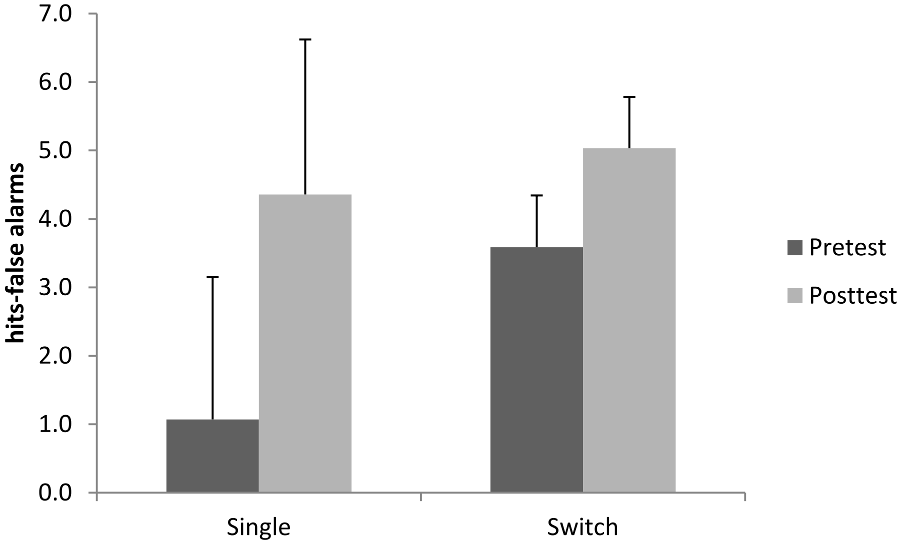

Figure 18 3-back mean performance (hits – false alarms) as a function of Training group (single, switch) and Session (pretest, posttest) for young adults. Error bars refer to the standard errors of the mean.

Working-memory

Working-memory capacity was measured by the counting span, reading span and digit backward tests. Individual test scores were standardized and averaged. There was no main effect of Session (p = .46). The group contrast comparing single-task and task-switching groups showed a tendency for an interaction with Session, $F(1, 158) = 3.31$, $p = .07$, $\eta^2 = .02$, indicating a non-significant decrease in performance in single-task groups, $t(33) = 1.31$, $p = .19$, and non-significant increase in task-switching groups, $t(128) = 1.54$, $p = .14$. With regard to age differences, there was an interaction between Age Group and Session, $F(1, 161) = 4.33$, $p < .05$, $\eta^2 = .03$, indicating a non-significant decrease in performance in older adults, $t(81) = 0.93$, $p = .36$, and significant increase in younger adults, $t(80) = 2.01$, $p < .05$. Group contrasts did not modulate the interaction of Age Group and Session (all ps > .73).

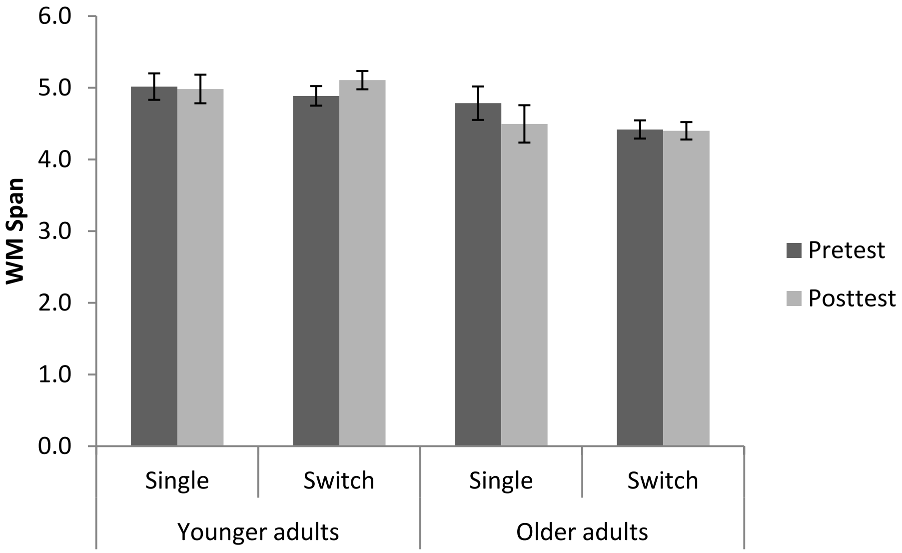

Figure 19. WM span as a function of age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

Fluid intelligence

Raven

There was a main effect of Session, *F*(1, 161) = 7.54, *p* < .05, η^2 = .04, indicating a decrease in performance from pretest to posttest. The group contrast comparing single-task and task-switching groups showed a tendency for interaction with Session, *F*(1, 157) = 3.14, *p* = .08, η^2 = .02, indicating a non-significant increase in performance in single-task groups, *t*(33) = .33, *p* = .74, and significant decrease in task-switching groups, *t*(127) = 3.26, *p* < .001. With regard to age differences, there was a tendency for an interaction between Age Group and Session, *F*(1, 160) = 3.49, *p* = .06, η^2 = .02, indicating a non-significant decrease in performance in older adults, *t*(80) = .68, *p* = .50, and significant decrease in younger adults, *t*(80) = 3.07, *p* < .05. Group contrasts did not modulate the interaction of Age Group and Session (all *p*s > .13).

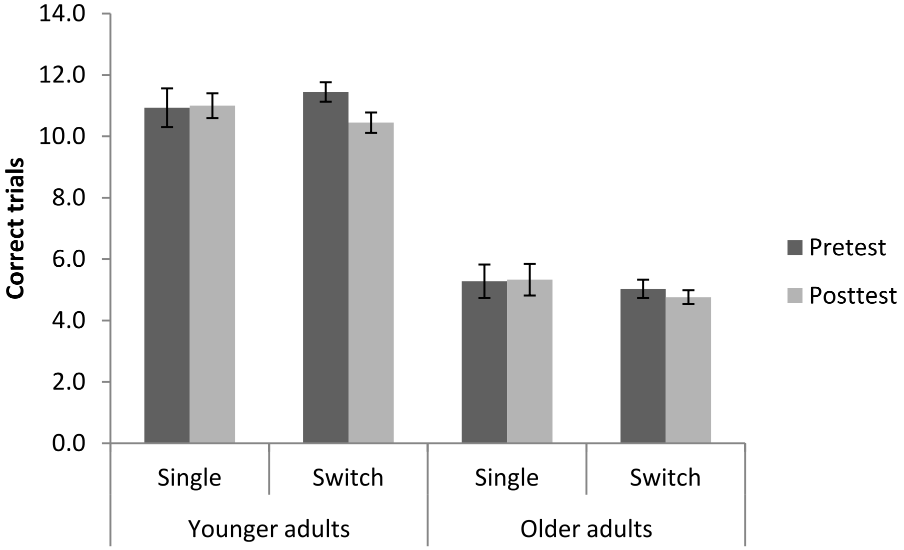

Figure 20 Raven mean performance (correct trials) as a function of age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

BOMAT

Due to printing errors in the test material the BOMAT data from younger adults couldn't be analyzed. Therefore the analysis was restricted to the older adult's data. There was a main effect of Session, $F(1, 81) = 11.05$, $p = .001$, $\eta^2 = .12$, indicating an increase in performance from pretest to posttest. However the group contrast comparing single-task and task-switching groups showed no interaction with Session ($p = .29$).

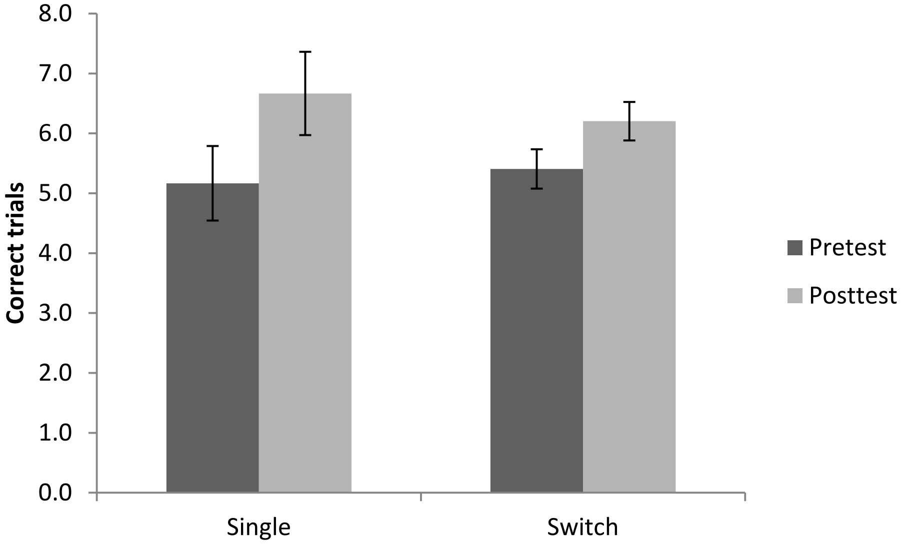

Figure 21 BOMAT mean performance (correct trials) as a function of Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

Digit Symbol

In addition to the near and far transfer tasks, we also measured participants on a control test, the Digit Symbol test, which is not closely related to cognitive control but a measure of perceptual speed. The expectation was that cognitive control training does not lead to performance improvement on this test. There was a main effect of Session, $F(1, 162) = 26.62$, $p < .001$, $\eta^2 = .14$, indicating an increase in performance from pretest to posttest. The group contrast comparing single-task and task-switching groups showed no interaction with Session ($p = .76$). With regard to age differences, there was an interaction between Age Group and Session, $F(1, 161) = 25.35$, $p < .001$, $\eta^2 = .13$, indicating a non-significant increase in performance in older adults, $t(81) = .37$, $p = .72$, and significant increase in younger adults, $t(80) = 7.69$, $p < .001$. Group contrasts did not modulate the interaction of Age Group and Session (all *p*s > .39).

Table 13 Digit symbol mean (*M*) scores and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posstest.

	Training group				
	Group 1 single task – bivalent stimuli *n*=(34)	Group 2 cued switching – univalent stimuli *n*=(32)	Group 3 cued switching – bivalent stimuli *n*=(29)	Group 4 uncued switching – univalent stimuli *n*=(32)	Group 5 uncued switching – bivalent stimuli *n*=(33)
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Pretest				
Younger adults	69 (11)	69 (12)	67 (5)	64 (11)	68 (9)
Older adults	47 (8)	47 (8)	46 (8)	47 (9)	44 (7)
	Posttest				
Younger adults	75 (9)	77 (13)	72 (8)	68 (9)	71 (10)
Older adults	48 (14)	47 (10)	48 (7)	46 (11)	43 (8)

FOLLOW-UP ANALYSES

We also checked the follow-up data for the near transfer effects in task switching. We were interested whether the training gains in the high-inhibition task-switching training groups in older adults still remains after six months. Data were submitted to a three-way ANOVA including the within-subjects factors Session (pretest, follow-up) and Trial type (single, stay, switch) and the between-subjects factor Training group (Group 1, Group 2, Group 3, Group 4, Group 5). We used to same contrasts as in the near-transfer analysis to compare training groups, and trial types. Mean mixing costs for all training groups and sessions are displayed in Table 14.

Analyses revealed that there was no larger reduction in mixing costs from pretest to follow-up in the task-switching groups than in the single-task group (p = .21), but there was still a larger reduction in mixing costs from pretest to follow-up in the bivalent stimuli groups than in the univalent stimuli groups, $F(1, 69) = 6.61$, $p < .05$, $\eta_p^2 = .08$. There was no difference in the reduction of mixing costs from pretest to follow-up between the bivalent cued switching group and the bivalent uncued switching group (p = .10).

Table 14. Mean (M) reaction times and standard deviations (SD) for mixing costs for younger and older adults separately for each training group at pretest, posttest and follow-up.

	Training group				
	Group 1	Group 2 cued/univalent	Group 3 cued/bivalent	Group 4 uncued/univalent	Group 5 uncued/bivalent
Session	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
			Younger		
Pretest	125 (96)	118 (98)	113 (80)	135 (137)	122 (76)
Posttest	84 (50)	64 (53)	59 (50)	81 (94)	64 (49)
Follow Up	77 (63)	73 (58)	64 (46)	61 (43)	71 (57)
			Older		
Pretest	282 (128)	272 (144)	271 (140)	278 (149)	268 (119)
Posttest	231 (101)	199 (137)	118 (117)	214 (98)	180 (83)
Follow Up	244 (97)	230 (163)	198 (142)	244 (104)	180 (93)

EFFECT SIZES OF TRAINING AND TRANSFER

In this last section the effect sizes of training and transfer measures will be presented. Values of Cohens' *d* were calculated, which is a measure of the standardized mean difference between the performances of the first and last sessions in the case of the training results, and standardized mean differences between pretest and posttest with regard to transfer effects. All d-values were corrected for small sample bias using the formula (*d'*[6]) suggested by Hedges and Olkin (1985 p. 79-81.)

First, effect sizes were calculated for the reduction of switch costs from the first training session to the fourth training session in the task-switching training groups (see Figure 22). Effect sizes were relatively large for both age groups in all training groups (*d'* = 0.62 - 1.59). In both age groups effect sizes were largest in the cued–univalent group (*d'* = 1.42 - 1.59). In cued–bivalent group effect sizes dropped somewhat for younger adults (*d'* = 1.26), but dropped noticeably in older adults (*d'* = 0.62). In the uncued

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[6] d_{unbiased} = =(1-3/(4×(*N*-2)-1))×*d;* where *N* represents the total sample size on which *d* is based

groups effect sizes were on similar levels for younger adults (*d’* = 1.21), for older adults it increased compared to the cued-bivalent group (*d’* = 0.96 - 0.99).

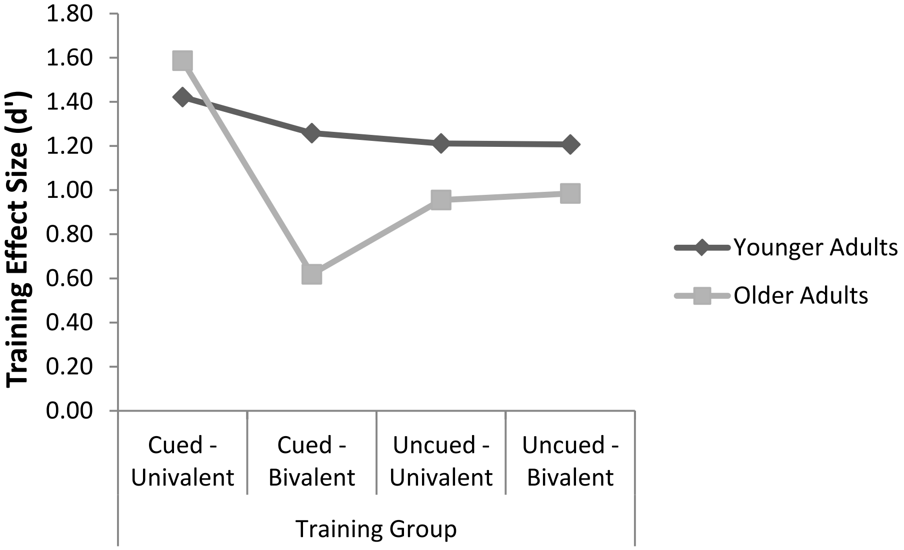

Figure 22. Effect sizes (*d’*) for switch cost reductions during training for younger and older adults in the four task switching groups.

Next, effect sizes were calculated for the reduction of switch costs and mixing costs from pretest to posttest in all five groups (see Figure 23 and Figure 24). With regard to switch costs in younger adults effect sizes were on a comparable moderate level in three of the task-switching groups (*d’s* = .34 - .47) and also in the single-task group (*d’* = .40). However, the uncued-bivalent group showed relatively large effect size (*d’* = .75). In comparison, older adults, showed small or even negative effect sizes (*d’s* = -.21 - .10).

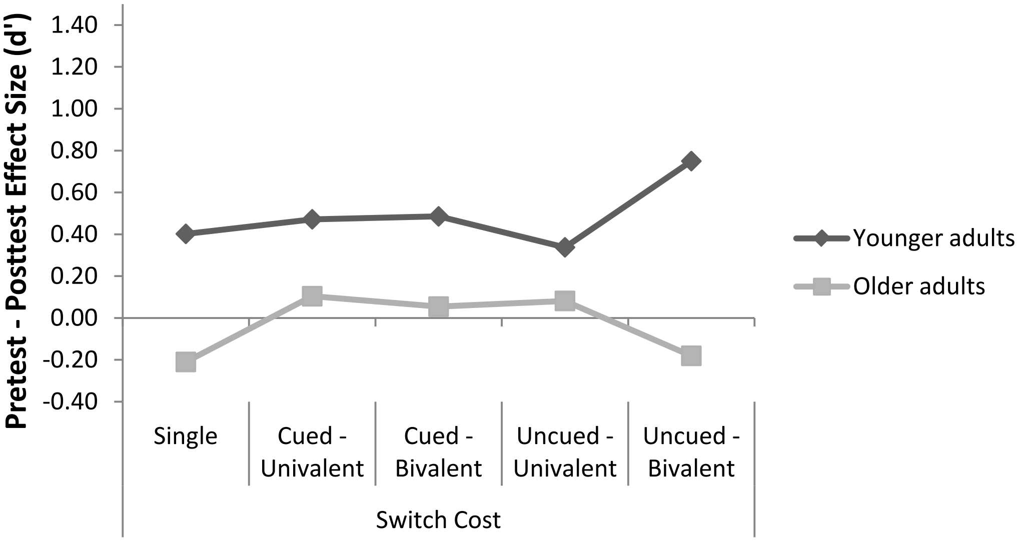

Figure 23. Effect sizes (d’) for switch cost reductions from pretest to posttest for younger and older adults in the five training groups.

With regard to mixing costs effect sizes were moderate to large in both age groups (*d’s* = 0.46 - 1.35). For younger adults effect sizes were on similar levels for the uncued-univalent and the single-task group (*d’s* = 0.46 - 0.51), and larger for the other three task-switching groups (*d’s* = 0.69 - 0.76). For older adults effect sizes were comparable in the two univalent groups (*d’s* = 0.53) and the single-task group (*d* = 0.60), and they were larger in the bivalent groups (*d’s* = 0.97 - 1.35), especially in the cued-bivalent group.

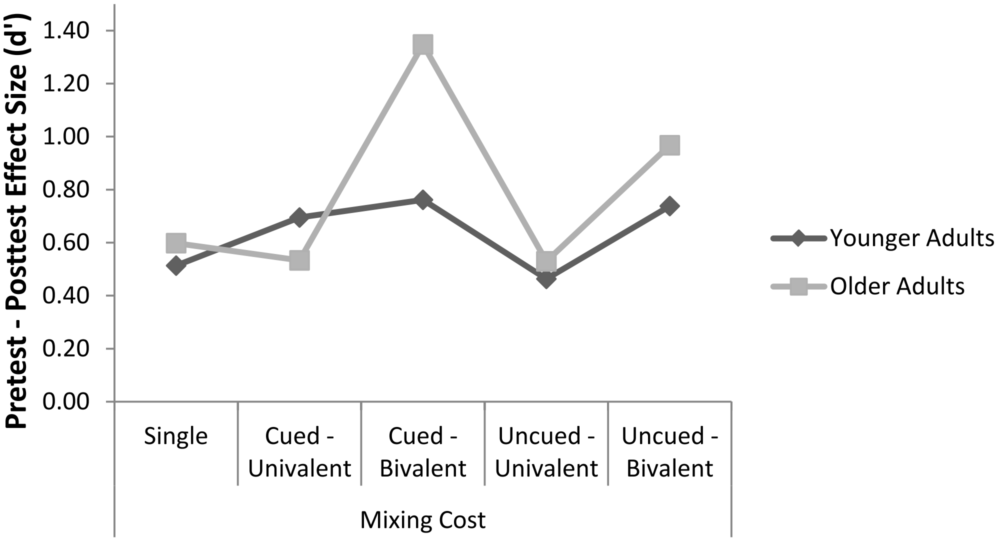

Figure 24. Effect sizes (*d'*) for mixing cost reductions from pretest to posttest for younger and older adults in the five training groups.

Next, effect sizes were calculated for the far transfer measures from pretest to posttest for task-switching and single-task groups (see Figure 25 and Figure 26). In general effect sizes for far-transfer measures were smaller than for near-transfer (largest *d's* = 0.47 - 0.54). For younger adults there were small effect sizes for the task-switching group for Working Memory, AXCPT and Number Stroop (*d's* = 0.21 - 0.28) as well as for the 2-back task (*d* = 0.16). Effect sizes for the single-task group were on a moderate levels for Color Stroop, 2-back, and 3-back (*d's* = 0.29 - 0.47). For older adults except for the Bomat (*d's* = 0.31 - 0.54) effect sizes were low in both task-switching and single-task groups (all *d's* < 0.23).

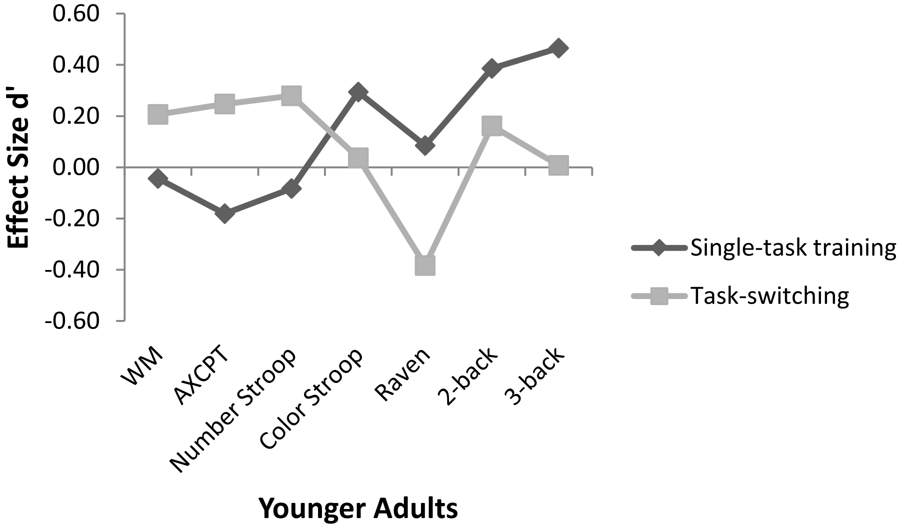

Figure 25. Far-transfer effect sizes (*d′*) for younger adults as a function of measure (WM: Working Memory; AXCPT: RT Interference; Number Stroop: RT Interference, Color Stroop: RT Interference; Raven; 2-back, 3-back).

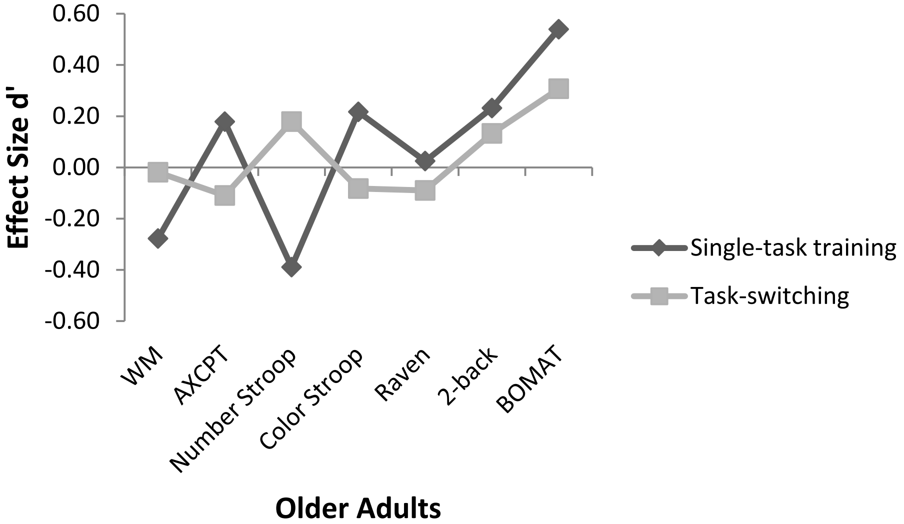

Figure 26. Far-transfer effect sizes (*d′*) for older adults as a function of measure (WM: Working Memory; AXCPT: RT Interference; Number Stroop: RT Interference, Color Stroop: RT Interference; Raven; 2-back, 3-back).

Discussion

SUMMARY OF MAIN RESULTS

The present study aimed to identify what processes are trained during task-switching training and which of these processes facilitate transfer across task domains. To this end we manipulated updating and inhibition demands in four task-switching groups and compared performance improvements in a pretest-training-posttest design to an active control group in younger and older adults. Task-switching groups had higher cognitive control demands than the active control group that practiced only with a single task, as task-switching groups were required to switch between two different task-sets regularly during training. Updating demands were manipulated by the presence or absence of task cues. In task switching groups without task-cues updating demands were higher than in task-switching groups with task-cues, as in the former task-sets had to be continually updated internally without external help from the cue. Inhibition demands were manipulated by using bivalent or univalent stimuli. In the groups with bivalent stimuli, a task-relevant character was always paired with another character that would be relevant in the other task-set, which resulted in interference between task sets. In the groups with univalent stimuli, a task-relevant character was always paired with a neutral character that was not associated with any task-set in the context of the task-switching task; therefore it did not induce interference between task sets. We measured both near-transfer to a switching task which was structurally similar to the one used during training, and far-transfer to other cognitive tasks which were structurally different than the task switching paradigm used during training.

During the four sessions of training we could track changes in switch costs, and group differences therein. Analyses revealed that switch costs decreased as a function of sessions in both age groups. There were no age differences with regard to switch costs.

With regard to group differences, groups with higher updating demands (i.e. without cues) had larger switch costs, than groups with low updating demands (i.e. with cues). Also, groups with high inhibition demands (bivalent stimuli) had larger switch costs than groups with low inhibition demands (univalent stimuli).

With regard to near-transfer, we assessed performance cost reductions from pretest to posttest in both mixing and switch costs. Interestingly, only older adults showed transfer effects, and they did so only with regard to mixing costs. With regard to group differences, older adults trained with high inhibition demands (bivalent stimuli) showed larger reduction in mixing costs. Furthermore, within bivalent groups, the group with low updating demands (with cue) had larger reductions in mixing costs than the group with high updating demand (without cue). Finally, far-transfer measures did not indicate more improvement in task-switching groups from pretest to posttest as compared to single-task groups. In the following I will take these results into context and discuss them in more detail.

Effects of Age, Cuing Type and Stimulus Ambivalence on Task-Switching Training

Reaction times reduced in all training groups throughout the four training sessions and older adults were generally slower than younger adults. Slower reaction times were expected from older adults in line with general observations and theory from the literature (e.g., T. Salthouse, 1996). With regard to error rates we can conclude that older adults were generally more accurate than younger adults, and that overall, accuracy improved from the first session to the fourth. The more accurate performance in older adults might reflect a more conscientious stance of older adults towards finishing the task, while younger adults might have wanted to finish the task fast and therefore were more careless. This idea is in line with findings showing that older adults put more effort into task performance than younger adults (Ennis, Hess, & Smith, 2013).

Previous findings showed that switch costs are larger in bivalent than in univalent conditions (e.g., Allport et al., 1994; Jersild, 1927; Rogers & Monsell, 1995; Spector & Biederman, 1976). Our task-switching data from the four training sessions are in line with these prior findings. It shows that reconfiguring task-sets is more difficult in the face of ambivalence.

Consistent with previous findings, switching costs reduced in all task-switching training groups in both younger and older adults (Bherer et al., 2005; Karbach & Kray, 2009; Kramer et al., 1999; Kray & Lindenberger, 2000), indicating that plasticity of this cognitive control process is spared with aging. Furthermore, the amount of reduction in switch costs did not differ between groups. This means that no matter the differing levels of inhibition or updating demands imposed by the different task-switching training groups in the present paradigm, switch costs reduced from the first to the fourth session at a similar rate. Previous findings also suggested that there are no differences in the rate of reduction between younger and older adults in switch costs (Bherer et al., 2005; Karbach & Kray, 2009; Kramer et al., 1999; Kray & Lindenberger, 2000). Together these findings indicate that older adults do not have more difficulty to reduce their switch costs in conditions that involve bivalent stimuli, as compared to univalent conditions. So, despite larger bottom up interference, older adults are capable to implement relevant task sets, and to improve in this ability on par with younger adults.

Transfer gains

The first set of analyses investigated whether the observed effects in the present study are in line with those observed in the literature with regard to age differences in task switching. Our results are consistent with previous findings showing both reliable mixing and switch costs in the task-switching paradigm, as well as larger mixing costs in older adults (Cepeda et al., 2001; Karbach & Kray, 2009; Kray et al., 2004; Kray & Lindenberger, 2000; Kray, 2006; Mayr, 2001; Reimers & Maylor, 2005; Verhaeghen & Cerella, 2002). However, the near transfer results showed that there was a larger reduction in mixing costs from pretest to posttest in the task-switching groups relative to the single-task group only in older adults. This is inconsistent with the findings of Karbach and Kray (2009), which showed large mixing cost reductions in younger age as well.

Furthermore our results indicated that there was no far transfer, i.e. groups that took part in task-switching training showed no better performance after training than did the group that took part in the single task training. This result is inconsistent with previous findings (e.g. Karbach & Kray, 2009). This result is unfortunate, as we were interested in how manipulations of updating and inhibition demands modulate far-transfer effects in younger and older adults during task-switching training. However we cannot answer these questions based on the present results. In the following I will discuss in detail the possible reasons for the smaller transfer effects.

EXPLANATIONS FOR THE SMALLER TRANSFER GAINS

In recent years there have been a number of studies that similarly had difficulties in replicating transfer effects resulting from task-switching training (Pereg, Shahar, & Meiran, 2013a; von Bastian & Oberauer, 2013; Zinke et al., 2012). In the following I will present the differences between these studies, explain how our study contribute to this landscape of findings, and explain which factors are important to elicit transfer from task-switching training. I will do this separately for near- and far-transfer.

Near transfer

Comparing effect sizes with previous study

In general the magnitude of mixing costs in our study was smaller for both age groups, (at pretest: 79 ms for younger adults, 224 ms for older adults) than in the study by Karbach and Kray (2009) (172 ms and 371 ms for younger and older adults respectively). Furthermore, with regard to the reduction of switch costs from pretest to posttest, there were no differences, in either the younger or older adults, between the task-switching groups and the single-task group, or between the task-switching groups with different stimuli. This is also inconsistent with the findings of Karbach and Kray (2009), which showed large switch cost reductions in both age groups in the task-switching groups compared to the single-task group. Again, the magnitude of switch costs in our study was smaller for both age groups, (at pretest: 87 ms for younger adults, 101 ms for older adults) than in the study by Karbach and Kray (2009) (204 ms and 337 ms for younger and older adults respectively). The smaller mixing and switch costs already at pretest indicate that the task was not that challenging in our paradigm as in the previous study by Karbach and Kray (2009). Given the relatively good performance already at pretest it is reasonable to assume that there was no room to improve, which can explain the lack of transfer effects with respect to mixing and switch costs.

With regard to the older adults, comparing the task-switching groups to each other, the results indicated that there was a larger reduction in mixing costs from pretest to posttest in the bivalent stimuli groups than in the univalent stimuli groups. The results also indicated a larger reduction of mixing costs in the bivalent cued switching group than in the bivalent uncued switching group. This means that older adults are not that able to benefit from training in uncued switching, but also that training with bivalent condition transfers better within the task switching domain.

However there are some additional factors that need to be addressed. At both pretest and posttest participants performed task switching blocks from all types of conditions, thus the performance in each of these tasks conditions contributed to the measured mixing cost. It is reasonable to assume that the hardest condition will not be that easy for those trained in the easiest condition. So those trained in the hardest condition should show the largest reduction in mixing costs, since they got better in the most demanding task. In other words, there was more transfer to similar conditions and given that bivalent conditions produce the highest mixing costs, the greatest transfer occurred in bivalent groups. However, the transfer is still not so narrow as this benefit remained even though we changed task-set from training to posttest, indicating that older adults got better at resolving bivalent task-switching in general. They improved in decreasing their response time difference between resolving single-tasks trials and mixed-task trials. The source of this improvement is primarily better interference resolution, rather than better updating processes as we have found differences between univalent and bivalent groups, but there were no differences between cued and uncued groups. Thus, a more substantial part of the mixing cost likely reflects some form of inhibition related process rather than updating processes.

Other studies

A study by Pereg, Shahar and Meiran (2013b) using the same paradigm as Karbach and Kray (2009) could replicate previous findings with respect to switch cost reduction in alternating-runs task-switching paradigm; however, in a cued task-switching paradigm they have found only a marginally significant effect, and no effect when run length changed from 2 to 3. With respect to mixing costs there were no transfer effects. Furthermore, the switch cost reductions were smaller than those found in Karbach and

Kray’s (2009) study (d’=0.93 vs. d’≈ 1.6 respectively). There is another study by von Bastian (von Bastian & Oberauer, 2013), which used the same stimuli as Karbach and Kray (2009). Near-transfer was assessed on a similar alternating-runs task-switching paradigm, with bivalent stimuli. Results showed transfer to switch costs, the size of which also correlated with improvements during training. Another study by Zinke and colleagues (Zinke et al., 2012) also attempted to replicate the transfer effects of the study by Karbach and Kray (2009) in adolescents. The reduction in switch costs during the training sessions were comparable to the switch cost reductions seen in the study by Karbach and Kray. In a similar task-switching paradigm they were able to replicate transfer effects with regard to mixing costs, but not with regard to switch costs, which is similar to our results. In summary, in all these studies near transfer effects from Karbach and Kray were partly replicated, but not completely, so it is not unique that some of our results are negative.

Which processes improved?

The study by Pereg, Shahar and Meiran (2013b) tried to disentangle whether switching or working memory updating is improved during task-switching training, and found support for the notion that updating is improved during task-switching training. From these findings Pereg (2013) concluded that updating processes are involved in alternating-runs task-switching training, yet they are not too demanding, leading to limited transfer to similar contexts. Furthermore, Pereg et al. noted that it seems like some very specific updating skills were trained in the alternating-runs task-switching paradigms: those related to changing tasks every 2nd trial, but broader working memory updating skills were not (cf. Pereg et al., 2013b). According to our study interference control is a more likely candidate of improvement, at least in older adults. But the pattern of findings was similar in younger adults if we compare mixing cost reductions in the five groups with older adults. As mentioned previously, it is a reasonable explanation that there was not much room to improve given the already small mixing costs at pretest in the younger groups which resulted in non-significant results. It would be interesting to see whether a similar paradigm as in the original study by Karbach and Kray (pictorial), with the present idea (of manipulating inhibition and updating demands) could show these results in younger adults as well.

Far-transfer

Inhibition

As mentioned in the introduction, the Stroop tasks that were used in our study required similar executive control demands as the task-switching training. In both task domains, inhibition of currently irrelevant information and maintenance of currently relevant information was necessary. Therefore we expected to find larger improvements in Stroop tasks after task-switching training compared to single-task training, especially in bivalent task-switching conditions, that are most similar to the Stroop setting (i.e. stimulus triggers both task-sets). However our results did not show larger improvements in the Stroop task after task-switching training, and there were no differences in performance improvement between bivalent and univalent task-switching groups.

At first inspection, our result regarding the Stroop task is inconsistent with previous findings. Therefore, it is important to consider details about the experiments. In the study by Karbach and Kray (2009) task-switching groups showed more improvements than the single-task group, and effect sizes were relatively large, at least for younger adults (younger adults: d’ ~ 0.8; older adults: d’ ~ 0.2). However, Karbach and Kray (2009) mention that there was an unexpected deterioration in the Stroop performance for younger adults in the single-task group. This might be explained due to the fact that for younger adults at pretest the task-switching group had almost twice as much interference-cost as the single-task group (57 ms and 30 ms respectively). Thus matching of the groups was not ideal which might have influenced the results. At posttest interference costs changed to 27 ms and 48 ms for task-switching and single-task groups respectively. Thus, what happened is that the task-switching group reached the pretest level of the single-task group after training, while the single-task group got worse from pretest-to posttest. Apparently, the same was the case for the older group. For the single-task group pretest-posttest interference costs change from 57 ms to 72 ms, while for the task-switching group it changed from 77 ms to 56 ms.

These problems could have been avoided in our study, however, unfortunately we also encountered problems during matching the groups. We assumed that the color and number versions of the Stroop task measure the same underlying construct, and therefore we used an aggregate score of the two tasks during matching. However, later analysis showed that there was no significant correlation between the two tests (*r* = .04 for RT interference cost). Therefore, analysis was performed separately for these two tests, but on the separate tests there were large baseline differences between the groups (see Table 17 and Table 18). Thus, from the present Stroop results we cannot make inferences regarding transfer effects. With regard to AX-CPT interference costs we didn’t find transfer effects.

With regard to other studies, the study by Pereg et al. (2013b) found a marginally significant training-related improvement for a manual Stroop task, but not for a vocal Stroop task. In the study by Zinke (2012) with adolescents there was no transfer to inhibition as measured by a color stroop and a flanker task. In the study by von Bastian and Oberauer (2013) there was also no transfer to inhibition as measured by a number

Stroop and a Flanker task. Thus, there is weak support for the idea that task-switching training in the present format is demanding enough to cause generalized improvements in inhibitory processes per se.

Working memory

The measure for working memory was an aggregate of two operation span tests, the reading span and counting span, and the digit backward test. We found no transfer effects for working memory. Although there was a tendency for a larger improvement in task-switching groups this might be partly due to the fact that there was an unexpected decrease in the performance of the single-task group. Our result is somewhat inconsistent with results from Karbach and Kray (2009). With regard to n-back tests or AX-CPT updating we also couldn’t find transfer effects.

A previous study, which investigated multitask video game training on cognitive control processes in older adults, indicated that whereas improvements were observed for tasks where one has to frequently switch items in working memory (n-back), there were no improvements in working memory span per se (as measured by operation span tasks) (Basak et al., 2008). Our results are in line with the finding that working-memory span does not change with task-switching training, however, we did not find transfer to n-back tasks.

Transfer effects to working-memory measures were also absent in other task-switching training studies (e.g. Pereg et al., 2013; Bastian & Oberauer, 2013). Only in one study was there a tendency for transfer effect with respect to faster responses in a 2-back task, but not to improved accuracy (Zinke et al., 2012). Thus there is weak support for the idea that task-switching training causes generalized improvements in working-memory span or working-memory updating.

Fluid Intelligence

With regard to the fluid intelligence tests we also faced some problems. For younger adults we couldn’t analyze data of the BOMAT due to printing errors of the test sheets for a large number of participants, and with regard to the Raven test, we found that performance decreased from pretest to posttest. The performance decrease in the Raven test can be explained due to the fact that test items followed increasing difficulty, and at pretest participants only did odd numbered items while they did the even numbered items at posttest. There was a tendency for differences in pre-post changes between groups, but not in the expected direction, showing a non-significant increase in single-task and a significant decrease in task-switching groups. The BOMAT did not show differences in pre-post improvements between task-switching and single-task groups.

Our result regarding fluid intelligence is inconsistent with previous findings. In the study by Karbach and Kray (2009), task-switching groups showed more improvements than the single-task group. This might be explained by the more reliable measure there, as they measured fluid intelligence on the latent level by combining several test scores. However, there were similar problems with matching the groups as mentioned previously. There were ceiling effects for both younger and older adults in the single-task groups that might weaken the results regarding transfer effects to fluid intelligence. However, in the study by von Bastian and Oberauer (2013) there was also transfer to fluid intelligence after task-switching training. As both of these studies used mostly similar stimuli during training, the differences in transfer effects between our study and theirs might be related to that factor (i.e. stimulus complexity during training). I will explore this possibility later.

EXPLANATIONS FOR THE TRANSFER GAINS IN OLDER ADULTS

Impairments in dual-task contexts

Meta-analyses in the aging literature suggest that age-related deficits occur prominently in divided attention and dual-task contexts (Verhaeghen, 2011; Wasylyshyn et al., 2011). However, it has also been shown that dual-task performance can be improved, even in older age, and that training leads to transfer effects involving new stimuli (Bherer et al., 2005). Our findings are in line with these observations in that we have seen age-related deficits mainly in mixing costs. We have also demonstrated that mixing costs can be decreased with training, and have found evidence for transfer effects in high-interference task-switching conditions in older adults.

We can postulate that task-switching facilitate performance in dual-task settings compared to a single task setting (i.e. reduce mixing costs). In a single task setting there is no interference between competing task sets, however in dual-task setting there is interference. Task-switching training under high interference conditions might help cognitive processes related with facilitation and suppression of relevant and irrelevant task-sets respectively. Older adults have more difficulties in this respect; however, a proper task-switching setting might provide a way of training these processes. Thus, our results extend previous findings by highlighting a specific source (interference) for the dual-task costs in older adults and indicating the possibility of improving cognitive processes that are affected by age in dual-task settings.

Improved interference resolution in older adults

There are theories postulating age-related inhibitory deficit as the underlying cause of impaired cognitive performance (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). There is supporting evidence that problems with inhibitory processes underlie impaired performance in different cognitive domains, such as working memory (Gazzaley et al., 2005) and processing speed (Lustig, Hasher, & Tonev, 2006). However, it is important to specify exactly which aspects of inhibitory processes might show age-related deficits. It has been suggested that a unitary view of age-related decline in inhibition is not appropriate as there is age equivalence in many aspects of inhibitory processing (Kramer et al., 1994). Also, there are studies that indicate that there is no task-inhibition deficit per se in older adults, as there are no age-differences in the size of n-2 task repetition costs (Lawo, Philipp, Schuch, & Koch, 2012; Li & Dupuis, 2008; Mayr, 2001). With regard to training effects, it has been shown that older adults are able to improve their ability to inhibit task-irrelevant information (Wilkinson & Yang, 2011).

On the other hand, it has been suggested that cognitive control relies on the flexible adaptability of fronto-parietal brain networks and that this flexibility is instantiated by hubs of brain regions that can rapidly update connectivity patterns according to task demands (Cole et al., 2013). It has also been suggested that multitasking leads to more substantial performance costs in older adults because of a diminished ability in older adults to switch between task-relevant and task-irrelevant brain networks (Clapp et al., 2011). In light of these studies, our results might indicate that older adults improved in flexible switching between task-relevant and task-irrelevant representations. Transferable improvements in our study were only observed in task-switching groups with high-interference load. In these conditions interruptions might potentially occur from the irrelevant task-set. Therefore, older adults might have improved in their ability to switch between the currently irrelevant task-set and the relevant task-set more efficiently, which led to transferable gains. This mechanism for the transfer effects is also consistent with the idea that novel task performance is dependent upon the reuse of flexible connectivity patterns used during a practiced task (Cole et al., 2013).

Our results showing near transfer effects of the training groups only with high inhibition demands are in line with recent results from Anguera and colleagues (Anguera et al., 2013). In that study, older adults showed improvements in multitasking (i.e. a task involving interference), and this improvement lead to better performance on untrained cognitive abilities, such as enhanced sustained attention, divided attention, and enhanced working-memory after training multitasking with a three dimensional video game. Given that in their study both the single-task-training and the multitask-training led to similar improvements on single task components, but only the multitask-training led to enhanced multitasking, sustained attention and working memory performance, the mechanism that must have driven the training effects was most likely the interference resulting from overlapping cognitive control processes during task execution in the multitask-setting. It is likely that task-switching training as well might produce transfer effects based on similar principles as multi-task training. The results presented in this thesis also support the idea that older adults are able to improve processes related with better interference control, although the transfer scope of the present study was limited.

Plasticity of cognitive control components

Apart from the general slowing hypothesis, some theories postulate that a limited number of executive control processes might be responsible for age-related decline in cognitive performance (Braver & Barch, 2002). Previous studies have indicated that even in older age cognitive control might be improved with training (Basak et al., 2008; Karbach & Kray, 2009). Our training results support the notion that switching costs can be reduced through training. However, we found no transfer effects for switching cost, which questions whether the switching component of cognitive control is subject to training-induced improvements in general. Furthermore, our results suggest a difference in the plasticity of different components of cognitive control as we have found no correlations between training gains in switching costs and pre-post gains in mixing costs.

Our results are in line with previous studies suggesting that there are separable components of cognitive control (Miyake et al., 2000), and specifically with studies suggesting that switching and mixing costs are separable constructs (Kray & Lindenberger, 2000). Furthermore, similar to previous studies we also found that while switching processes are spared with aging, processes underlying mixing costs are more affected by aging (Kray & Lindenberger, 2000; Reimers & Maylor, 2005). It is an interesting problem, that in theory switching and mixing costs are not independent of each other. While in switching cost calculations we compare trials that have the same level of maintenance demands (resulting from keeping two task-sets in mind), when we compare mixed and single trials there is a difference between maintenance demands. Furthermore, when we compare mixed trials and single trials for the mixing cost calculations, the mixed trials are affected by both the higher maintenance and the additional switching demands. These processes can be separated by a variant of the task-switching paradigm, the fade-out paradigm. Studies with the fade-out paradigm show that age-related differences in mixing costs are evident even when switching processes are potentially no longer necessary (Mayr & Liebscher, 2001). The question regarding the relative contribution of different cognitive control processes remains open.

Context, cuing, preparation

The difference between providing cues and not providing cues in the present task-switching paradigm is that in the latter case the need for internal cognitive control is increased. There are theories suggesting that older adults have difficulties when task uncertainty increases due to lack of contextual cues from the environment (Lindenberger & Mayr, 2013). In agreement with previous studies (e.g., Kray et al., 2002) our results from the four training sessions showed larger switch costs in uncued groups than in cued groups, but no age differences therein. While some studies indicated that older adults can use task cues to prepare for an upcoming task in a similar way as younger adults as evidenced by a similar amount of reduction of switch costs with changing cue stimulus interval (Cepeda et al., 2001; Kray, 2006), there is also a study showing age-related impairments in mixing costs when time for task preparation is decreased (Lawo et al., 2012). Our results showed a similar amount of reduction in switch costs in younger and older adults throughout the four training sessions in both cued and uncued groups, which implies that switching ability might be independent of contextual demands. Furthermore, it has been demonstrated that in an alternate runs task-switching paradigm if updating demands are increased then older adults are less able to reduce switch costs through training (Kramer et al., 1999). Consistent with this finding we found larger mixing cost reductions in older adults in cued-bivalent task-switching groups than in uncued-bivalent task-switching training groups.

With regard to other studies, as reported by Pereg and colleagues (2013a), there are two studies which showed only limited transfer of cued task-switching training. The first of these studies is a Ph.D. work of Armony-Shimoni (2001). “In Armony-Shimoni's Ph.D. study, participants were trained on the randomized-runs paradigm (Altmann and Gray, 2002, Altmann and Gray, 2008 and Gopher et al., 2000) in which task-cues appeared at the beginning of runs of trials varying in length between 4 and 12 trials. The results indicated some transfer of training effects across different kinds of stimuli (e.g., from letters to digits) or across different computational operations as long as they belonged to the same modality, such as spatial processing (e.g., from comparing which one of two groups has more items to evaluating whether a group has more or less than five items). However, when the processing mode changed (e.g., from spatial to semantic) or when the judgment goals changed (e.g., from judging high-vs.-low to judging odd-vs.-even) no transfer of training was found” (cf. Pereg et al., 2013a, p. 468.).

The second study showing limited transfer of task-switching is a master thesis from Sosna (2001). “Sosna's Master's Thesis included 2 experiments in which participants were trained in a cued-TS paradigm involving two spatial location tasks (up-down and right-left). In Experiment 1, there were three training sessions and switch probability varied between training groups. In Experiment 2 (6 training sessions), different versions of the training paradigm were used. In both experiments the switch costs were subjected to training effects but not to transfer effects” (cf. Pereg et al., 2013a, p. 468).

The differences between ours and Karbach and Kray’s study and the above two are that we and Karbach and Kray used an alternating-runs task-switching paradigm, while they used cued task-switching paradigms. The previously mentioned study by von Bastian and colleagues also used cues to indicate upcoming task sets, whereas in Karbach and Kray’s study it was uncued. In our study, we had both cued and uncued conditions. However, this was not decisive from the perspective of far-transfer effects. On the other hand we also changed stimuli from pictorial to characters, as I mentioned previously. It might imply that it is important to have stimuli inducing high inhibition, but it is also important for the task-switching to go uncued, so that there is higher demand for updating. One can argue that when task switching goes uncued it resembles more of a multitask setting because participants are engaged in two processes simultaneously.

Further studies could investigate this issue to provide more insight into the role of updating processes.

COMPARING DIFFERENT PARADIGMS

Stimulus complexity

We should consider the similarities and differences between studies in the stimuli and task-sets used. In our experiment stimuli consisted of characters, such as digits and letters, and task-sets were based on decisions regarding these characters, such as parity decision, magnitude decisions, etc. In Karbach and Kray's study, ambiguous stimuli were used, and these were pictorial, and both task-sets were bound to a simple picture. It is reasonable to assume that there is a much higher level of interference in that case than in the present study, where interference is a bit lighter, coming from two characters standing next to each other. By focusing selective spatial attention to the relevant character on the left or the right the interference from the irrelevant character could have been arguably smaller in the present study than it was in the study of Karbach and Kray. Nevertheless, in our study there was still a significant difference between bivalent groups and univalent groups with regard to switch and mixing costs, as we could see during the training and also in the transfer of older adults' mixing costs. What would have been better in our study is to use during training not digit-digit-letter-letter task, but only digit tasks, for instance, using a sequence like parity-parity-magnitude-magnitude, such that one stimulus, a number, would be bound with both task sets. That would have been equivalent with regard to interference with Karbach and Kray's study.

In the study by Zinke and colleagues (2012), there were two different versions of task-switching tasks at pretest and posttest. One of them was very similar to that used during training, an alternating-runs task-switching paradigm, using similar stimuli (pictorial). The other was a random-cued task-switching paradigm, with different stimuli (numerical). In the similar task-switching paradigm they were able to replicate transfer effects with regard to mixing costs, but not with regard to switch costs, which is similar to our results from the older participants. However, in the random-cued task-switching paradigm with numerical stimuli no transfer effects were found.

The lack of near-transfer effects in *younger* adults in our study is in line with the results of the study by Minear and Shah (2008) in which they showed no transfer (either switch or mixing costs reduction) from a predictable task-switching training to a similar predictable task-switching paradigm. In one of their experiment, there was no difference between a predictable switching, a random switching and a control group with regard to transfer in a predictable switching paradigm. More importantly, task-sets and stimulus complexity was similar to ours (such as: odd-even, consonant-vowel, uppercase-lowercase, greater than-less than, etc. decisions). The only transferable gain in their experiments was mixing cost reductions from unpredictable task-switching paradigms to similar unpredictable task-switching paradigms, but not from a predictable to an unpredictable paradigm.

Training duration

In general, it should be assumed that transfer effects are proportional to training improvements in the practiced tasks, and many training studies have indeed found such a relationship (Anguera et al., 2013; Basak et al., 2008; Jaeggi et al., 2008). It also should be noted however, that most training studies have found transfer effects only after extensive practice (>20 hours). In contrast, we used a relatively short training (1,5-2 hours). Minear and Shah (2008) used a comparable amount of training (1152 trials). The study by Zinke et al. (2012) used even less, only three training sessions. The presence of near transfer effects even after such a short training in older adults is encouraging, and it would be interesting to know how far older adults' performance might be improved with more extensive training. Furthermore, the short training duration coupled with a decrease in task difficulty might be responsible for the lack of far-transfer effects in the present study as compared to previous studies (Karbach & Kray, 2009).

Training difficulty

While in our study the training difficulty was not adaptive, other studies used adaptive training designs to achieve far-transfer effects (e.g., Anguera et al., 2013; Jaeggi et al., 2008). With regard to updating training with n-back tasks Jaeggi (2008) argues that updating demands need to be kept high throughout training in order for updating processes to improve. Another study with working memory training directly compared the effectiveness of adaptive and non-adaptive regimens (Brehmer, Westerberg, & Bäckman, 2012) and showed that adaptive training results in generally larger transfer gains. In contrast, the task-switching trainings applied in the previously mentioned studies did not fulfill that criterion with the exception of von Bastian and colleagues (2013). They used a more intensive (20 sessions, 30-40 min / session), adaptive training, with three different stimulus dimensions (pictorial, verbal and figural, i.e., cliparts, words, and simple geometrical shapes respectively). Also, as there were more sessions, new task sets were introduced every fourth session to keep participants motivated and enhance variability of training. Future task-switching training studies should therefore apply adaptive training paradigms.

Control groups

As mentioned in the introduction the implementation of proper control groups in training studies is essential. However, there were differences in the training studies with regard to what kind of control groups they used, and these differences might be important to keep in mind as we compare the separate studies. In the study by von Bastian and colleagues (2013), the active control group did not perform single-task blocks as in the Karbach study. Their task comprised three visual matching tasks (face matching, digit matching, pattern matching). Training for this control group was also adaptive, which meant reducing the allowed time to respond as participants improved their performance. The study by Zinke at al. (2012) included a task-switching training group and a no-contact control group. Matching of control groups to experimental groups is also often carried out based on only a subset of the tests that are eventually used during comparisons. The present study was relatively well controlled in that respect compared to other studies, and it is recommended for future studies as well to use a comprehensive matching along all measures.

MAINTENANCE OF TRAINING GAINS

With regard to the maintenance of the training gains, our results showed enhanced task-switching performance in older adults in high-inhibition groups compared to low-inhibition groups which lasted at least up to six months. This is a novel finding as previous studies with task-switching training did not look for maintenance of training gains. This result is important, as it indicates that the plasticity of cognitive control functions achieved by the training is not a transient phenomenon, and joins studies which showed maintenance effects after training (e.g., Brehmer et al., 2012; Dahlin, Nyberg, et al., 2008; Li et al., 2008).

INDIVIDUAL AND GROUP LEVEL TRAINING GAINS

In studies of cognitive training we often look for differences on the group level. However, individual variability in training gains of a given regimen can be also an important aspect. Individual differences in the amount of training gains can be substantial (Bissig & Lustig, 2007), and training benefits are often smaller for those individuals who are cognitively more impaired. There is evidence for instance, that memory plasticity decreases monotonically with advancing age (Verhaeghen et al., 1992). Our results indicate that there is a strong correlation between mixing costs at baseline and pre-post gain in mixing costs. This means that those individuals who have more problems at baseline improve more, which is an encouraging finding from the perspective of remedial applications.

FUTURE DIRECTIONS - MECHANISM OF CHANGE WITH TRAINING IN OLDER ADULTS

In this study we measured reaction times and try to decipher changes in cognitive functions. However, direct measurements of the brain could complement our studies and give additional information about cognitive aging. Multiple studies have indicated that the prefrontal cortex plays a key role in cognitive control by modulating activity of diverse brain areas (Miller, 2000). The exact mechanism for this long range modulation is not entirely known, but inter-areal phase synchronization between distributed neural populations is likely to play an important role in the process (Varela, Lachaux, Rodriguez, & Martinerie, 2001). It has also been demonstrated that working memory training increases prefrontal and parietal activity (Olesen, Westerberg, & Klingberg, 2004) and that during working memory performance increasing memory load strengthens frontoparietal phase synchrony (Palva, Monto, Kulashekhar, & Palva, 2010). It might be postulated, that with older age top-down biasing of functional networks is diminished which leads to impaired cognitive performance. It has been shown that frontal theta-power and long-range theta-coherence is positively correlated with improved task performance after multitask training in older adults, and that older adults show more youth like patterns of theta-activity after training (Anguera et al., 2013). Slow wave theta synchrony of distributed neural networks is indeed a likely signature of cognitive control (Mizuhara & Yamaguchi, 2007; Schroeder & Lakatos, 2009; Womelsdorf, Johnston, Vinck, & Everling, 2010; Womelsdorf, Vinck, Leung, & Everling, 2010), and might play an important role in our understanding of the mechanism of age-related and training-related changes in cognitive control. Future studies might focus more on these physiological aspects which are so far largely underexplored.

LIMITATIONS OF THE STUDY

Selection of sample was not representative to the population. Our young adults were mainly psychology students. Furthermore, there are many disadvantages of a cross-sectional study in comparison to a longitudinal study (Raz & Lindenberger, 2011; Salthouse, 2011). Age-differences in measurements might be attributed to factors other than the effects of aging on the brain.

We often find age-related decline in cross-sectional comparisons of cognitive measures (e.g. see review by Hedden & Gabrieli, 2004). We might uncritically make the assumption that progressive age is related with mental deterioration. However, we should have good explanations of how and why specific factors, such as specific changes in brain volume or function, might cause changes in cognitive behavior. There can be many competing explanations for differences between groups in cross-sectional studies that can fit certain empirical findings equally well or even better than simply assuming age as the causal agent. Not addressing these issues might hinder our progress towards understanding cognitive aging. If one approaches the field with the mindset that there must be age-related differences, one will easily find evidence in a cross-sectional dataset. But one has to be always critical keeping in mind alternative explanations. In the specific field of task-switching longitudinal studies are still lacking, and so a precise estimate of age related decline in task-switching performance remains to be elucidated; although at present there are no good alternative explanations for the observed cross sectional differences than assuming progressive impairment of performance with the aging brain.

CONCLUSION

There is a growing body of literature investigating the transfer effects of cognitive trainings, and remedial applications of such trainings in the elderly (Anguera et al., 2013; Karbach & Kray, 2009). It is important to understand which aspects of cognition show age-related decline, the extent to which such decline can be prevented, and how to restore cognitive function to levels observed in younger adults. The present study was designed to uncover which cognitive control processes contribute to general training related improvements and elucidated important factors that need to be minded in future training studies. Specifically, our findings lend support to the idea that cognitive control can be enhanced in high-interference dual-task contexts in the elderly. Interference resolution seems to be the most likely factor that underlies age related cognitive impairments, but our study suggests that it can be improved through training with paradigms such as task-switching featuring bivalent stimuli. Furthermore, we suggest that stimulus complexity is an important factor in driving transfer effects that should be further examined in future studies. We found no far transfer effects, which seems to be in agreement with recent task-switching studies. However, other studies with high-interference multitasking paradigms involving engaging complex stimuli did find far-transfer effects. Thus, we believe that designing engaging training programs in keeping with the present theoretical considerations (i.e. importance of interference level) might be a fruitful approach to counteract cognitive aging. Lastly, the maintenance of transfer gains after six months also points towards the practical applicability of the present approach.

Appendices

Table 15 Mean reaction times (ms) as a function of Session (1, 2, 3, 4), Age (younger adults, older adults), Group (Group 2, Group 3, Group 4, Group 5) and Trial (stay, switch)

	Session															
	Training 1				Training 2				Training 3				Training 4			
	Stay		Switch		Stay		Switch		Stay		Switch		Stay		Switch	
Training Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Younger adults															
Group 2	592	63	721	122	537	56	614	94	508	47	557	74	501	52	540	70
Group 3	724	94	950	210	627	89	758	151	574	68	667	110	565	79	652	121
Group 4	595	129	757	211	536	86	628	135	519	81	591	124	514	81	574	111
Group 5	703	122	939	222	613	78	775	191	577	83	700	180	564	78	667	159
	Older adults															
Group 2	848	181	1020	244	712	112	805	156	663	100	735	133	651	93	715	111
Group 3	1110	280	1329	373	997	245	1155	333	903	197	1033	273	855	209	979	267
Group 4	866	198	1119	329	777	192	952	365	705	124	828	221	688	123	798	221
Group 5	1104	223	1440	247	968	179	1251	233	888	160	1080	210	847	154	1056	243

Table 16 Percentage of correct trials (%) as a function of Session (1, 2, 3, 4), Age (younger adults, older adults), Group (Group 2, Group 3, Group 4, Group 5) and Trial (stay, switch)

	Session															
	Training 1				Training 2				Training 3				Training 4			
	Stay		Switch		Stay		Switch		Stay		Switch		Stay		Switch	
Training Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Younger adults															
Group 2	96	3.39	91	5.71	95	3.73	93	5.95	96	3.09	94	4.78	95	3.47	93	6.73
Group 3	96	2.92	91	5.75	96	2.61	93	3.60	95	2.92	95	3.85	95	3.13	95	2.92
Group 4	96	3.36	90	5.29	95	3.22	93	4.34	95	4.09	93	4.80	95	5.02	92	4.74
Group 5	95	4.24	91	6.55	97	2.25	94	3.82	96	2.74	94	3.31	95	2.97	94	4.05
	Older adults															
Group 2	99	1.04	96	2.95	99	0.98	97	2.18	99	0.63	97	1.48	99	0.83	97	2.06
Group 3	94	8.14	92	8.60	98	1.23	95	4.05	99	1.10	96	2.74	99	1.51	97	2.99
Group 4	98	2.84	95	3.81	99	1.03	97	3.33	99	0.62	97	2.36	100	0.51	98	2.26
Group 5	95	4.01	92	4.93	97	2.90	95	4.25	98	1.88	96	2.66	98	1.66	97	1.73

Table 17 Mean reaction times (*M*) and standard deviations (*SD*) of the Color Stroop test for each trial type (neutral, incongruent) for each training group at pretest and posttest.

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Younger adults								
Group 1 (*n* = 16)	618	80	657	101	584	83	611	88
Group 2 (*n* = 16)	602	65	630	99	585	116	604	120
Group 3 (*n* = 16)	616	93	629	117	565	82	601	90
Group 4 (*n* = 16)	598	89	635	97	601	104	624	110
Group 5 (*n* = 16)	621	107	648	94	600	86	616	88
Older adults								
Group 1 (*n* = 17)	862	122	984	139	829	142	934	152
Group 2 (*n* = 17)	947	175	1032	203	860	120	966	167
Group 3 (*n* = 14)	836	146	909	154	809	122	870	121
Group 4 (*n* = 16)	959	118	1071	179	928	121	1015	153
Group 5 (*n* = 16)	894	128	1005	171	877	99	1008	137

Table 18 Mean reaction times (*M*) and standard deviations (*SD*) of the Number Stroop test for each trial type (neutral, incongruent) for each training group at pretest and posttest.

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Younger adults								
Group 1 (*n* = 16)	638	84	651	79	599	67	614	67
Group 2 (*n* = 16)	659	92	679	114	616	79	624	80
Group 3 (*n* = 16)	613	71	649	80	583	75	596	85
Group 4 (*n* = 16)	650	148	661	159	611	91	635	111
Group 5 (*n* = 16)	628	68	655	79	593	69	606	73
Older adults								
Group 1 (*n* = 17)	979	136	985	124	923	143	956	156
Group 2 (*n* = 17)	1051	153	1084	152	945	137	977	130
Group 3 (*n* = 14)	953	120	957	113	906	113	939	139
Group 4 (*n* = 16)	1011	138	1043	146	973	162	978	165
Group 5 (*n* = 16)	962	134	1010	148	929	115	943	127

Table 19 Mean percentage correct trials (*M*) and standard deviations (*SD*) of the Color Stroop test for each trial type (neutral, incongruent) for each training group at pretest and posttest.

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Younger adults							
Group 1 (*n* = 16)	97	3.59	95	6.44	95	3.78	93	5.34
Group 2 (*n* = 16)	96	4.25	95	5.19	92	6.91	92	7.56
Group 3 (*n* = 16)	97	2.85	95	4.38	95	4.56	94	4.11
Group 4 (*n* = 16)	96	6.24	94	3.86	92	5.35	93	6.63
Group 5 (*n* = 16)	97	2.34	96	3.76	96	2.99	94	6.56
	Older adults							
Group 1 (*n* = 17)	97	3.90	91	9.18	98	3.75	95	7.33
Group 2 (*n* = 17)	97	5.05	90	16.77	99	2.23	97	4.75
Group 3 (*n* = 14)	98	1.91	97	4.42	99	2.33	98	2.33
Group 4 (*n* = 16)	99	2.25	92	8.54	98	2.27	96	5.19
Group 5 (*n* = 16)	97	3.46	93	7.72	98	2.77	95	5.47

Table 20 Mean percentage correct trials (*M*) and standard deviations (*SD*) of the Number Stroop test for each trial type (neutral, incongruent) for each training group at pretest and posttest.

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Younger adults							
Group 1 (*n* = 16)	96	4.49	92	5.70	96	3.76	93	6.43
Group 2 (*n* = 16)	96	6.45	89	7.39	94	5.10	91	6.94
Group 3 (*n* = 16)	97	7.56	93	12.60	95	3.61	90	6.68
Group 4 (*n* = 16)	97	8.30	92	10.27	93	5.17	89	7.99
Group 5 (*n* = 16)	97	3.86	95	4.49	94	4.82	95	5.17
	Older adults							
Group 1 (*n* = 17)	97	4.06	90	8.61	97	2.81	92	7.31
Group 2 (*n* = 17)	96	4.21	91	6.72	97	2.68	95	4.00
Group 3 (*n* = 14)	98	3.71	91	8.92	97	3.77	93	7.60
Group 4 (*n* = 16)	96	4.82	92	8.22	97	4.34	94	7.13
Group 5 (*n* = 16)	96	3.99	94	5.13	96	4.60	94	6.24

Table 21 2-back mean (*M*) scores and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posstest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Pretest				
Younger adults	13.38 (6.96)	12.27 (8.05)	11.14 (7.13)	10.94 (8.55)	15.53 (5.26)
Older adults	11.00 (7.32)	12.25 (7.57)	10.79 (7.68)	12.50 (6.92)	12.40 (8.44)
	Posttest				
Younger adults	15.75 (5.32)	14.13 (5.08)	13.47 (6.78)	12.19 (7.49)	16.33 (5.43)
Older adults	13.24 (6.86)	14.13 (5.60)	13.21 (6.00)	10.69 (7.99)	15.00 (4.10)

Table 22 3-back mean (*M*) scores and standard deviations (*SD*) for younger adults separately for each training group at pretest and posstest.

Training group				
Group 1 single task – bivalent stimuli *n*=(14)	Group 2 cued switching – univalent stimuli *n*=(13)	Group 3 cued switching – bivalent stimuli *n*=(15)	Group 4 uncued switching – univalent stimuli *n*=(16)	Group 5 uncued switching – bivalent stimuli *n*=(14)
M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Pretest				
1.07 (7.77)	4.46 (3.45)	1.80 (5.88)	2.31 (7.10)	6.14 (5.07)
Posttest				
4.36 (8.47)	6.08 (4.37)	4.13 (5.72)	3.94 (7.53)	6.29 (4.34)

Table 23 Working Memory aggregated scores (*M*) and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posttest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Pretest				
Younger adults	5.02 (.74)	4.92 (1.12)	4.83 (1.27)	5.03 (1.01)	4.77 (1.09)
Older adults	4.79 (.99)	4.59 (.81)	4.44 (1.07)	4.22 (1.26)	4.43 (.95)
	Posttest				
Younger adults	4.98 (.80)	5.27 (1.01)	4.86 (.93)	5.12 (.92)	5.17 (1.27)
Older adults	4.50 (1.11)	4.57 (1.12)	4.25 (.92)	4.30 (.97)	4.47 (.92)

Table 24 Raven mean (*M*) scores and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posstest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Pretest				
Younger adults	10.93 (2.43)	11.25 (3.19)	11.44 (2.16)	11.47 (2.37)	11.63 (2.66)
Older adults	5.28 (2.32)	5.27 (2.22)	5.33 (2.26)	4.69 (2.68)	4.88 (2.55)
	Posttest				
Younger adults	11.00 (1.56)	9.81 (3.23)	11.50 (1.79)	10.00 (2.76)	10.50 (2.58)
Older adults	5.33 (2.20)	5.00 (2.04)	4.67 (1.76)	4.38 (1.15)	5.00 (2.13)

Table 25 BOMAT mean (*M*) scores and standard deviations (*SD*) for older adults separately for each training group at pretest and posstest.

Training group				
Group 1 single task – bivalent stimuli *n*=(18)	Group 2 cued switching – univalent stimuli *n*=(16)	Group 3 cued switching – bivalent stimuli *n*=(15)	Group 4 uncued switching – univalent stimuli *n*=(16)	Group 5 uncued switching – bivalent stimuli *n*=(17)
M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Pretest				
5.17 (2.64)	4.63 (3.44)	5.80 (2.54)	5.56 (2.03)	5.65 (2.40)
Posttest				
6.67 (2.95)	6.81 (2.20)	5.80 (2.65)	6.94 (2.11)	5.29 (3.04)

Table 26 Counting span mean percentage of correct trials (*M*) and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posttest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
			Pretest		
Younger adults	82 (9)	82 (14)	81 (13)	82 (11)	78 (12)
Older adults	76 (15)	72 (12)	77 (17)	74 (13)	69 (11)
			Posttest		
Younger adults	83 (12)	86 (14)	80 (14)	81 (11)	80 (12)
Older adults	73 (15)	76 (19)	77 (11)	81 (11)	74 (16)

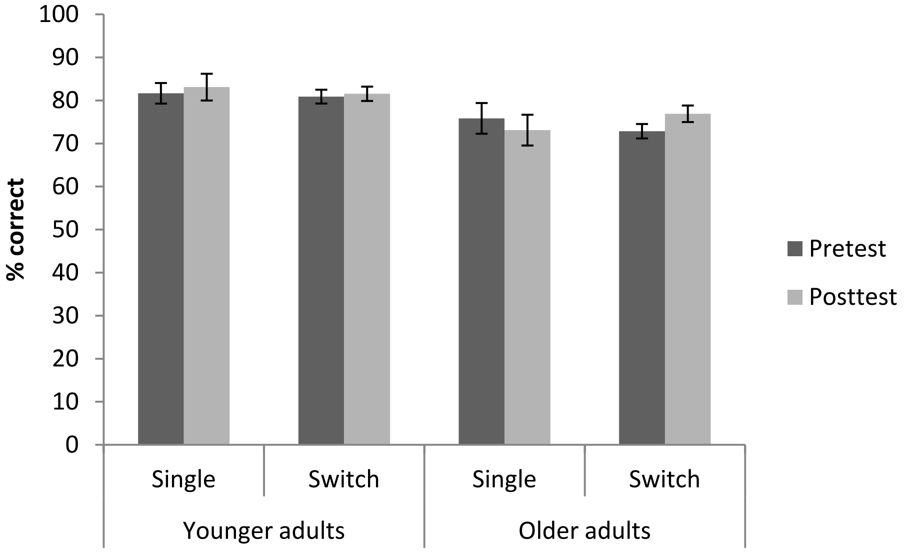

Figure 27 Counting span mean performance (% correct) as a function of age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

Table 27 Reading span mean percentage of correct trials (*M*) and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posttest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
			Pretest		
Younger adults	81 (10)	76 (14)	78 (13)	76 (18)	76 (15)
Older adults	74 (14)	73 (15)	73 (14)	77 (12)	72 (16)
			Posttest		
Younger adults	77 (12)	78 (15)	78 (16)	79 (15)	82 (10)
Older adults	66 (16)	71 (14)	71 (17)	71 (14)	70 (19)

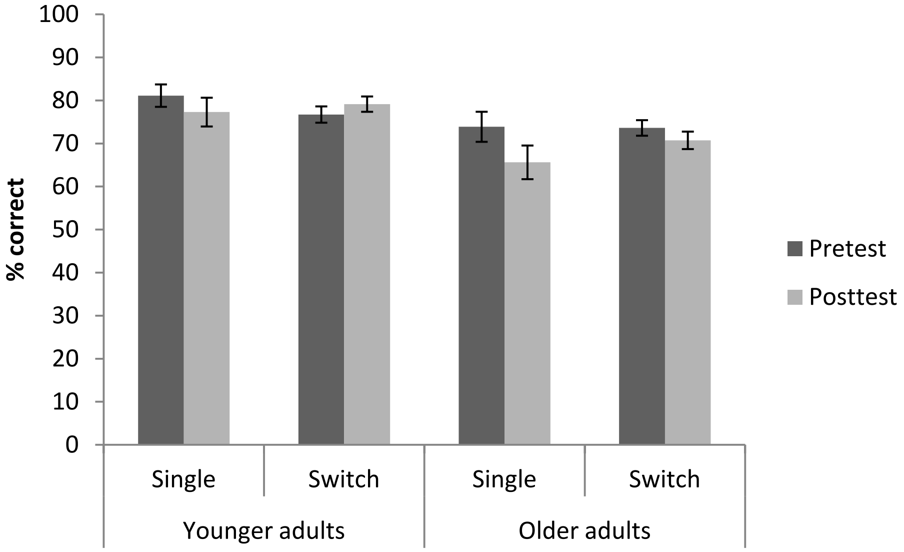

Figure 28 Reading span mean performance (% correct) as a function of age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

Table 28 Digit backwards mean (*M*) scores and standard deviations (*SD*) for younger and older adults separately for each training group at pretest and posstest.

	Training group				
	Group 1 single task – bivalent stimuli	Group 2 cued switching – univalent stimuli	Group 3 cued switching – bivalent stimuli	Group 4 uncued switching – univalent stimuli	Group 5 uncued switching – bivalent stimuli
Age group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
	Pretest				
Younger adults	8.75 (2.18)	8.53 (1.68)	8.67 (2.55)	8.29 (2.62)	8.67 (1.95)
Older adults	7.17 (1.62)	6.00 (2.88)	6.27 (1.94)	5.25 (2.11)	6.94 (2.86)
	Posttest				
Younger adults	9.87 (2.22)	8.87 (1.88)	9.67 (2.23)	8.76 (2.95)	10.07 (3.92)
Older adults	7.50 (2.38)	6.73 (2.66)	6.73 (1.83)	6.00 (2.13)	7.06 (2.51)

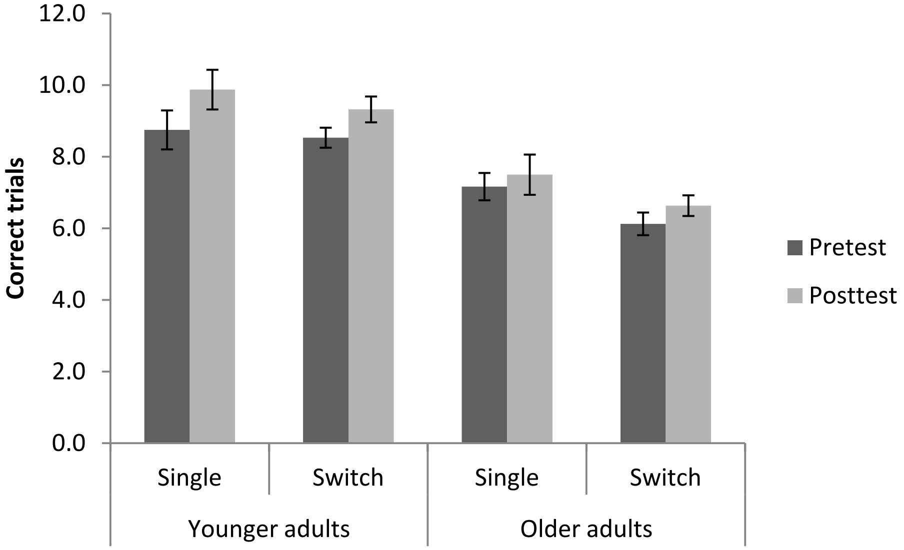

Figure 29 Digit backward mean performance (correct trials) as a function of age group (younger adults, older adults), Training group (single, switch) and Session (pretest, posttest). Error bars refer to the standard errors of the mean.

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