The “Cue” to Success

Improving Cognitive Control Processes in Older Adults by means of Cued Task-Switching Training

An ERP Approach

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Zusammenfassung in deutscher Sprache

Mit den ersten grauen Haaren kommt meistens die erste Verunsicherung. Älterwerden wird heutzutage immer noch als Abbauprozess angesehen, der mit unumgänglichen Einbußen in Auffassungsvermögen, Konzentration und Merkfähigkeit einhergeht. Dabei kann das gesunde, ältere Gehirn durchaus in der Lage sein, diesen Einbußen entgegenzuwirken und neue Aufgaben zu lernen. Unterstützt wird diese Annahme von Studien, die die Wirksamkeit bestimmter kognitiver Trainingsprogramme bei älteren Erwachsenen untersuchen. Dabei ist vorerst wichtig zu verstehen, wie altersbedingte Unterschiede in der kognitiven Leistungsfähigkeit und im Gehirn manifestiert sind. Die Altersforschung fokussiert hierbei auf Prozesse der „kognitiven Kontrolle“ (auch exekutive Kontrolle genannt), die für die Steuerung zielgerichteten Verhaltens verantwortlich gemacht werden (Braver, Gray & Burgess, 2007). Unter kognitiver Kontrolle werden Prozesse der Informationsverarbeitung verstanden, die größtenteils unbewusst ablaufen. Dazu gehören beispielsweise Selektion und Einprägung von Informationen aus der Umwelt, die wichtig für die Lösung einer bestimmten Aufgabe sind. Aber auch Prozesse der Aktualisierung und Inhibition von Information gehören zur kognitiven Kontrolle (Miyake et al., 2000).

Im Alter scheinen diese kognitiven Kontrollmechanismen an Effizienz zu verlieren, was zu einer merklichen Leistungsdifferenz zwischen Jung und Alt in kognitiven Aufgaben führt. Ein beliebtes Paradigma, das zur Untersuchung altersbedingter Unterschiede in kognitiver Kontrolle eingesetzt wird, ist das Aufgabenwechselparadigma (Monsell, 2003). Beim Aufgabenwechsel werden Probanden instruiert, zwischen zwei einfachen kognitiven Aufgaben hin- und herzuwechseln. In dieser Studie wurde eine bestimmte Variante des Paradigmas untersucht, welche Hinweisreize (sogenannte „Cues“) einsetzt, um den Probanden anzuzeigen, welche Aufgabe im nächsten Durchgang gelöst werden muss (Logan, Schneider & Bundesen, 2007). Der Aufgabenwechsel (in heterogenen Aufgabenblöcken) führt in der Regel zu einer verlangsamten Reaktionsgeschwindigkeit und zu erhöhten Fehlerraten im Vergleich zu der alleinigen Bearbeitung einer Aufgabe (in homogenen Aufgabenblöcken, Karbach, 2008). Diese Leistungsdifferenzen innerhalb des Aufgabenwechselparadigmas werden als „kognitive Kosten“ bezeichnet. Im Aufgabenwechsel zeigen sich Altersunterschiede in den Kostenmaßen und in der Aktivierung neuronaler Netzwerke im Gehirn (Cepeda, Kramer & Gonzalez de Sather, 2001; Karbach, 2008; Karbach & Kray, 2009; Kray & Lindenberger, 2000; Reimers & Maylor, 2005). Letzteres wurde beispielsweise durch die Untersuchung von ereigniskorrelierten Potenzialen (EKPs) im Elektroenzephalogramm (EEG) belegt (Gaál & Czigler, 2015; Eppinger, Kray, Mecklinger & John, 2007; Karayanidis, Whitson, Heathcote & Michie, 2011; Kopp, Lange, Howe & Wessel, 2014; West & Travers, 2008). EKP-Daten ermöglichen die Auswertung von Prozessen der Informationsverarbeitung im Millisekundenbereich und sind daher ein ideales Medium, um altersbedingte Unterschiede im Gehirn sichtbar zu machen. Forschungsergebnisse deuten darauf hin, dass im Alter eine zeitliche Verschiebung der kognitiven Kontrollprozesse stattfindet (Braver, 2012). Das „Dual-Mechanism of Control“ Modell von Braver (2012) unterscheidet zwei kognitive Prozesse der Informationsverarbeitung in kognitiven Aufgaben: Ein proaktiver Kontrollstil ist gekennzeichnet durch eine frühzeitige Auswahl und aktive Aufrechterhaltung von aufgabenrelevanter Information, schon bevor ein bestimmter Zielreiz erscheint, der eine Reaktion verlangt. Proaktive Kontrollstile werden beim Aufgabenwechsel dementsprechend bei der Präsentation des Hinweisreizes aktiviert und sorgen dafür, dass die korrekte Reaktion vorbereitet wird. Unter einem reaktiven Kontrollstil wird ein Korrekturprozess verstanden, der erst später im Verlauf und auch nur bei auftretender Interferenz während der Präsentation des Zielreizes eingesetzt wird. Generell sind beide Kontrollstile wichtig, um Aufgaben mit Hinweisreizen und Zielreizen zu lösen. Jedoch konnten EKP-Studien beweisen, dass sich ältere Erwachsene weniger auf proaktive Kontrolle berufen, sondern verstärkt reaktive Kontrolle einsetzen, selbst wenn keine Interferenz vorliegt (Karayanidis et al., 2011; Paxton, Barch, Storandt & Braver, 2006; Schmitt, Ferdinand & Kray, 2014). Darüber hinaus konnte bei älteren Erwachsenen ein Inhibitionsdefizit festgestellt werden (Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Zanto & Gazzaley, 2014). Das bedeutet, dass sich mit dem Alter die Fähigkeit, aufgabenirrelevante Informationen zu unterdrücken, zunehmend verschlechtert. Die zeitliche Verschiebung der Kontrollprozesse sowie das Inhibitionsdefizit bei älteren Erwachsenen sorgen schließlich für den altersbedingten Nachteil in Aufgaben zur kognitiven Kontrolle.

Um altersbedingten Unterschieden entgegenzuwirken, trainierten Forscher den Aufgabenwechsel mit älteren Erwachsenen und konnten beweisen, dass diese Art des Trainings zu einer Verbesserung in der Leistung sowie zu einer gesteigerten Effizienz neuronaler Verarbeitungsprozesse führte (Cepeda et al., 2001; Fehér, 2015; Gaál & Czigler, 2017; Karbach, 2008; Karbach, Könen & Spengler, 2017; Karbach & Kray, 2009; Karbach, Mang & Kray, 2010; Kray & Fehér, 2017). Diese Ergebnisse lassen darauf schließen, dass der Aufgabenwechsel verschiedene kognitive Kontrollprozesse erfolgreich trainiert. Dazu gehören unter anderem die Selektion, Aufrechterhaltung, Aktualisierung und Inhibition von Information (Monsell, 2003). Neben Verbesserungen in den Trainingsaufgaben sind Generalisierungseffekte auf anderen Aufgaben, die nicht trainiert wurden, interessant. Sogenannte „Transfereffekte“ konnten bei älteren Erwachsenen tatsächlich in strukturell ähnlichen und unähnlichen Aufgaben zur Messung der kognitiven Kontrolle gefunden werden (Karbach, 2008; Karbach & Kray, 2009). Allerdings beziehen sich Trainingsstudien meist auf Verhaltensmaße und weniger auf EKPs (Gajewski & Falkenstein, 2012). Nichtsdestotrotz boten vereinzelte neuronale Studien Grund zur Annahme, dass Transfereffekte im alternden Gehirn nach einem Aufgabenwechseltraining möglich sind (Gaál & Czigler, 2017).

Vor dem wissenschaftlichen Hintergrund hat sich diese Studie zum Ziel gesetzt, Trainings- und Transfereffekte eines kognitiven Kontrolltrainings, welches auf dem Aufgabenparadigma basiert, bei älteren Erwachsenen zu untersuchen. Dabei standen sowohl die Replikation vorangegangener wissenschaftlicher Befunde als auch die Ausweitung der Resultate auf EKP-Daten im Vordergrund. Mehr als 60 ältere Erwachsene nahmen an einem kognitiven Kontrolltraining teil, das sich über acht Sitzungen erstreckte. Die Intervention umfasste zwei Formen des Trainings: Ein reines Aufgabenwechseltraining und ein Einzelaufgabentraining. Die Evaluation der unterschiedlichen Trainingsformen beruht auf der Feststellung, dass ein reines Aufgabenwechseltraining durch die Übung von verschiedenen, spezifischen Kontrollprozessen eine erhöhte Effektivität gegenüber dem

Einzelaufgabentraining hat, welches lediglich zur Automatisierung der Einzelaufgaben führt (Karbach, 2008; Karbach et al., 2010; Karbach & Kray, 2009). Zusätzlich zu den beiden Trainingsgruppen wurde eine Kontrollgruppe von ca. 30 jungen, untrainierten Erwachsenen rekrutiert, um grundlegende Altersunterschiede in der kognitiven Leistung und neuronalen Aktivität zu untersuchen. Neben der Überprüfung der Altersunterschiede standen vor allem die Transfereffekte im Vordergrund. Um Transfereffekte zu messen, wurde ein Pretest–Training–Posttest Design gewählt. Vor und nach dem Training bearbeiteten die Teilnehmer drei kognitive Kontrollaufgaben: eine untrainierte Aufgabenwechselaufgabe, eine Kontextaktualisierungsaufgabe (AX-CPT, basierend auf Schmitt, Ferdinand & Kray, 2014) und eine Arbeitsgedächtnis- und Interferenzkontrollaufgabe (WMC Aufgabe, basierend auf Clapp, Rubens & Gazzaley, 2009). Die Transferaufgaben wurden anhand ihrer konzeptuellen Überschneidung mit dem Aufgabenwechselparadigma ausgewählt. Außerdem wurde eine Überlappung der neuronalen Kontrollnetzwerke, die in Trainings- und Transferaufgaben aktiviert werden, angenommen (Dahlin, Nyberg, Bäckman & Neely, 2008; Lövdén, Bäckman, Lindenberger, Schaefer & Schmiedek, 2010).

Die Ergebnisse der Studie zeigten deutliche Alterseffekte in den Transferaufgaben vor dem Training, sowohl in Leistungsmaßen als auch in den EKP-Daten. Vergleichbar mit bisherigen Forschungserkenntnissen verdeutlichten diese Effekte den Nachteil in der kognitiven Kontrollfähigkeit seitens der älteren Erwachsenen.

Darüber hinaus führte das kognitive Training zu einer Verringerung altersbedingter Unterschiede in den Transferaufgaben. Dabei zeigte sich insbesondere in den EKP Daten, dass beide Trainingsgruppen auf unterschiedliche Weise von dem Training profitierten. Während das Einzelaufgabentraining zu einer allgemeinen Automatisierung von Informationsverarbeitungsprozessen führte, wurden im Aufgabenwechseltraining mehrere Kontrollprozesse gezielt trainiert, was zu einer Leistungsverbesserung und neuronaler Umstrukturierung führte, die sogar in trainingsfremden Aufgaben nachweisbar war. Allerdings wiesen die EKP-Daten darauf hin, dass das Training weniger zu einer rückwirkenden Verschiebung der Kontrollprozesse, sondern zu einer verstärkten Effizienz sowohl proaktiver als auch reaktiver Kontrolle bei älteren Erwachsenen führte. Das bedeutet, dass sich durch spezifisches Aufgabenwechseltraining eine verbesserte Balance kognitiver Kontrolle im alten Gehirn etablierten lässt, die zu einer Optimierung zielgerichteten Verhaltens führen kann. Folglich bieten diese Befunde eine wertvolle Grundlage für die Ausarbeitung wissenschaftlicher Trainings zur Minderung altersbedingter Abbauprozesse in der Leistung und im Gehirn.

I. Theoretical Part

1. Introduction

Life is full of changes. Contrary to the belief that developmental changes in behavior and cognition solely happen until a certain point in adulthood, the "life-span theory" proposes that people constantly adapt their behavior and cognition to their surroundings, and this adaptation proceeds into old age (Baltes, Lindenberger, & Staudinger, 2006). In this context, it is important to emphasize that developmental change is multidirectional. Across the lifespan, there are processes of growth, decline, regulation, and maintenance happening in human cognition (Baltes et al., 2006). The issue of cognitive decline is of particular importance with regard to changes in very old age[1]. Changes in the older brain become apparent in everyday life, as older adults complain about troubles remembering phone numbers, concentrating on essential information during a conversation, or simply keeping up with our high pace environment. Scientific studies showed that these problems are manifested in common age-related differences in memory, attention, or processing speed. However, older adults seem particularly wise as they gathered knowledge and experiences throughout their entire life, characterizing another developmental change that happens over the lifespan. This dichotomy in cognitive aging is described in the "two-component model of lifespan intellectual development" (Baltes, 1993; Baltes, Staudinger, & Lindenberger, 1999; Cattell, 1971; Horn, 1982; Lindenberger, 2001).

In order to pin down age-related differences in cognitive functions such as processing speed or memory performance, it is important to understand how the human brain coordinates these functions summarized under the concept "cognitive control" (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001). Cognitive control mechanisms allow information processing and behavior to adapt depending on individual goals and rules of the environment (Braver, Gray, & Burgess, 2007). This construct is well researched because markers of cognitive control can be measured empirically in standardized cognitive tasks.

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[1] In this study, the term "older adults" refers to the population from 60 years of age, whereas "younger adults" refers to the age range of 20-30 years.

Furthermore, there are prominent age-related differences one can observe in the performance and processing during cognitive control tasks. Older adults typically show a general decline in cognitive control processes, resulting in poorer performances in the tasks (Bishop, Lu, & Yankner, 2010; Reuter-Lorenz, 2002). This performance gap can be linked to age-related differences in the functionality of neural networks of the older brain (e.g., Braver et al., 2001). The fundamental question is: Are these age-related differences inevitable?

Returning to the principle of multidirectional change in cognitive development, the question has been raised whether the older brain is capable of the regulation or even the prevention of cognitive decline. Recent intervention studies aiming at enhancing cognitive control in older adults showed that a cognitive training can lead to significant performance improvements in several tasks (for a review, see Karbach & Verhaeghen, 2014; Karr, Areshenkoff, Rast, & Garcia-Barrera, 2014; Kelly et al., 2014). Public markets and industries are taking the opportunity to publish innumerable different training programs tailored to the hopes of older adults to boost their cognitive abilities. With catch lines like “Train your brain!”, these programs promise improvements in cognition, such as better memory performance, faster processing speed, or even higher intelligence. Openly advertised and widely available, cognitive trainings appear in various forms and are accepted as a trusted tool.

With the increasing supply of training programs, there is a responsibility to inquire if and how trainings can enhance the performance in specific or general cognitive functioning in older adults. One problem concerning the investigation of training efficiency is the vast variety of training concepts and designs. It has proven difficult to pin down certain training characteristics that are responsible for its efficiency. For example, the probable success of a cognitive training relies on its material and inherent structure, the frequency and intensity of its application, and not least on the individual that is being trained.

Another question that arises is whether training-induced changes in cognition can actually be measured empirically after the training intervention. Is it possible to determine substantial changes in behavioral performance and inside the brain, meaning modifications in structural or functional characteristics of neural networks? Empirical evidence on this issue mostly relies on the concept of “cognitive plasticity”, which means the ability of the brain to modify the structure or function of its networks (Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010). This process generally allows the constant adaptation to changing environments across the lifespan, but it can also be activated in order to recover cognitive functions that were lost, for example, due to physical or cognitive disorders. The possibility that cognitive training might support potential brain plasticity is another good argument for investigating the efficiency of training programs, especially for older adults.

The last question concerns the transferability of training effects to other, untrained cognitive domains or even to everyday life situations. Is there an additional performance improvement in tasks that were not part of the training intervention, but that call for the same cognitive mechanisms and therefore the same neural networks that have been trained? The issue of so-called “transfer effects” in the research literature is comprehensive, yet complex. Studies showed that the possibility of transfer effects often is limited in its extent and duration (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008). There are various factors that can influence the probability of transfer, for example the structural similarity of the trained and untrained tasks (Rickard & Bourne, 1996). Transfer effects, in terms of improved cognitive performance in a transfer task, seem more likely to occur when the two tasks are similar (near transfer), than when they are dissimilar (Woodwarth & Thorndike, 1901). Nonetheless, far transfer is possible as long as the transfer task demands the trained cognitive functions (Gajewski & Falkenstein, 2012; Shipstead, Redick, & Engle, 2012). Literature on training and transfer effects of cognitive practice mainly focuses on processes of attention, memory, reasoning, or general cognitive control, showing that specific interventions were able to improve behavioral performance in older adults (e.g., Basak, Boot, Voss, & Kramer 2008; Bherer et al., 2005). However, there are less studies that use neuroimaging techniques like electroencephalography (EEG) or functional magnetic resonance imaging (fMRI) to investigate training-induced changes on the neural level underlying the observable behavioral changes (Gajewski & Falkenstein, 2012).

This thesis was dedicated to answering all these questions in a scientific manner. The goal was to examine training-induced changes in age-related differences after cognitive control training. Not only was the efficiency of the training procedure important but the transferability of the training effects to other, similar and dissimilar cognitive control tasks was of interest. Therefore, a scientific experiment with older adults was conducted in a pretest–training–posttest design. Training-induced changes were examined in task performance and neural activity by means of EEG. Age-related differences in behavior and neural activity were examined by comparing older adults with an additional study group of younger adults. The cognitive control training in this study was based on the task-switching paradigm (e.g., Monsell, 2003) because the paradigm is well studied and widely cited in the literature on cognitive control. As previous studies pointed out, training-specific characteristics play an important role in the generalization of training effects (e.g., Karbach & Kray, 2009). Therefore, two forms of trainings were implemented.

Numerous scientific training studies examined task-switching trainings on the behavioral and neuronal level (e.g., Gaál & Czigler, 2017; Karbach, 2008; Karbach & Kray, 2009). Task-switching training has proven to display age-related differences and to be trainable in older adults. Lastly, the paradigm is known to elicit distinct neural activation, which can be detected by means of EEG techniques and interpreted as components of cognitive control.

In order to integrate the study results into the current theoretical background, the thesis is divided into a theoretical and an empirical part. The theoretical part provides a summary of scientific literature, including definitions and models of cognitive control, training, and transfer. Moreover, the task-switching paradigm and its operationalization are described. Empirical effects of task-switching training to the behavioral performance and neural activity in older adults are presented hereinafter. The theoretical part ends with the research hypotheses that are derived from the theoretical background. The empirical part outlines the experimental design and measures of the study, and is followed by the presentation of the results. The thesis concludes with a discussion of the study outcome with regard to the pre-existing literature and the accentuation of implications for further scientific endeavor.

To sum up, this thesis contributes to the clarification whether a compensation of cognitive decline in older adults can be achieved by means of cognitive training and whether this compensation is limited to the trained task or can be transferred to untrained tasks. Because in the end, training programs that boost cognitive performance and neural activity in the older brain, would result in an enhanced life quality for the elderly (Gajewski & Falkenstein, 2012).

2. Review of Literature

The review of literature is divided into two main sections. The first section introduces the construct of cognitive control, including its theoretical background, measurements, and empiric findings on age-related differences. The second section provides an overview of the trainability and transferability of cognitive control processes, as well as the operationalization of cognitive training. Moreover, recent behavioral and neural findings on training-induced changes in age-related differences by means of cognitive control training are presented.

2.1 Cognitive Control

2.1.1 Attempt at a definition.

Cognition is referred to as the collection of thoughts, experiences, and expectations. Cognitive control, sometimes labeled as executive functions, describes the mechanisms of regulation and coordination of the many cognitive and motivational abilities that are involved in goal-directed behavior (Botvinick & Braver, 2015; Jurado & Rosselli, 2007; Unsworth et al., 2009). Because of the complex interaction of many diverse abilities that form part of cognitive control, this construct is hard to grasp and to define (Baggetta & Alexander, 2016; Jurado & Rosselli, 2007; Miyake et al., 2000; Morton, Ezekiel, & Wilk, 2011). However, there are several approaches that agree upon certain characteristics of the construct. In general, cognitive control involves higher-order control processes, such as working memory, that operate lower-order processes, such as sensory perception, and thus allows the execution of adaptive responses to a complex environment (Ahmed & Miller, 2011; Cooper, Garrett, Rennie, & Karayanidis, 2015; Hughes, 2011; Miller & Cohen, 2011). These higher-order processes act upon internal goals and expectations, as well as external conditions of the environment (Braver, 2012). Although cognitive control processes are typically described as being of voluntary nature, it is difficult to assess these processes in behavioral performance. Neuroimaging techniques are able to uncover neural activity that is associated with cognitive control, however, the identification of individual control mechanisms remains problematic. Consequently, experts target specific functions, which proved to be measurable in behavior and also to be associated with explicit patterns of neural activity. Exemplary functions include the selection, maintenance, inhibition, and updating of information (Braver & Barch, 2002; Braver & Cohen, 2000; Diamond, 2013; Grange & Houghton, 2014; Morton et al., 2011). Response selection means the goal-directed selection of a particular action or information that seems relevant in a specific situation from a variety of alternatives. Before a reaction can be performed, actions or information has to be actively maintained and shielded against distraction like predominant or automatic responses. This protection is supported by processes of working memory and response inhibition (Baggetta & Alexander, 2016; Clapp & Gazzaley, 2012). Finally, the updating of context information depending on current goals and rules is important for the adaptation to changes in the environment (Schmitt, Ferdinand, & Kray, 2014). The labels for the specific cognitive control functions differ between the theoretical models. However, there is a consensus on the idea that cognitive control includes a set of regulatory functions that guide actions and allow processes of learning (Baggetta & Alexander, 2016; Giesen, Eberhard, & Rothermund, 2015).

Cognitive control processes can be discovered and explained in everyday life. The following example is based on Miller and Cohen (2001) and shows how basic cognitive control processes act and interact in order to guide goal-directed behavior: While standing at a crosswalk, people generally choose to look left before crossing, which reflects the selection of relevant behavior based on their knowledge about traffic rules. The action of crossing will be performed successfully if people can maintain the current intention and context information, which includes looking out for cars and other obstacles. Another key task of cognitive control is the inhibition of upcoming distractions or the appropriate allocation of attention in order to perform two tasks at once, for example, when the phone is ringing. Moreover, in some countries like the United Kingdom, it is important to adapt the goal-directed behavior and to look right before crossing, considering the different traffic rules. In this case, foreign people even need to inhibit the predominant reaction to look left first before crossing[2].

2.1.2 Models of cognitive control.

Scientific models of cognitive control made great progress in the 1980s with Baddeley's "multi-component model of working memory". In his model, Baddeley (1986) specified one central executive; a storage unit of limited capacity that regulates further subsidiary systems for language and visuospatial information. Another influential model was proposed by Norman and Shallice (1986), which also included a central supervisory attentional system (SAS) that manipulates the selection of action sequences, so-called "schemata". According to the authors, every action and situation is stored in form of mental schemata in working memory and is reactivated in the confrontation with similar situation. In their "model of attentional control", the authors assumed that the SAS is required when actions are novel or when intentional planning is necessary. Therefore, the SAS operates on a higher level in order to coordinate lower-level processes by either activating or inhibiting schemata with regard to the demands of the current situation. Furthermore, Norman and Shallice (1986) proposed different modes of control, on a scale from automated behavior to deliberate conscious control.

The verification of one single cognitive control component proved to be difficult, and a more modern view on cognitive control suggests that several distinct, but interacting mechanisms are involved in the control process (Weingartner, 2000). Miyake and colleagues (2000) suggested a concurrent unity and diversity of cognitive control mechanisms, which means that "executive functions may be characterized as separable but related functions that share some underlying commonality" (Miyake et al., 2000, p. 88). The authors categorized three components of cognitive control: (1) mental set shifting, (2) information monitoring and updating, and (3) inhibition of predominant actions. A confirmatory factor analysis confirmed a separable, but moderately correlated co-existence of the three cognitive control functions. Miyake's model seems to be

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[2] It should be noted that this example is meant for illustrating purposes only. In any case, people should look both left and right before crossing a street.

largely accepted, and the three components rank amongst the most frequently mentioned components of cognitive control in adults (Baggetta & Alexander, 2016). Diamond (2013) argued that three independent components of cognitive control (inhibition, working memory, and cognitive flexibility) work together to form more complex cognitive functions like reasoning and problem solving.

One demonstration for the diversity of cognitive control functions can be derived from clinical studies on patients with frontal brain damage (Miyake et al., 2000). The application of cognitive control tasks or so-called "frontal lobe tasks" led to a selective dissociation in performance among the patients, although all subjects shared damage in the prefrontal cortex (PFC, Godefroy, Cabaret, Petit-Chenal, Pruvo, & Rousseaux 1999). Hence, it is not yet clearly determined if the prominent cognitive control functions are coherent or truly independent from each other. It seems that the answer to the unitary-diversity question of cognitive control lies somewhere in between. The "symphony orchestra metaphor" by Brown (as cited in Hass, Patterson, & Sukraw, 2014) captured the integrative and supervisory characteristics of cognitive control well: While individual musicians in an orchestra may play well, a whole symphony only arises with the support of a reliable conductor.

Especially with the growing possibilities in the field of neuroscience over the last decades, research put forth several neural correlates of cognitive control processes. As mentioned above, cognitive control processes have been linked to the activation of certain neural networks in the brain (e.g., Godefroy et al, 1999). Neural networks are generally understood as a cluster of neurons that serves the successful implementation of a specific cognitive mechanism (Tau & Peterson, 2010). Therefore, neural networks are in constant exchange with each other in order to receive and transmit collected information and to adapt to current situations or cognitive tasks. The importance of the frontal cortex in such regulatory processes of cognitive functioning became apparent in clinical case studies. A popular example from the 19th century is Phineas Gage, a patient who suffered from a major brain lesion in the frontal lobe that caused a profound change in his personality. A further consequence of the damage was his impaired functioning in everyday life, despite intact cognitive functioning of speech, memory, and intelligence. Researchers claimed that it was the higher-order ability of reasoning and behavioral control that was affected after Gage's accident (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). As other clinical cases of similar frontal brain damage arose, scientific interest in the assignment of frontal areas to cognitive functioning grew further. Especially the PFC has been associated with cognitive control processes like rule use and planning of human behavior (Braver, 2012; Braver et al., 2007; Bunge & Zelazo, 2006; Jurado & Rosselli, 2007; Miller & Cohen, 2001). Because the PFC consists of several subregions with different cellular structures and connections to other brain regions, it is assumed that each subregion makes a unique contribution to cognitive control. That would explain the great diversity of impaired cognitive control function in patients with prefrontal brain damage (Miyake et al., 2000). Miller and Cohen (2001) suggested that the dopaminergic system, which is located in the PFC, is connected to cognitive control processes. Their "guided activation theory of prefrontal cortex" states that neural activity within the PFC is related to the mental representations of current goals and context rules. The authors further proposed that the major responsibility of the PFC is sending top-down signals to posterior (sub)cortical areas that are involved in the implementation of the mental representations into behavioral responses.

The great variability in cognitive control performance is not restricted to clinical studies. According to Braver (2012), variabilities in the healthy brain can be caused by differences in temporal dynamics of information processing. In the "dual-mechanism of control" (DMC) model, he postulated two distinct modes of control that work semi-independently and operate at different times during information processing (Braver, 2012; Braver et al., 2007). A proactive control mode is characterized by the sustained maintenance of context information that is relevant for the response to a certain stimulus. This control mode occurs at an early stage in information processing and serves as a top-down mechanism. Proactive control is associated with the activation of neural networks in the lateral PFC. Reactive control modes are necessary at a later stage in information processing and serve the purpose of interference resolution in confrontation with a conflict. Whereas proactive control is of an anticipatory and preventive nature, reactive control is brief and stimulus-driven. Reactive mechanisms function in a bottom-up manner as they reactivate task goals and intentions by recruiting the lateral PFC alongside additional brain networks (Braver, 2012). Despite their temporal division, the activity of both control modes is necessary to optimize goal-directed behavior. The DMC model can be illustrated with the Stroop task, which is the most commonly used task to measure cognitive control (Baggetta & Alexander, 2016; Braver, 2012; Stroop, 1935, for a review, see MacLeod, 1991). In the Stroop task, individuals are presented with consecutive color words and are instructed to read them out loud. The letters are either inked in the same color as the word (congruent condition, i.e., the word “blue” in blue color) or in a different color (incongruent condition, i.e., the word “red” in green color). A Stroop interference effect can be detected as individuals usually respond slower and make more errors in incongruent task conditions than in congruent task conditions. According to Braver (2012), people show intra- and inter-individual tendencies toward proactive or reactive control modes in the Stroop task (see Figure 1). Subjects who respond slower in incongruent task conditions usually have a tendency toward a reactive control mode, which is activated when interference is detected (last picture). In contrast, subjects with an enhanced proactive control mode engage processes of active maintenance of task-relevant goals during the inter-trial interval (first and third picture), which leads to a smaller Stroop interference effect for incongruent task conditions.

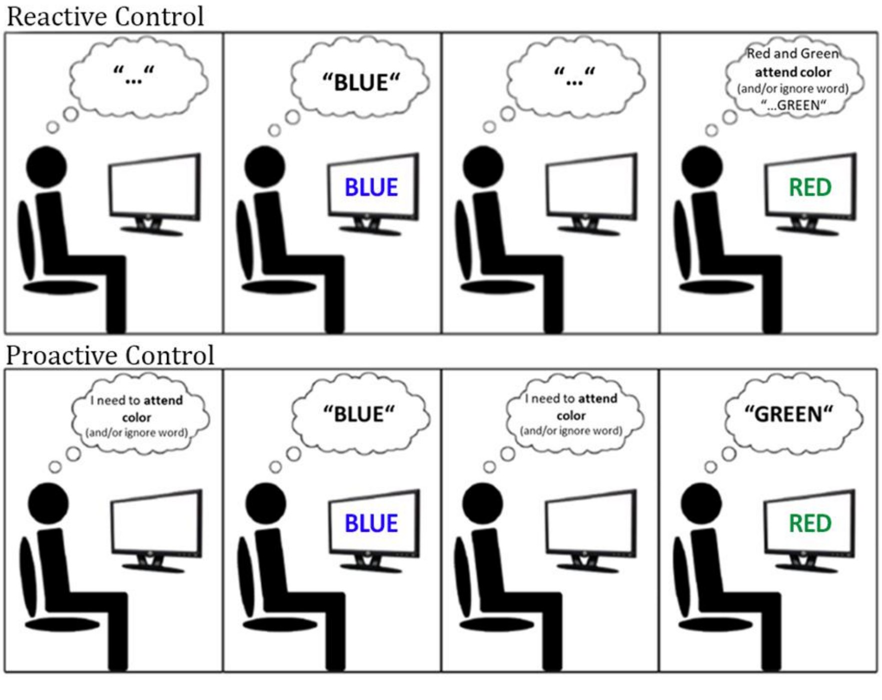

Figure 1. Illustration of proactive (upper panel) and reactive (lower panel) control modes, according to the DMC model by Braver (2012) in the Stroop color-naming task.

The goal of the dual-mechanisms framework is the explanation of inter- and intra-individual variability in cognitive control performance. Braver (2012) argued that people vary in their tendency toward one type of control strategy, depending on the features of a given task, but also depending on their age. According to the DMC model, age-related differences in cognitive control tasks are caused by a shift from proactive to reactive control modes in older adults.

Aging and cognitive control. As people grow older, cognitive performance declines, which is linked to developmental changes in the brain. Although cognitive control processes play an important role in cognitive aging, only few scientific studies included populations of old age (Baggetta & Alexander, 2016). The most prominent model that explains life span developments in cognition is the “two-component model of lifespan intellectual development” (Baltes, Staudinger, & Lindenberger, 1999). Based on the model of fluid and crystallized intelligence (Cattell, 1971; Horn, 1982), the two-component approach describes two central components of intellectual functioning. The first component is named “cognitive mechanics”. Mechanics include basic functions of information processing, such as speed, accuracy, and the coordination of mechanisms. Cognitive mechanics are domain-specific and can be measured in cognitive tasks that demand memory performance, selective attention, or stimulus discrimination. The second component is named “cognitive pragmatics” and stands for bodies of knowledge that can be both universal in human evolution and specific to human cultures. Examples for pragmatics are verbal knowledge, expertise, problem-solving in everyday life situations, and general self-knowledge and -awareness (Baltes et al., 2006). Mechanics and pragmatics do not function independently, and their trajectories show a different gradient throughout the human life span. Mechanics develop earlier and are a result of ongoing biological evolution. They tend to decline during adulthood, proceeding into old age. Pragmatics on the other hand are assumed to gain importance at a later stage in life as they remain stable throughout adulthood and are sensitive to change in a very late stage of life. According to the two-component model, age-related differences in cognitive control are based on the decline in cognitive mechanics in older age, which leads to impaired response selection, memory, inhibition, and multitasking (Baltes et al., 2006). According to the “goal maintenance account of aging“, Braver and Barch (2002) proposed that age-related differences in cognitive control mainly result from impairments in the maintenance of task-relevant information in older adults. The interface between cognitive control in general and cognitive mechanics in Baltes’ model (2006) is the manifestation of belonging processes in the PFC. As humans grow older, this brain area and functionally connected regions show the first signs of decay and so do mechanics and cognitive control processes (Baltes et al., 2006).

In order to link age-related decline in cognitive functioning to neuropsychological frameworks, Albinet, Boucard, Bouquet, and Audiffren (2012) contrasted two theoretical approaches: the “processing speed theory of adult age differences” (Salthouse, 1996) and the “prefrontal executive theory” (West, 1996). Salthouse (1996) assumed that poorer cognitive performance in older adults is related to a general slowing in processing speed. The general slowing impairs the successful execution of basic cognitive operations and the synchronization of early and late functions of information processing. Hence, the processing-speed theory states one global slowing mechanism that is responsible for age-related differences in various cognitive domains. The prefrontal executive theory (West, 1996), however, proposes a reverse chain of events that leads to impaired cognitive control in older adults. According to this theory, age-related differences are due to neural changes in specific areas within the PFC. These local changes cause a decline in the specific corresponding cognitive control functions, which then leads to a more general cognitive impairment (Albinet et al., 2012). In their study, Albinet and colleagues (2012) concluded that both theories are not mutually exclusive and can be integrated in order to explain age-related differences in cognitive control.

As stated above, there is a consensus about the involvement of the PFC and associated brain networks in cognitive aging (Braver, 2012; Braver & Barch, 2002; Schmitt, Ferdinand, & Kray, 2014). Braver and colleagues (2001) focused on functional and dynamic changes in the PFC and postulated that an age-related change in the prefrontal dopamine system is linked to the decline in context information processing in older adults. According to the DMC model (Braver, 2012), older adults show a less efficient use of proactive control, whereas reactive control appears to remain intact. Evidence for this assumption was provided by neuroimaging studies with older adults that demonstrated decreased brain activation in early stages and increased brain activation in later stages of information processing within the same regions of the lateral PFC (e.g., Paxton, Barch, Storandt, & Braver, 2006).

In sum, impairments in cognitive control that increase with age are most likely to be traced back to a combination of a general slowing of executive operations and a decline in specific cognitive control functions, both related to neural changes in the lateral PFC. One reliable way to assess age-related differences in cognitive control is to compare the performance and neural activity between older and younger adults in standardized cognitive tasks. A selection of prototypical tests of cognitive control will be presented in the following section.

2.1.3 Representative measures of cognitive control.

The operationalization of cognitive control is as diverse as its definition. Baggetta and Alexander (2016) reviewed cognitive control tasks from the latest literature and argued that the most commonly used measures demanded processes of information updating, maintenance, and inhibition. Attention will be drawn to the three performance-based cognitive control tasks that were used in this study. The selected tasks allowed the investigation of cognitive costs in specific domains of cognitive control in a controlled setting. Cognitive costs in terms of performance differences usually emerge when task stimuli are ambiguous and cause interference (e.g., Posner & Snyder, 2004).

Task switching. The task-switching paradigm is well-investigated and subject of many scientific studies, especially regarding age-related differences in cognitive control (Cepeda, Kramer, & Gonzalez de Sather, 2001; Eppinger, Kray, Mecklinger, & John, 2007, Fehér, 2015; Gaál & Czigler, 2015; Karayanidis, Whitson, Heathcote, & Michie, 2011; Karbach, 2008; Karbach & Kray, 2009; Kray, 2006; Kray, Eber, & Lindenberger, 2004; Kray, Eppinger, & Mecklinger, 2005). The following section will provide a general introduction to the paradigm. For a detailed description of the cued switching task that was applied in this study, see chapter 4.3.2.

Task switching is defined as the ability to flexibly switch between at least two cognitive tasks. First applied in the early 20th century by Jersild (1927), switching tasks are used to investigate alternation costs in the response time that occurred between trials in which subjects repeated one simple task and trials in which they alternated between tasks. With the ongoing progress in research, including reliable measurements of reaction times (RT), the task-switching paradigm was widely used and further modified in many studies (for a review, see Kiesel et al., 2010; Monsell, 2003).

In the switching task, individuals are usually instructed to respond to target stimuli that are presented in rapid succession on a computer screen. One example of a switching task would be a two-choice task that requires the categorization of shapes (task A) or colors (task B) of target items (cf. Karbach, 2008). To evoke interference and thus to increase cognitive demands, target items are ambiguous, meaning they are either round or angular, and either red or green. There are two types of task blocks: During single-task blocks, only task A or task B has to be performed, whereas mixed-task blocks require the performance of both tasks in an alternating sequence. The task switch can either be predetermined by internal cues, for example, with a fixed sequence of tasks (AABBAABB…, cf. Kray & Lindenberger, 2000), or can be signalized by an external cue (Jost, De Baene, Koch, & Brass, 2013; Karbach & Kray, 2007; Kray, 2006). The latter method is called cued task-switching (e.g., Logan, Schneider, & Bundesen, 2007).

Although shifting between two simple tasks sounds easy, the action includes more than just going back and forth, but switching between the different mental representations of the tasks, the so-called task sets (Monsell, 2003). A task set usually refers to the mental representation of the global context as well as the specific characteristics of the task, including the distinct responses and their mappings to the task stimuli, such as cues and targets (Gade & Koch, 2007; Koch & Brass, 2013). The different task sets have to be learned, maintained in working memory, and reconfigured, once the task demands for a switch. Task switching requires the manipulation of internal intentions (e.g., task goals) and external, contextual influences (e.g., characteristics of cue and target stimuli). Moreover, it demands higher-order mechanisms of response-selection and -inhibition, maintenance and retrieval of the task sets from working memory, as well as updating of the relevant information in response to context changes

(Monsell, 2003). With that in mind, Diamond (2013) declared the ability of task switching to be a fundamental component of cognitive control (see also Czernochowski, 2015; Karbach & Kray, 2009; Kiesel et al., 2010; Koch & Brass, 2013; Miyake, et al., 2000).

Shifting between cognitive tasks comes at a cost, which is usually reflected in slower response times and increased error rates when trials involve a task switch (for a review, see Grange & Houghton, 2014; Rogers & Monsell, 1995). The task-switching process allows the examination of different types of cognitive costs. The first type can be measured by comparing task performance between mixed-task blocks and single-task blocks (Kray & Lindenberger, 2000). Possible labels are global costs, set selection costs, or mixing costs (Kiesel et al., 2010; Mayr, 2001; Reimers & Maylor, 2005). However, it should be noted that there is another definition for mixing costs, when referred to as being non-switch specific (Huff, Balota, Minear, Aschenbrenner, & Duchek, 2015; Marí-Beffa & Kirkham, 2014). Non-switch specific costs are defined as the difference in task performance between non-switch trials (repetition of task A or B without a switch between the tasks) within the mixed-task blocks and single-trials within the single-task blocks (Cragg & Chevalier, 2012; Karayanidis et al., 2011). The latter form of mixing costs was investigated in the present study and is referred to as general switch costs. The underlying cognitive process signified by the general switch costs is the sustained maintenance of the multiple task sets in working memory as well as the selection of the relevant task set over the alternative one (Cragg & Chevalier, 2012; Marí-Beffa & Kirkham, 2014; Reimers & Maylor, 2005). Grange and Houghton (2014) pointed out that task repetitions within mixed-task blocks take more time than pure repetitions within the single-task blocks, even though both trial types are, strictly speaking, repetition trials.

Besides general switch costs, the switching task evokes specific switch costs that refer to the difference in task performance between switch trials and non-switch trials in the mixed-task blocks (Kray & Lindenberger, 2000). Other terms used in the literature are local costs or switching costs (Cragg & Chevalier, 2012; Karbach & Kray, 2009). The underlying mechanism associated with specific switch costs is the preparation for the switch itself, meaning the reconfiguration of the task sets. Specific switch costs appear due to more time-consuming initiations of responses in switch trials compared to non-switch trials (Monsell, 2003). Cognitive costs were usually reduced when individuals had more time to prepare their responses or when they received training in the switching task (Sohn & Anderson, 2001). However, residual costs remained, which indicates a limitation in advance preparation. Residual costs occur because inhibitory processes of the previously suppressed task-set have to be resolved (Arbuthnott & Frank, 2000; Kieffaber & Hetrick, 2005; Verbruggen, Liefooghe, Vandierendonck, & Demanet, 2007).

AX-Continuous Performance task (AX-CPT). The ability to maintain and update task information as key functions of cognitive control can also be measured in continuous-performance tasks (Braver, 2012; Schmitt, Ferdinand, & Kray, 2014). The AX-CPT allows testing proactive and reactive control modes because the task demands both anticipatory and inhibitory processes. One example for the AX-CPT was implemented by Braver and colleagues (2001, see Figure 2). In their version, cue-target combinations of single letters were shown successively on a computer screen. Responses had to be given by button presses to the target letter X, but only if the target was preceded by the cue letter A. For the three non-target combinations, A-Y, B-X, or B-Y[3], a non-target response by pressing a different button had to be executed. Hence, correct responses to the target letter depended on the context information that was provided by the cue letter (A versus not A, Braver et al., 2001; Schmitt, Ferdinand, & Kray, 2014).

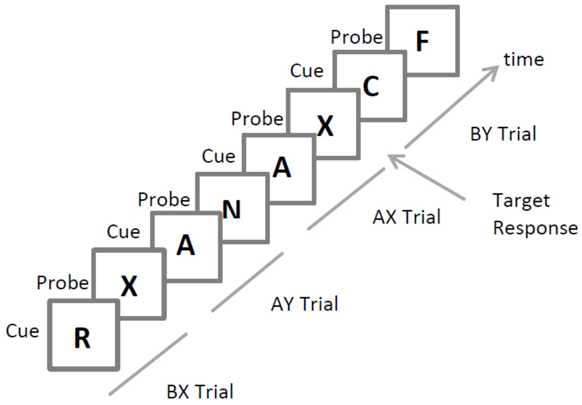

Figure 2. Trial procedure of the AX-CPT (Braver et al., 2001, adapted from Schmitt, 2015).

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[3] B standing for any other cue letter, Y standing for any other target letter.

The AX-CPT in this study was based on the version by Schmitt, Ferdinand , and Kray (2014), which included four cue and four target stimuli in order to form a context-independent and a context-dependent task condition (Lenartowicz, Escobedo-Quiroz, & Cohen, 2010). For a detailed description of the task, see chapter 4.3.2.

Working memory and interference control task. Working-memory performance is one important mechanism of cognitive control. In order to maintain mental representations of task goals, rules, and sets, the working-memory system is needed. Furthermore, processes of enhancement or inhibition of certain information can support the performance in a cognitive task (Clapp & Gazzaley, 2012). Delayed-recognition tasks allow the investigation of the cognitive ability to maintain and manipulate information over a certain time period. Individuals are instructed to memorize a given input (e.g., a picture of a landscape), maintain this information during a delay, and make a match/non-match decision when confronted with the target (landscape). In order to increase the cognitive demands, interfering stimuli can be presented during the delay period. When confronted with interference, individuals usually show poorer working-memory performance for the match/non-match task (Clapp & Gazzaley, 2012; Clapp, Rubens, & Gazzaley, 2009). The working-memory control (WMC) task applied in this study was similar to the delayed-recognition task by the Gazzaley Lab (Clapp et al., 2009; Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Gazzaley, Cooney, McEvoy, Knight, & D'Esposito, 2005, see chapter 4.3.2).

In sum, research literature provides a wide range of tasks to measure the key functions of cognitive control. The switching task, AX-CPT, and WMC task will be used in this study, as they capture specific key components of cognitive control, including switching, maintenance and updating, and inhibition of task information. Nevertheless, every task puts the focus on selective components of cognitive control.

2.1.4 Electrophysiological correlates in cognitive control tasks.

Neuroimaging studies are an exciting approach for the understanding of the cognitive processes that underlie human behavior. Neuroimaging techniques provide insights into cognitive activity, even if no behavioral action is happening, for example, when preparing for responses or when ignoring task-irrelevant information. Electroencephalography (EEG) is a commonly used technique for measuring brain activity during cognitive tasks. In EEG, scientists investigate event-related potentials (ERPs) that are clearly distinguishable from the EEG activity during a resting state. The occurrence of ERPs is linked to certain cognitive mechanisms that are activated in order to operate a task. For example, the presentation of a cue that indicates a particular response to an upcoming target evokes a particular ERP that can be associated to task-preparatory processes. The main advantage of EEG over structural neuroimaging techniques is its high temporal solution, meaning that different stages of information processing can be addressed in units of milliseconds. Especially when neural activity is generated within the same brain region, structural techniques fail to separate individual processes on a continuous timeline. Furthermore, the investigation of amplitude and topography of ERPs can provide information on the functional and structural characteristics in the brain (Linden, 2005). Results of EEG studies are usually based on data of amplitudes and latencies for ERPs. Due to the large scale of this study, and in order to maintain consistency, neural results are based on mean amplitude scores only (see chapter 5).

Many EEG studies focused on the P3, a component that has been hypothesized to reflect higher-order processes of cognitive control (e.g., Polich, 1996, 1998). The P3 is a positive component that appears around 300-600 ms after stimulus presentation (Bledowski et al., 2004; Polich, 1996; Schmitt, Ferdinand, & Kray, 2014). The potential was first reported by Sutton, Braren, Zubin, and John (1965) in connection with processes of anticipation and uncertainty that occurred in the time interval between a cue and target stimulus. Subsequent studies investigated the P3 in the oddball paradigm in which an infrequent target is presented in the context of frequent standard stimuli (Donchin, Ritter, & McCallum, 1978). Results from oddball studies showed robust P3 activity in conjunction with the presentation of novel, task-relevant stimuli (cf. Donchin & Coles, 1988).

As neuroimaging techniques improved over time, studies found that P3 activity was generated and manifested in frontal and parietal brain regions (e.g., Bledowski et al., 2004; Kieffaber & Hetrick, 2005; Periáñez & Barcélo, 2009).

Besides its multifocal occurrence, the P3 seems to consist of multiple components. Kok (2001) described an overlap of the P3 with other neural components, such as negative slow waves, as well as an overlap between multiple P3s. Polich (2007) separated an early frontal positivity (P3a) reflecting stimulus-driven attentional processes from a late parietal positivity (P3b) reflecting memory processes. Despite the diversity in the temporal partitioning, the sustained brain activity of the P3 is generally presumed to reflect various processes of task preparation.

Given the fact that the P3 is sensitive to experimental manipulations in cognitive tasks, the connection between the P3 component and cognitive control mechanisms is not far-fetched. In fact, clinical studies provided evidence that patients with frontal brain damage not only showed abnormalities in behavioral performance, but also in P3 activation during cognitive control tasks compared to healthy individuals (Beer, Shimamura, & Knight, 2004; Knight, 1984).

The investigation of the P3 in experimental settings allows a linkage of the waveform pattern to distinct stimuli in a cognitive task in order to isolate separate mechanisms of information processing. Therefore, the P3 is a popular tool to approach processes in cognitive control tasks that measure task switching, context processing, and interference control (Donchin and Coles, 1988; Gajewski & Falkenstein, 2012; Gajewski, Freude, & Falkenstein, 2017; Karayanidis et al., 2011; Polich, 1998, 2007; Schmitt, Ferdinand, & Kray, 2014). The "context updating model of the P3 component" claims that P3 activity reflects updating of working memory (Donchin & Coles, 1988; Verleger, Jaśkowski, & Wascher, 2005). According to the theory, the magnitude of the P3 is associated with attentional resources that are available to adjust to incoming stimuli (Donchin & Coles, 1988). Therefore, P3 amplitudes are expected to differ between the context conditions of cognitive control tasks, depending on the workload.

In the cued task-switching paradigm, P3 amplitudes were investigated for the interpretation of cognitive costs. Barceló, Periáñez, and Nyhus (2008) showed that cue-locked positivity amplitudes in a switching task were larger for switch trials than for non-switch trials (see also Gajewski & Falkenstein, 2011; Hsieh & Chen, 2006; Karayanidis et al., 2011, Kieffaber & Hetrick, 2005; Kray et al., 2005; Li, Wang, Zhao, & Fogelson, 2012). The authors assumed two underlying mechanisms of task preparation in the cue-target interval: (1) the reactivation of task sets and (2) the updating of stimulus-response mappings. Changing task representations elicited larger cue-locked P3 amplitudes due to updating processes (Donchin & Coles, 1988; Periáñez & Barceló, 2009). In the target-response interval, P3 amplitudes appeared to be related to the implementation of task sets as a part of the response execution (see also Mansfield, Karayanidis, & Cohen, 2012; Nicholson, Karayanidis, Bumak, Poboka, & Michie, 2006, Nicholson, Karayanidis, Poboka, Heathcote, & Michie, 2006; Rushworth, Passingham, & Nobre, 2002). In contrast to the cue-locked P3, target-locked amplitudes were smaller when task representations changed (Gaál & Czigler, 2015; Periáñez & Barceló, 2009). Donchin and Coles (1988) argued that the smaller target-locked P3 reflects higher demands on updating processes in working memory during switch trials, which consequently leads to limited neural activity.

In order to align neural results with the DMC model (Braver, 2012), Karayanidis and colleagues (2011) investigated waveform patterns in a cued task-switching task against the background of proactive and reactive control modes. The authors found that cognitive costs were related to positivity patterns in the P3 after cue and target presentation. In the cue-target interval, a parietal pronounced “mixing cost positivity” emerged with larger amplitudes for non-switch trials within the mixed-task blocks than for single trials within the single-task blocks. The positivity effect was followed by a “switch cost positivity” with larger amplitudes for switch trials than for non-switch trials within the mixed-task blocks. The authors associated the differential effects with cue-driven, proactive control modes and linked larger amplitudes to more effortful advance preparation. Furthermore, early and late differential effect in the P3 occurred in the target-response interval with larger amplitudes for single trials than for non-switch trials, and larger amplitudes for non-switch trials than for switch trials (see also Gajewski et al., 2017; Kieffaber & Hetrick, 2005). The authors associated target-locked P3 activation with stimulus-driven, reactive control processes and linked larger amplitudes to a lower need for advance preparation due to little target interference.

P3 activity was also found in cognitive tasks measuring context updating and conflict detection because the task requires similar mechanisms of cognitive control (Kieffaber & Hetrick, 2005; Schmitt, Ferdinand, & Kray, 2014). Continuous performance tasks such as the AX-CPT demand the selection, attentional maintenance, and reconfiguration of context information. To identify specific cognitive control mechanisms in the AX-CPT, the investigation of cue-locked P3 activity gives insight into neural processes that are specific to proactive, preparatory processes after cue presentation. In a refined version of the AX-CPT, Lenartowicz and colleagues (2010) compared ERPs in context-independent and context-dependent trials and found a "context effect" between the trial types. Similar to results in task switching, P3 amplitudes were larger for trials that require updating of task information, compatible to the theory by Donchin and Coles (1988). In the AX-CPT, context-dependent trials required rule switches and task-set reconfigurations, which translated in larger cue-locked P3 amplitudes (Lenartowicz et al., 2010). Further evidence for the linkage of P3 activity to processes of context maintenance and updating during the cue-target interval was provided by Schmitt, Ferdinand, and Kray (2014), who replicated context effects in the cue-locked P3 between the task conditions in younger adults. The authors associated the result with a proactive engagement in context updating during context-dependent trials. P3 effects in the target-response interval of the AX-CPT are less investigated, but reactive control processes of conflict processing are assumed to be evoked by the target stimuli, particularly in context-dependent trials (Schmitt, Wolff, et al., 2014). The N450 is a negative component that emerges around 350 to 650 ms after stimulus onset and is associated to processes of conflict detection (Eppinger et al., 2007; Kray et al., 2005; Schmitt, Wolff, et al., 2014; West, 2004; West & Alain, 2000). Due to the fronto-central focus of the N450, the origin of the negativity was liked to neural mechanisms in the anterior cingulate cortex (ACC, Liotti, Woldorff, Perez, & Mayberg, 2000). West (2004) found a correlation between the magnitude of the negativity and the extent of interference in a Stroop task (see also Kray et al., 2005). Schmitt, Wolff, and colleagues (2014) examined the N450 after target presentation in the AX-CPT and found a context effect with larger negativities for context-dependent trials than context-independent trials. The authors associated the context effect with processes of conflict detection that are evoked in context-dependent trials.

During task switching, working memory plays an important role. Delayed-recognition tasks are one possible measurement for the temporal dynamics in working memory because ERPs in the delay period between the cue and target stimulus are assumed to reflect the maintenance of task-relevant information (Clapp et al., 2009). Furthermore, inhibitory mechanisms are known to evoke certain patterns of neural activity (Gazzaley et al., 2008). The WMC task in this study used photos of human faces as interfering stimuli during the delay period. Human faces typically evoke an early negativity (N170) in the occipito-temporal cortex, reflecting visual encoding within the first 200 ms after stimulus detection (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Daniel & Bentin, 2012; Gao et al., 2009; Gazzaley et al., 2005; Miller, Rietschel, McDonald, & Hatfield, 2011). The N170 amplitude was found to be sensitive to manipulations of attentional demands and is assumed to reflect cognitive control processes of enhancement and suppression of the information carried by the interfering stimulus (Gazzaley et al., 2005). In an EEG study by Clapp and colleagues (2009), N170 amplitudes were more negative for trials in which an interfering stimulus was viewed passively than for trials including an interruptive stimulus that demanded attention. Deiber and colleagues (2010) found a larger negativity for ignored faces (distractor condition) than for attended faces (interrupter condition). In contrast, Gazzaley and colleagues (2005) found larger negativity effects for task conditions that required encoding of face stimuli compared to conditions that required the ignorance of face stimuli. In a delayed-recognition task by Clapp and Gazzaley (2012), N170 amplitudes were largest for interrupter trials, followed by passive view and distractor trials. The inconsistency of results stresses a conflict in the utility of ERP amplitudes as a measure of attentional resources (e.g., Kok, 2001).

Besides the N170, the P3 shows sensitivity to the attentional allocation for interfering stimuli (Gazzaley et al., 2008). Furthermore, working-memory tasks were generally found to evoke P3 activity (Fabiani & Friedman, 1995; Pinal, Zurrón, & Díaz, 2014; Polich, 2007). Study results showed that the P3 is connected to task difficulty and mental workload (Allison & Polich, 2008; Kok, 2001; Miller et al., 2011). Kok (2001) stated that the “P3 amplitude reflects activation of elements in an event-categorization network that is controlled by the joint operation of attention and working memory" (p. 557). The author referred to the generation of the P3 component as a reflection of higher-order cognitive control mechanisms that involves the recruitment of prefrontal and posterior brain networks. In his review, Kok (2001) argued that increased task difficulty due to task manipulations can result in higher demands on attentional operations and lead to lower P3 activity. Polich (2007) studied the sensitivity of P3 amplitudes to the amount of attentional resources that were engaged in cognitive tasks. He also linked a decline in P3 amplitudes to increasing task demands and resulting limited attentional resources. In a study by Studer and colleagues (2010) however, P3 amplitudes were larger for trials with a higher work load, resembling a larger cognitive engagement. It should be noted that this result was limited to the encoding phase of a serial visual working-memory task. In sum, increasing task difficulty is believed to alter the information flow in the processing system while interfering with the actual categorization process that is necessary to solve the task (Kok, 2001). That means that attentional mechanisms are engaged in the enhancement and suppression of the ongoing information flow during the delayed-recognition task. Scientific evidence on the P3 activity during delayed-recognition tasks that were similar to the WMC in this study is scarce, but theoretical assumptions about the relationship between resource allocation, task demands, and the P3 amplitude can be used to hypothesize P3 patterns during the delay period.

To sum up, P3 amplitudes were found to be sensitive to costs that occur in cognitive control tasks. In switching tasks and the AX-CPT, cue-locked P3 activity is claimed to be related to proactive control, and target-locked P3 activity is associated with reactive control. Furthermore, both tasks involve the experimental manipulation of context information that demands processes of task-set reconfiguration and results in modulations of P3 amplitudes. All three cognitive tasks, including the WMC, are assumed to recruit similar frontal and parietal neural networks, which are associated with higher-order control processes. Lastly, the interaction of the diverse, but shared cognitive control processes in task switching, context processing, and working memory and interference control is needed in all three tasks, supporting the legitimate link between them.

It should be noted that, in order to maintain consistency, the term “P3” is subsequently used in reference to the positivity component commonly evoked around 300 ms after stimulus-onset. Time windows for the empirical analyses of the ERPs were selected according to their maximum peaks and therefore differed between the cognitive control tasks (see chapter 5).

2.1.5 Age-related differences in cognitive control.

Throughout the life span, neurochemical changes in the aging brain happen naturally. Especially older adults show a slowing in neural functioning that is assumed to cause impairments in cognitive control processes (Brehmer, Kalpouzos, Wenger, & Lövdén, 2014). The following section provides a brief overview of empiric evidence on age-related differences in cognitive control with a focus on task switching, context processing, as well as working memory and interference control.

***Age-related differences in task switching*.** The manifestation of cognitive costs in switching tasks varies across the lifespan. Previous studies found a u-shaped function with increased costs in young children and older adults (Cepeda et al., 2001; Karbach, 2008; Kray et al., 2004; Kray, Eber, & Karbach, 2008; Polich, 2007). Literature on task switching in children reports larger general switch costs compared to adults, which was explained by an earlier onset of the ability to switch between rules, whereas the ability to maintain task sets developed at a later stage during childhood (Crone, Ridderinkhof, Worm, Somsen, & Van Der Molen, 2004; Karbach & Kray, 2007). Hence, the development of complex task-switching skills is claimed to underlie the progressive maturation of distinct neuronal networks within the PFC (Bunge & Zelazo, 2006). The PFC also plays an important role in age-related differences between younger and older adults in task switching. In the aging brain, the dopamine system within the PFC seems to be compromised early in the natural progression of cognitive decline, which is claimed to translate in poorer behavioral task-switching performance in the elderly (Braver et al., 2001).

In general, older adults tend to respond slower and make more errors in switching tasks compared to younger adults. Moreover, age-related differences in task switching are more pronounced in general switch costs, resulting from impairments in the selection and maintenance of task sets in older adults, which is required in non-switch trials, but not in single trials (Huff et al., 2015; Karayanidis et al., 2011). Age-related differences in specific switch costs are usually less pronounced in their significance (Karbach, 2008; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005, but see Kray, Li, & Lindenberger, 2002). In fact, older adults often show smaller specific switch costs than younger adults because they tend to update task sets in every run, even in non-switch trials where a reconfiguration process is not necessary. The tendency to treat non-switch trials like switch trials results in fewer differences between the trial types and hence to reduced or non-existent specific switch costs (Karayanidis et al., 2011; Kopp, Lange, Howe, & Wessel, 2014; Mayr, 2001; Schmitt, Ferdinand, & Kray, 2014). Eventually, older adults show slightly increased residual switch costs, although scientific results were not always significant and vanished with practice (Meiran, Gotler, & Perlman, 2001).

Furthermore, age-related differences in task switching appear in the P3 component (Eppinger, et al., 2007; Gaál & Czigler, 2015; Karayanidis et al., 2011; Kopp et al., 2014; Kray et al., 2005; West & Travers, 2008; Zanto & Gazzaley, 2014). Karayanidis and colleagues (2011) examined age-related differences in cued task-switching by means of ERPs after cue and target presentation. Results for the cue-locked P3 showed an early mixing cost positivity with larger amplitudes for non-switch trials than for single trials followed by a late switch cost positivity with larger amplitudes for switch trials than for non-switch trials in both age groups (see also Gajewski & Falkenstein, 2011; Eppinger et al., 2007; Karayanidis et al., 2010). In contrast to younger adults, older adults showed a prolonged mixing cost positivity and a smaller switch cost positivity (see also Gaál & Czigler, 2015). Karayanidis and colleagues (2011) linked these findings to age-related differences in proactive control and argued that older adults needed more preparation time for non-switch trials than for single trials, which led to the prolonged mixing cost positivity. The smaller switch cost positivity was traced back to the argument that older adults prepared for non-switch trials the same way as they prepare for switch trials. The target-locked P3 showed larger differential effects between non-switch trials and single trials as well as between non-switch trials and switch trials in older adults compared to younger adults.

The mixing cost effect was attenuated and reversed in the course of the target-locked P3 due to prolonged P3 amplitudes for single trials in older adults. In contrast, Gaál and Czigler (2015) found no target-locked P3 in older adults when the preceding cue was informative.

Besides age-related differences in P3 amplitudes, there is scientific evidence for distinct scalp distribution of the positivity between younger and older adults. Kray and colleagues (2005) found increasing cue-locked P3 amplitudes from frontal to parietal electrodes, with a greater extent in younger adults compared to older adults. West and Travers (2008) further confirmed decreased parietal, but increased frontal cue-locked P3 activity in older adults compared to younger adults. ERP results by Karayanidis and colleagues (2011) demonstrated that differential effects in the cue-locked P3 were focused over parietal electrodes in younger adults, whereas older adults showed more evenly distributed effects across the scalp. Additionally, Kopp and colleagues (2014) found a stronger engagement of frontal areas in the generation of the target-locked P3 in older adults compared to younger adults. The recruitment of frontal networks in older adults is generally hypothesized to result from compensatory control processes (Angel, Fay, Bouazzaoui, & Isingrini, 2010; Goffaux, 2007; Goffaux, Phillips, Sinai, & Pushkar, 2008; Park & Reuter-Lorenz, 2009). The increased frontal activity is assumed to reflect an attempt to cope for deficient processes in other brain regions (for example in posterior networks, Angel et al., 2010).

Overall, results from ERP studies suggest that older adults rely more on reactive control modes, whereas younger adults tend to use proactive control modes in cued task-switching tasks. The underlying hypothesis implies that older adults have difficulties implementing the task sets during the cue-target interval and therefore have to "catch up on the omitted preparatory task settings" when confronted with the target stimulus (Kopp et al., 2014, p. 209). This compensational view is based on the "load-shift model" (Velanova, Lustig, Jacoby, & Buckner, 2006) that declared the increased activity during retrieval as a compensational control process for deficits in earlier top-down attention.

Age-related differences in context processing. The ability to maintain and update context information during continuous performance tasks was found to be compromised in older adults (e.g., Schmitt, Ferdinand, & Kray, 2014; Zanto & Gazzaley, 2014). Scientific studies provided evidence for profound differences in the AX-CPT between young and old age groups. Braver and colleagues (2001) proposed a linkage between impaired context processing in older adults and the age-related decline in the prefrontal brain networks (see also Braver, Paxton, Locke, & Barch, 2009; Braver, Satpute, Rush, Racine, & Barch, 2005). The authors further assumed that older adults rather rely on reactive control whereas younger adults use proactive control in order to solve the AX-CPT. This assumption was supported by slower response times, but intact accuracy for BX-trials in older adults compared to younger adults (Braver at al., 2005). The authors argued that older adults reactivate the cue information in order to resolve the BX-conflict when confronted with the target stimulus. In the modified AX-CPT, Schmitt, Ferdinand, and Kray (2014) found context effects in the form of slower responses and higher error rates for context-dependent trials than for context-independent trials with larger effects in older adults. Interestingly, younger adults also showed a neural context effect in the cue-locked P3 activity in the form of larger amplitudes for context-dependent trials compared to context-independent trials. This result was explained by the younger adults' proactive engagement in context updating after cue presentation in order to prepare for the target response, which was necessary in context-dependent trials. In contrast, no context effect in the cue-locked P3 was found in older adults, reflecting an equal cognitive engagement in both context conditions. This means that older adults updated context information constantly, even if not necessary. Similar to the results in switching tasks, P3 activity in the cue-target interval was more evenly distributed across the electrodes in older adults, possibly due to the compensatory recruitment of frontal brain areas, whereas younger adults showed a focused P3 activity at parietal electrodes.

Age-related differences in target-driven conflict processing were also evident in the AX-CPT. Schmitt, Wolff, and colleagues (2014) found a context effect in the N450 with more negative amplitudes for context-dependent trials than context-independent trials in high performing older adults, but not in high performing younger adults after target presentation. The authors interpreted the context effect in older adults as the application of enhanced reactive control strategies that was needed to solve the task interference.

Age-related differences in working memory and interference control. In order to solve cognitive tasks that include interfering stimuli, processes of attention, working memory, and interference control are needed. It is known that older adults struggle in cognitive tasks that involve said functions (e.g., Clapp & Gazzaley, 2012; Giesen et al., 2015). Scientific evidence points toward an “inhibitory deficit” in older adults, meaning a restricted top-down suppression of task-irrelevant information (Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Zanto & Gazzaley, 2014). Gazzaley and colleagues (2008) proved that the ability to inhibit task-irrelevant information was delayed in older adults. Furthermore, the authors found that older adults paid more attention to distracting stimuli, which was linked to increased neural activation in frontal brain areas. In an ERP study, Clapp and Gazzaley (2012) investigated the N170 as a marker for attentional allocation to faces in a delayed-recognition task. Older adults showed higher error rates accompanied with larger neural engagement in a delayed-recognition task when a distractor was present compared to the passive viewing of the stimuli. The impact of the distraction on working-memory performance and neural activity was larger in older adults than in younger adults. The authors argued that older adults exhibit insufficient maintenance abilities, which increased the susceptibility to irrelevant stimuli. Although older adults’ working-memory performance was worse compared to younger adults for trials including interrupter stimuli, Clapp and Gazzaley (2012) assumed that the mental representation for the enhancement of interruptions is the same in both age groups, supported by finding no age-related differences in the cognitive enhancement for interrupter stimuli. Thus, age-related differences in the N170 amplitude were only found for the distractor stimulus, pointing toward a selective suppression deficit in older adults.

Age-related differences in delayed-recognition tasks were also evident in the P3 component. However, most of the empirical studies focused on the investigation of P3 latency scores in order to account for cognitive slowing in older adults (Deiber et al., 2010; Gazzaley et al., 2008), whereas scientific results on age-related differences in P3 amplitudes are scarce. Gazzaley and colleagues

(2005) claimed both magnitude and speed of the P3 to be indices for top-down processes of suppression and enhancement. The authors further proposed that these processes can be manipulated by task demands in the delayed-recognition task.

In sum, age-related differences in the temporal dynamics during switching tasks and the AX-CPT seem to be characterized by a shift from proactive to reactive control modes in the elderly. Older adults show impaired task reconfiguration (apparent in switching tasks), updating and maintenance of context information (apparent in the AX-CPT), and interference control (apparent in delayed-recognition tasks). Besides the older adults' poorer behavioral performance in these tasks, the P3, the N450, and the N170 proved to be sensitive parameters to index age-related differences in cognitive control on the neural level.

2.2 Cognitive Training and Transfer

As stated before, the scientific literature on age-related differences in cognitive control points toward a general degeneration of the neural networks in the older brain. In this sensitive phase of neural regression, cognitive training interventions proved to induce compensatory effects on impaired cognitive control processes in older adults (Karbach, 2008; Karbach & Kray, 2009). The following section will provide an overview of the theoretical background of cognitive training as well as their implementation in empirical studies on cognitive control.

2.2.1 Theoretical background of cognitive training.

Cognitive training programs are based on the premise that repeated practice of certain tasks leads to improvements of cognitive abilities or to the preservation of impaired cognitive functions (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008). The population of cognitive training programs has been growing fast over the years, however, it is important to take the diversity of theoretical approaches and designs of training into account when speaking about their efficiency. The lack of consistency among existing training studies hampers the identification of distinct, essential characteristics that account for efficient training programs (Morrison & Chein, 2010). Based on this dilemma, empirical studies provided conflicting findings on training efficiency, depending on the study population, training conditions, and frequency and intensity of trainings. Therefore, it is important to focus on theoretical frameworks and methodical standards that proved to be effective in previous studies on cognitive training and that serve the purpose of this study.

Types of cognitive training. With regard to modern forms of cognitive training, experts distinguish between strategy-based and process-based training. Since this study implemented a process-based task-switching training, the concept of strategy-based training is mentioned briefly. Strategy-based training interventions promote the use of specific strategies to succeed in a cognitive task. The strategies are typically taught in order to reduce task difficulty, aiming at significant improvements in the trained tasks. Empirical evidence for training effects of strategy-based interventions were found in studies by Brom and Kliegel (2014) who trained memory performance in older adults, or by Karbach and Kray (2009) who trained task switching in different age groups. However, the transferability of training effects to similar cognitive tasks can be limited due to the specific nature and usage of the strategies. One example for training strategies is the verbalization technique in task switching (Karbach, 2008; Karbach & Kray, 2009; for a review, see Kray & Ferdinand, 2014).

On the other hand, process-based training programs train skills that are more general in order to improve underlying cognitive mechanisms, such as processing speed or cognitive control (Karbach & Verhaeghen, 2014; Kray & Ferdinand, 2013). By applying variable tasks and stimuli, the trainings target broad cognitive mechanisms without the communication of explicit strategies. In contrast to strategy-based training, this training form aims at the minimization of automated processes during the performance of a cognitive task. Experts assume that the training of a more common underlying cognitive process can increase the probability of transfer to other similar and dissimilar cognitive tasks (for a review, see Karbach & Verhaeghen, 2014; Klingberg, 2010; Morrison & Chein, 2011). Process-based trainings were primarily used to support working-memory functions (Berry et al., 2010; Gavelin, Boraxbekk, Stenlund, Järvholm, & Neely, 2015), but recent training studies are gaining interest in the investigation of further cognitive control domains, such as task switching (e.g., Zinke, Einert, Pfennig, & Kliegel, 2012).

The concept of cognitive plasticity and flexibility. The concept of cognitive plasticity is often used to explain possible training and transfer effects after a cognitive practice. Karbach and Schubert (2013) defined plasticity as "the potential modifiability of a person's cognitive abilities and brain activity" (p. 1). At first, training studies mainly used neuroimaging techniques to shed light on structural and functional changes in the brain after cognitive training in animals or patients with brain injuries. Scientists explained cognitive plasticity as a secondary process of restoring or compensation in consequence of a primary change (cf. Wieloch & Nikolich, 2006). Further research approaches are devoted to cognitive and neural plasticity caused by enriched environments or practice (for a review, see Van Prag, Kemperman, & Gage, 2000). With regard to cognitive training, the term plasticity goes beyond reactive changes in the brain structure and rather refers to possible functional changes in brain representations, such as perceptions, thoughts, and actions. The progress in neuroimaging techniques enables the examination of functional changes in the healthy human brain during and after cognitive training. In this context, Lövdén and colleagues (2010) introduced the term "cognitive flexibility" as the ability of the brain to optimize cognitive performance caused by a mismatch between incoming demands and available cognitive resources. Whereas structural changes (plasticity) usually require a sustained demands-supply mismatch, functional changes (flexibility) can appear even after a short exposure to the mismatch. Short-term mismatch can be evoked by cognitive trainings in which task demands exceed the available cognitive resources (Braver et al., 2001; Raz et al., 2005). According to the flexibility approach, ongoing training results in behavioral and neural adjustments as the mismatch gradually reduces with the practice. In their review, Brehmer and colleagues (2014) pointed toward the sensitivity to training-induced neural changes in the older brain, which endorses training studies with older adults. Although training-induced neural flexibility in older adults tends to be more limited compared to populations of young age, it is possible to find functional changes in the older brain after cognitive training interventions (cf. Anguera et al., 2013). However, it is important to consider certain methodical characteristics with respect to the design of training studies. Therefore, the following section will provide an overview of the theoretical concepts of training and transfer effects.

2.2.2 Measurements of cognitive training – training and transfer effects.

The efficiency of training programs in terms of learning effects can be measured empirically on different levels. First, a cognitive training should evoke performance improvements in the trained task. These fundamental training effects typically appear in the form of a learning curve with largest improvements in the beginning of the training session (Klauer, 2000, 2003). In order to prove that training effects in performance can be attributed to training-induced alterations in the underlying cognitive mechanism and are not resulting from "time on task", the intervention should also result in nontrivial "transfer effects" to untrained cognitive tasks (Klauer, 2000; Shipstead, et al., 2012). Transfer effects therefore represent the transmission of trained cognitive skills to untrained cognitive abilities. Hasselhorn and Gold (2009) defined transfer as the successful application of trained knowledge or performance to new situations that were not part of the training program. Cognitive trainings can induce positive or negative transfer effects. The term positive transfer is used to refer to performance improvements in a similar, transfer task after the training compared to the baseline performance prior to the practice. In contrast, negative transfer reflects impaired performance in a similar task after the training compared to the baseline. Negative transfer can be explained by an interference of the old, habitual and the newly learned behavior (Kaiser, Kaminski, & Foley, 2013; Singley & Anderson, 1989).

Besides the extent of learning effects, a further distinction between near and far transfer must be made, considering the range of transfer effects. Near transfer implies a generalization of training effects to other cognitive tasks of similar structure (Kaiser et al., 2013; Karbach, 2008; Karbach & Kray, 2009). Other terms for this type of transfer are lateral or low-road transfer (e.g., Gonzales, 2012). Near transfer effects are probable when the training task and transfer task share common characteristics. This assumption is underpinned by the "theory of identical elements" (Woodwarth & Thorndike, 1901), which claims that the repeated cognitive demand during the training facilitates the generalization of trained skills to other similar situations. For instance, Karbach (2008) proved that a task-switching training resulted not only in improved switching performance between training task A and B but also in enhanced performance in the form of faster reaction times and reduced error rates when switching between task C and D in a transfer task. Because near transfer effects are widely investigated in the field of educational science, the terms "transfer" and "learning" are often used interchangeably (Karbach, 2008). Although transfer implies a learning effect, Perkins and Salomon (1989) describe transfer effects as genuine "spill-over" effects from one situation to another that exceed the expectations of trivial learning.

The transfer of skills from a training task to a transfer task that shares a low degree of compatibility is called far transfer, sometimes referred to as vertical or high-road transfer (e.g., Gonzales, 2012). Despite the structural diversity, both tasks should demand interrelated cognitive mechanisms. Exemplary empirical evidence for far transfer effects of task-switching training to the Stroop task was found by Karbach (2008). Compared to near transfer, empirical proof for far transfer after cognitive training is more confined and inconsistent due to the specificity of the learned skill (Barnett & Ceci, 2002; Cormier & Hagmann, 2014; Green & Bavelier, 2008). Yamnill and McLean (2001) further listed several factors that can influence the probability of far transfer effects, including precise training instructions, variability in task context, and novelty of the training tasks. In fact, a variable training was found to broaden the underlying trained mechanism and detached it from its original context, causing a larger usability in other tasks (Salomon & Perkins, 1989; Schmidt & Bjork, 1992).

Transfer effects are not restricted to behavioral performance but can also be identified in neural parameters, supposing that the training task and the transfer task demand a common functional brain substrate (Dahlin, Nyberg, Bäckman, & Neely, 2008; Lövdén et al., 2010). In general, near and far transfer effects are probable whenever the same underlying cognitive mechanism is required for both the training task and transfer task. This assumption serves to clarify the distinction between "what is transferred and how it is transferred?" (Salomon & Perkins, 1989, p. 115). Schmidt and Bjork (1992) argued that the structural similarity between training and transfer task is one necessity, but not the exclusive cause for transfer effects. Another important principle is the overlap of cognitive processes that are acquired during training necessary for solving the transfer task. Scientists assumed that generalization effects occur when the transfer task demands at least one of the trained cognitive abilities (Dahlin, Nyberg, Bäckman, & Neely, 2008; Karbach, 2008). This might be interesting, regarding cognitive control processes, which proved to be not truly independent (e.g., Diamond, 2013). Training and transfer effects of cognitive control trainings to behavioral performance and neural correlates will be further discussed in the following chapter.

Training studies are typically structured in a pretest–training–posttest design, which allows the investigation of training-induced effects to other cognitive tasks (Kramer & Willis, 2003). The pretest session serves as a baseline measure for the cognitive abilities of interest, and the posttest session is essential to examine transfer effects compared to the baseline. As pretest and posttest sessions include the same cognitive measurements, transfer effects can be defined as "the performance improvement at posttest relative to baseline performance at pretest" (Karbach, 2008, p. 64). In order to interpret the quantifiable changes in cognitive parameters at posttest, a comparison between the training group and a control group is necessary (e.g., Klauer, 2000). A distinction is usually made between active and passive control groups. An active control group receives the same amount of training without aiming at cognitive improvement whereas passive control groups do not absolve any training at all. A compromise would be a waiting control group, which participates in the same cognitive program as the training group, but not until after the posttest session. Either way, it is important to match the study groups based on their demographic characteristics and baseline performance in order to interpret changes in the training group at posttest as pure training-induced effects.

Scientific training studies typically report effect sizes as quantification for the magnitude of training and transfer effects. Effect sizes allow a universal understanding of standardized measures across different studies and make them comparable (Olejnik & Algina, 2003; Wilkinson, 1999). In analyses of variance, eta squared (η_p^2) and Cohen's *d* are commonly used parameters for effect sizes

(Lakens, 2013). According to Klauer (2001), effect sizes should score at least 0.3 to allow a valid interpretation of effects. Cohen (1992) declared scores of effect sizes ranging around 0.3 as small effects, around 0.5 as medium effects, and around 0.8 as large effects.

The measurement of transfer effects is limited with respect to their generalization to everyday life. It is difficult to define characteristics of similarity between cognitive domains or task situations in order to predict transfer effects outside the scientific laboratory (Barnett & Ceci, 2002; Perkins & Salomon, 2001). Another limitation in the examination of transfer effects lies within their continuance after the training intervention. Therefore, some training studies include a follow-up session to investigate long-term effects.

Lastly, the probability of transfer effects highly depends on the age of the study group (Green & Bavelier, 2008; Karbach, 2008). Although some studies showed that younger and older adults benefited equally from cognitive training (e.g., Karbach & Verhaeghen, 2014), Karbach (2008) provided evidence for larger beneficial transfer effects in young children and older adults (see also Karbach, Könen, & Spengler, 2017; Karbach & Kray, 2009, but see Dahlin, Nyberg, Bäckman, & Neely, 2008). Karbach and Kray (2009) argued that older adults seemed to benefit to a greater extent from cognitive training due to larger deficits in the baseline and resulting compensatory effects of practice.

2.2.3 Training of cognitive control – empirical evidence for near and far transfer effects in older adults.

Cognitive control plays an important role in learning, and therefore, it is not surprising that many studies investigated the efficiency and transferability of cognitive control practice. Of particular interest is the possibility to reduce age-related impairments in cognitive control by means of training. Overall, empirical studies demonstrated substantial training gains in older adults after cognitive control training (Ball et al., 2002; Bherer et al., 2005; Brom & Kliegel, 2014; Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008, Dahlin, Nyberg, Bäckman, & Neely, 2008; Li et al., 2008; Wilkinson & Yang, 2012). Furthermore, near and far transfer effects were found after interventions that aimed at enhancing cognitive control (Basak et al., 2008; Bherer et al., 2005, Karr et al., 2014; Kelly et al., 2014; Kueider, Parisi, Gross, & Rebok 2012; Lövdén et al., 2010). Kueider and colleagues

(2012) reviewed the efficiency of computerized trainings in older adults and found improvements in general cognitive control, processing speed, working memory, and attention. Moreover, training and transfer effects of cognitive control training were evident in older adults with mild cognitive impairment after a 12-week working memory and attention training (Herrera, Chambon, Michel, Paban, & Alescio-Lautier, 2012). These are just a few selected findings concerning cognitive control training in older adults.

Karbach and Verhaeghen (2014) specifically reviewed studies on process-based cognitive control training with older adults. Results pointed toward significant performance improvements in the trained tasks and in near transfer tasks compared to control groups. Furthermore, far transfer effects to untrained tasks were evident, albeit smaller than near transfer effects. The review also confirmed that process-based training effects could generalize to relevant tasks in daily functioning. Another meta-analysis by Karr and colleagues (2014) revealed overall improved problem solving and working memory in older adults after cognitive control training. Kelly and colleagues (2014) reviewed over thirty cognitive training studies and provided evidence that cognitive control trainings had a positive impact on measures of working memory and processing speed compared to passive controls.

Striking results were provided by Anguera and colleagues (2013) who conducted a multitasking training for older adults. The cognitive training included a video game that was designed to train the resolution of task interference. Older adults participated in 12 training sessions, including either multitasking or single-task training. Posttest data of the multitasking training group demonstrated reduced multitasking costs compared to the single-task training group and a passive control group. Moreover, explicit transfer effects to untrained cognitive control tasks measuring working memory were found after multitasking training. The authors argued that the generalization of multitasking training effects resulted from an overlap of cognitive control processes involved in interference resolution, which was required in the training task and the transfer tasks. More importantly, training-induced changes were found on the neural level in the multitasking training group. Participants showed increased midline frontal theta power, reflecting enhanced sustained attention. The authors further investigated age-related differences in neural correlates of multitasking between the older and the younger brain. They found reduced theta power in older adults at pretest, regardless of the task condition, which indicated impairments in the processing of both multitasking and single-task trials. However, after the multitasking training, levels of neural activity were comparable to the activity observed in younger adults. Finally, both behavioral and neural effects persisted after a six-month period. Taken together, the findings by Anguera and colleagues (2013) emphasize the importance of cognitive control training for mechanisms of neural flexibility in older adults.

Further evidence for training-induced neural flexibility in the older brain was provided in a fMRI study by Dahlin, Neely, Larsson, Bäckman, and Neely (2008) that demonstrated improved performance in a trained updating-task and a near transfer task (3-back task) in older adults after five weeks of computerized training in working-memory updating. The authors associated age-related differences in updating at pretest with deficient striatal activations in older adults. Moreover, older adults recruited additional fronto-parietal networks during the updating task. After the training, older adults showed increased striatal activation and decreased fronto-parietal activation. Edwards, Barch, and Braver (2010) showed that training of context updating led to significant changes in the neural functioning in schizophrenic patients, who showed similar impairments in cognitive control compared to older adults. After a two-sessions AX-CPT training, patients showed a shift toward the typical patterns of brain activity observed in healthy adults, along with improvements in behavioral performance.

Dual-tasks have a conceptual proximity to task switching and are subject of many training studies. Bherer and colleagues (2005, 2008) conducted a five-week dual-task training with younger and older adults and provided evidence for significant performance improvements in the trained dual-task as well as near transfer effects in a similar dual-task in older adults. Furthermore, dual-task training was found to result in performance improvements in older adults with dementia (Schwenk, Zieschang, Oster, & Hauer 2010).

The following section provides an overview of empirical findings regarding task-switching training in older adults in order to outline the scientific relevance for this study.

Task-switching training in older adults. As stated in chapter 2.2.1, Lövdén's "theoretical framework of cognitive flexibility" (Lövdén et al., 2010) implies that training-induced changes in impaired cognitive abilities are possible in older age. Age-related impairments can be found in task switching, as older adults show a poorer task performance compared to younger adults (see chapter 2.1.5). Based on the scientific background, cognitive training studies implemented task-switching training in order to investigate the impact on age-related differences in cognitive control. Intervention designs varied between the studies, but scientists agreed about the importance of the ideal cognitive load during task-switching training, especially when training older adults. Because training gains require an optimal mismatch between task demands and the available cognitive resources, the training should be challenging, without causing a cognitive overload. The continuity of adequate cognitive demands throughout all training sessions can be guaranteed by the use of different stimulus material. Confronting the trainee with new switching situations in each session keeps the cognitive mismatch at its highest. Moreover, a training that provides novelty and diversity can enhance training motivation by avoiding monotony (Gajewski & Falkenstein, 2012). However, it should be noted that training effects can be smaller compared to trainings with constant conditions (e.g., Karbach & Kray, 2009). Yet, variable trainings increase the possibility of transfer effects to other cognitive domains (Karbach, 2008, see chapter 2.2.2).

Besides the usage of variable stimulus material, training studies tend to conduct adaptive trainings that adjust the task difficulty to the individual's baseline performance in task switching. This "testing-the-limits" approach (e.g., Kliegl, Smith, & Baltes, 1989) is typically used in working-memory training. Brehmer, Westerberg, and Bäckmann (2012) showed that this type of training led to significant changes in cognitive flexibility in older adults compared to a non-adaptive training. However, results could not be replicated in other training programs that targeted cognitive control abilities, such as task-switching training (Karbach & Verhaeghen, 2014). Cognitive control trainings are generally multidomain trainings because they try to stimulate not only one, but several cognitive functions. They are also believed to enhance the probability of transfer effects (Gajewski & Falkenstein, 2012). Because task switching requires various cognitive skills, such as task-set selection, maintenance, and updating, they fall into the category of multidomain trainings.

Several training studies provided evidence for behavioral and functional training-induced flexibility in older adults by means of task-switching training (Fehér, 2015; Gaál & Czigler, 2017; Karbach, 2008; Karbach et al., 2017; Karbach & Kray, 2009; Karbach, Mang, & Kray, 2010; Kray & Fehér, 2017). Cepeda and colleagues (2001) trained children, younger adults, and older adults in two sessions of task switching. Results confirmed training effects in the form of reduced cognitive costs, and more importantly, training benefits were larger for older adults compared to younger adults. The same result pattern was found by Karbach (2008) after four sessions of task-switching training. Training gains as well as near transfer effects to a similar switching task were larger for children and older adults compared to younger adults. The author argued that individuals with lower baseline performance in task switching, which includes older adults, benefited most from the training intervention (see also Karbach et al., 2017). Besides training gains and near transfer effects, far transfer effects to other cognitive control tasks as well as to fluid intelligence were found across all age groups (see also Karbach & Kray, 2009). In a comprehensive training study by Gaál and Czigler (2017), age-related differences on the behavioral and the neural level were diminished after eight sessions of task-switching training with older women. Training-induced effects in older age groups were evident in the form of improved task performance and enhanced P3 components in the training and transfer tasks. Furthermore, training-induced changes on both levels persisted even one year after the training intervention.

The literature on far transfer effects after task-switching training shows a more heterogeneous result pattern. As stated earlier, far transfer effects to cognitive control measures of inhibition control, working memory, and fluid intelligence were found after task-switching training in older adults (Karbach, 2008; Karbach & Kray, 2009). In the training study by Fehér (2015), however, explicit far transfer effects to other cognitive tasks remained not significant for groups of young and old age. Thus, far transfer effects after task-switching training tend to be very specific and highly dependent on the characteristics of the training procedure, for example, the level of similarity between training and transfer tasks (e.g., Karbach, 2008, see chapter 2.2.2).

The design of the switching task allows the division in single-task blocks and mixed-task blocks. Therefore, some training studies examined two different types of trainings based on the paradigm. Typically, one training group participated in a pure task-switching training, consisting solely of mixed task-blocks while the second training group performed a single-task training (e.g., Minear & Shah, 2008). Karbach and Kray (2009) found reduced general switch costs in older adults after a task-switching training intervention, although effects were larger in the task-switching training group compared to the single-task training group. Same results were evident for far transfer effects to other cognitive control tasks and even to fluid intelligence. Karbach and colleagues (2010) demonstrated substantial near transfer effects to an untrained switching task in older adults who participated in a pure task-switching training, but not in participants who participated in a single-task training. According to Karbach (2008), larger transfer benefits of pure task-switching training points to the fact that the generalization of switching abilities is not solely based on automatization processes of the individual tasks A and B but is due to the training of reconfiguration process when switching between them.

3. General Summary & Research Predictions

The following chapter is divided into six sections. The first section briefly summarizes the main study goals, based on the theoretical and empirical literature. After that, the research predictions will be introduced, starting with the training effects in the two training groups. The subsequent section introduces the predictions for age-related differences in cognitive control on the behavioral and the neural level at pretest. Near transfer of the cognitive control training to a similar switching task is predicted in the fourth section. Finally, far transfer to context processing as well as to working memory and interference control are predicted in the fifth and sixth section. A brief summary of empirical evidence from previous studies is presented prior to the corresponding predictions.

3.1 Main Study Goals

The main goal of this study was to clarify whether age-related differences in cognitive control can be diminished by means of a cued task-switching training. Despite the inconsistency regarding the definition, it is general consensus that cognitive control includes higher-order processes that regulate and coordinate goal-directed behavior (Baggetta & Alexander, 2016; Jurado & Rosselli, 2007; Miyake et al., 2000; Morton et al., 2011; Unsworth et al., 2009). Instead of one central cognitive control mechanism (e.g., Baddeley, 1986; Norman & Shallice, 1986), experts agreed upon several key mechanisms, including shifting, updating, and inhibition of task information (e.g., Miyake et al., 2000). Clinical and neurocognitive studies provided evidence for the mapping of cognitive control processes to the PFC and associated networks in the parietal cortex, both found to be prone to age-related deterioration (Braver, 2012; Bunge & Zelazo, 2006; Godefroy et al, 1999; Jurado & Rosselli, 2007; Miller & Cohen, 2001).

Older adults typically show poorer performance and larger cognitive costs in cognitive control tasks (e.g., Karbach, 2008). On the basis of the DMC model, Braver (2012) attributed disadvantages of older adults to a temporal shift from early, proactive control modes of engaged task preparation toward later, reactive control modes of target-driven information retrieval. Because of the high temporal resolution of EEG measures, age-related differences also become evident in the dynamics of ERPs. Differences between the younger and older brain are apparent in the P3, a component that is associated with task-preparatory processes of cognitive control (e.g., Karayanidis et al., 2011). Further age-related differences were found in the N170 and the N450 (e.g., Clapp & Gazzaley, 2012; Schmitt, Wolff, et al., 2014). Studies confirmed the sensitivity of ERP amplitudes and fronto-parietal scalp distributions to age-related differences in switching tasks, the AX-CPT, and interference control tasks (e.g., Gazzaley et al., 2008; Karayanidis et al., 2011; Schmitt, Ferdinand, & Kray, 2014).

Cued switching tasks are well-investigated cognitive control tasks that demonstrate age-related differences in behavioral performance and in the P3 (e.g., Karayanidis et al., 2011). Based on the task-switching paradigm (e.g., Monsell, 2003), switching tasks typically evoke two types of cognitive costs, caused by occasional switches between two simple cognitive tasks. In this study, a cued switching task was used for the training and in the near transfer task. Furthermore, cognitive training studies that included switching tasks demonstrated improved task performance and higher efficiency of the cognitive processes that are reflected in the P3 after the training, even in other untrained cognitive control tasks (Gaál & Czigler, 2017; Karbach, 2008; Karbach et al., 2010, 2017; Karbach & Kray, 2009; Kray & Fehér, 2017). This study implemented a variable cognitive control training with older adults, including a pure task-switching training group and a single-task training group in a pretest–training–posttest design.

Based on the previous findings, it was assumed that the cued training enhances cognitive control mechanisms in older adults by facilitating the activation of relevant task information in a proactive control manner (Kray et al., 2002). Furthermore, trained abilities were expected to transfer to other untrained tasks that measured task switching (measured by a similar switching task), context processing (measured by the AX-CPT), and working memory and interference control (measured by the WMC task). As a result, changes in age-related differences were expected in the task performance and in ERPs. The following chapter provides a detailed overview of the research hypotheses based on the previously presented empirical findings.

3.2 Training Effects of Cognitive Control Training in Older Adults

The investigation of the training data is essential for the evaluation of the training efficiency. Empirical evidence confirmed that task-switching trainings are able to significantly improve the behavioral performance in the trained tasks (Cepeda et al., 2001; Fehér, 2015; Gaál & Czigler, 2017; Karbach, 2008; Karbach et al., 2010; Karbach & Kray, 2009). Despite the large volume and diversity of cognitive training designs, there is consensus that variable task-switching trainings increase the probability of transfer by constantly challenging cognitive control processes (Karbach & Kray, 2009). Because this study implemented a variable training, improved performance was expected within each session, rather than throughout the whole training period (cf. Pereg, Shahar, & Meiran, 2013). The training intervention included two training groups: A pure task-switching training group that only trained mixed-task blocks, and a single-task training group that only trained single-task blocks.

Prediction 1: Both training groups will show improved performance in the trained tasks (i.e., reduced latencies, decreased error rates, and smaller cognitive costs in the task-switching training group) within the training sessions.

3.3 Age-related Differences at Pretest

The status quo of age-related differences in cognitive performance and neural activity between older and younger adults at pretest was considered in order to replicate previous findings, and to detect and interpret training-induced changes in the transfer tasks at posttest. The cognitive test battery at pre- and posttest included three cognitive control tasks that were proven to be sensitive to age-related differences on the behavioral and the neural level: The switching task, the AX-CPT, and the WMC task (see chapter 2.1.5).

3.3.1 Age-related differences in behavioral performance.

Empirical evidence demonstrated generally poorer task performance in older adults compared to younger adults in cognitive control tasks (e.g., Braver & Barch, 2002). In task switching, cognitive costs were larger in older adults, and age-related differences were usually more pronounced in general switch costs than in specific switch costs (Karbach, 2008; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; West & Travers, 2008). It is assumed that larger general switch costs are caused by the older adults' impaired cognitive maintenance and the resulting tendency to constantly update task information, even if not necessary (e.g., Karayanidis et al., 2011). In the AX-CPT, context effects in performance between context-dependent and context-independent conditions were increased in older adults compared to younger adults (Schmitt, Ferdinand, & Kray, 2014; Schmitt, Wolff, et al., 2014). Age-related differences in the WMC were based on the inhibitory deficit theory (Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Zanto & Gazzaley, 2008). Previous studies on working memory and interference control tasks demonstrated poorer task performance in older adults compared to younger adults when interfering stimuli were present (Clapp & Gazzaley, 2012; de Fockert, Ramchurn, Van Velzen, Bergström, & Bunce, 2009).

Based on these findings, research predictions for age-related differences in behavioral performance at pretest are:

Prediction 2: Older adults will show slower responses, increased error rates, and larger cognitive costs in the switching task compared to younger adults. Age-related differences will be more pronounced in general switch costs than in specific switch costs.

Prediction 3: Older adults will show slower responses, increased error rates, and larger context effects in the AX-CPT compared to younger adults.

Prediction 4: Older adults will show slower responses, increased error rates, and larger effects of interference in the WMC task compared to younger adults.

3.3.2 Age-related differences in event-related potentials.

Previous studies examined age-related differences in amplitude and scalp distribution of ERPs in cue-, interference-, and target-locked data during switching tasks, the AX-CPT, and delayed-recognition tasks (e.g., Clapp & Gazzaley, 2012; Karayanidis et al., 2011; Schmitt, Ferdinand, & Kray, 2014). In accordance with previous study designs, analyses were carried out for selected time windows within EPRs.

Predictions for cue-locked ERPs. According to the DMC model (Braver, 2012), it was expected that age-related differences in cue-locked ERPs during the switching task and the AX-CPT demonstrate inefficient proactive control in older adults (e.g., Schmitt, Ferdinand, & Kray, 2014). Karayanidis and colleagues (2011) provided evidence for age-related differences in P3 amplitudes in a cued switching task. Due to the sustained activity of the cue-locked P3, the authors examined two time windows (early and late course of the P3). Results showed a prolonged mixing cost positivity and a smaller switch cost positivity in older adults compared to younger adults, linked to a more time-consuming preparation for non-switch trials and an equal cognitive engagement for both non-switch and switch trials with increasing age. Moreover, older adults showed a more flattened distribution for both differential effects, due to a larger compensatory engagement of frontal networks (cf. West & Travers, 2008). In the AX-CPT, context effects in P3 amplitudes were apparent between context-independent and context-dependent trials in younger adults, but not in older adults (Schmitt, Ferdinand, & Kray, 2014). Furthermore, amplitudes were increasing in an anterior-posterior gradient in younger adults, but more evenly distributed in older adults. With regard to the previous findings, research predictions for age-related differences in ERPs at pretest are:

Switching task. Prediction 5a: The mixing cost effect in the early course of the cue-locked P3 will persist in the late time window in older adults.

Prediction 5b: The switch cost effect in the later course of the cue-locked P3 will be smaller in older adults compared to younger adults.

Prediction 5c: Differential effects in cue-locked P3 amplitudes will be most pronounced at parietal sites in younger adults, whereas older will show an even distribution of amplitudes across the midline electrodes.

AX-CPT. Prediction 6a: Older adults will show smaller context effects in cue-locked P3 amplitudes compared to younger adults.

Prediction 6b: Cue-locked P3 amplitudes will increase from the frontal to the parietal electrodes in younger adults, whereas older adults will show an even distribution of amplitudes across the midline electrodes.

Predictions for interference-locked ERPs. The research predictions for the WMC task are phrased exploratory, and ERPs are solely analyzed for the interfering stimulus. There is a controversy in the scientific literature on the relationship between the amplitude of ERPs and the cognitive load on the working-memory system (Kok, 2001). Most studies linked smaller ERP amplitudes in delayed-recognition tasks to the ability to successfully suppress distracting stimuli (Clapp et al., 2009; de Fockert et al., 2009). Empirical evidence on the N170 showed a larger neural engagement for distractor stimuli than for passive viewed stimuli in an old age group, which was attributed to the inability of older adults to suppress task-irrelevant information (Clapp & Gazzaley, 2012; de Fockert et al., 2009). In contrast, no age-related differences were found for processes of cognitive enhancement, which points toward the exclusivity of the suppression deficit in older adults (Clapp & Gazzaley, 2012). A similar result pattern was expected for the P3, as smaller amplitudes proved to be connected to more effortful cognitive engagement of working memory and interference control during higher workload (Kok, 2001).

WMC task. Prediction 7: Older adults will show larger interference-locked N170 and P3 amplitudes for distractor stimuli compared to younger adults.

Predictions for target-locked ERPs. Age-related differences in target-locked ERPs were expected because of enhanced reactive control in older adults (e.g., Karayanidis et al., 2011). Previous studies demonstrated age-related differences in the P3 during the target-response interval in switching tasks (Gaál & Czigler, 2015; Karayanidis et al., 2011; West & Travers, 2008). Karayanidis and colleagues (2011) showed that mixing cost and switch cost effects were more pronounced in older adults compared to the young age group in the early P3, reflecting enhanced reactive control mechanisms. Moreover, effects were more evenly distributed in older adults due to increased frontal activity (cf. Kopp et al., 2014; West & Travers, 2008). In the late P3, mixing cost effects were reversed and attenuated in older adults due to prolonged P3 amplitudes in single trials. Empirical evidence on the target-locked N450 in the AX-CPT was provided by Schmitt, Wolff, and colleagues (2014). Based on the assumption that older adults rely on enhanced reactive control mechanisms in conflict detection, larger context effect in the target-response interval were expected in the old age group. Furthermore, and with regard to similar results in task switching, older adults were expected to show enhanced frontal activity due to compensatory mechanisms (Karayanidis et al., 2011; West & Travers, 2008).

Switching task. Prediction 8a: The mixing cost effect and the switch cost effect in the early course of the target-locked P3 will be larger in older adults compared to younger adults.

Prediction 8b: The mixing cost effect in the later course of the target-locked P3 will be smaller in older adults compared to younger adults.

Prediction 8c: Differential effects will be most pronounced at parietal sites in younger adults, whereas older adults will show an even distribution of amplitudes across the midline electrodes.

AX-CPT. Prediction 9a: Context effects in the target-locked N450 will be larger in older adults compared to younger adults.

Prediction 9b: Target-locked amplitudes will increase from the frontal to the parietal electrodes in younger adults, whereas older adults will show an even distribution of amplitudes across the midline electrodes.

3.4 Near Transfer Effects of Cognitive Control Training to Task Switching

The goal of many cognitive training interventions is proving the generalization of training effects to other situations. Therefore, it was of particular interest to investigate transfer effects of the cognitive control training to a switching task with a distinct structural similarity to the training task. The main purpose was to replicate behavioral results of near transfer effects from prior studies and to extend the research predictions to the neural level. As mentioned above, two types of training were implemented (pure task-switching training and single-task training) that put different demands on cognitive control. Therefore, it was expected that transfer effects in behavioral results are larger after task-switching training than after single-task training, and that transfer effects in ERPs vary between the training groups (Karbach & Kray, 2009).

3.4.1 Near transfer effects to behavioral performance.

Previous evidence demonstrated near transfer effects in older adults after task-switching training in the form of faster responses, reduced error rates, and smaller cognitive costs in similar switching tasks after the training (Cepeda et al., 2001; Fehér, 2015; Gaál & Czigler, 2017; Karbach, 2008; Karbach et al., 2010, 2017; Karbach & Kray, 2009). Thus, it was expected that older adults are able to compensate impaired cognitive control abilities by means of task-switching training. Furthermore, transfer effects in general switch costs were expected to be more pronounced in the task-switching training group than in the single-task training group, based on previous results (Karbach, 2008; Karbach et al., 2010; Karbach & Kray, 2009).

Prediction 10a: Near transfer effects (i.e., reduced latencies, decreased error rates, and smaller cognitive costs) will be evident in the training groups after the training, compared to the young control group.

Prediction 10b: Near transfer effects will be more pronounced in the task-switching training group than in the single-task training group.

3.4.2 Near transfer effects to ERPs.

The expectation of training-induced changes in task performance in older adults came along with presumed electrophysiological changes in ERPs that reflect cognitive control processes. Temporal distinguishable components of P3 activity were investigated in two time windows after cue and target presentation in order to clarify which cognitive processes were affected by the cognitive intervention. In general, age-related differences in the P3 amplitudes were expected to be smaller after the training. Due to the controversy over how frontal EEG activity reflects processes of cognitive compensation in older adults, it is unclear whether frontal P3 amplitudes are supposed to increase or decrease after the training. Therefore, research predictions on the distributions of the P3 are explorative (Angel et al., 2010; Goffaux, 2007; Park & Reuter-Lorenz, 2009).

With regard to the DMC model (Braver, 2012), it was expected that older adults show enhanced training-induced efficiency in proactive and reactive control modes. In younger adults, efficient proactive control was typically linked to larger differential effects between context conditions at parietal electrodes (Karayanidis et al., 2011; Schmitt, Ferdinand, & Kray, 2014). Similar results were expected in older adults for the cue-locked P3 amplitude, reflecting improved proactive differentiation between the trial types after the training.

Training-induced changes in cognitive control mechanism were also expected in form of a more efficient reactive control in older adults. Based on the findings by Karayanidis and colleagues (2011), it was expected that differential effects between the trial types in the target-response interval are less pronounced in older adults after the training due to improved post-target interference resolution for trials that put high cognitive demands.

If task-switching training leads to improved cognitive control processes and results in enhanced temporal efficiency in older adults:

Prediction 11a: Cue-locked neural activity will reflect larger cognitive engagement in proactive control (i.e., shortened mixing cost effects in the early P3 and larger switch cost effects in the late P3) in the training groups after the training, compared to the young control group.

Prediction 11b: Target-locked neural activity will reflect higher efficiency in reactive control (i.e., less differentiated mixing cost effects in the early P3 and reversed mixing cost effects in the late P3) in the training groups after the training, compared to the young control group.

Prediction 11c: Frontal neural activity will be modulated in the training groups after the training, compared to the young control group.

3.5 Far Transfer Effects of Cognitive Control Training to Context Processing

The generalization of trained cognitive control skills is not restricted to structurally similar tasks but can also appear in structurally dissimilar tasks that demand the practiced cognitive control processes. It was of interest to examine far transfer effects of the task-switching intervention to the AX-CPT because the training task and the transfer task share the requirement of selection, maintenance, inhibition, and updating of task information. Furthermore, it is assumed that the tasks share the neural recruitment of prefrontal networks (see chapter 2.1.4). However, there are no prior training studies that investigated far transfer effects of task-switching training to the AX-CPT. Therefore, the research predictions are exploratory, based on similar findings on far transfer effects after task-switching training in older adults.

3.5.1 Far transfer effects to behavioral performance.

It was pointed out that older adults are able to improve perceptual speed, sustained attention, and working-memory performance after task-switching trainings (Anguera et al., 2013; Karbach et al., 2017). Constructive similarity and diversity between cued switching tasks and the AX-CPT was demonstrated by Schmitt, Ferdinand, and Kray (2014) who stated that both tasks require the fundamental mechanism of context updating. Therefore, it was expected that enhanced context updating in older adults by means of task-switching training will result in improved behavioral performance in the AX-CPT. More specifically, it was expected that older adults show a more efficient differentiation between the context conditions, similar to the behavioral findings in younger adults.

Prediction 12: Far transfer effects (i.e., reduced latencies, decreased error rates, and smaller context effects) will be evident in the training groups after the training, compared to the young control group.

3.5.2 Far transfer effects to ERPs.

Anguera and colleagues (2013) provided evidence for neural far transfer effects in older adults after a multitasking training that was similar to task-switching training. Results showed reduced age-related differences in untrained, dissimilar cognitive control tasks that measured sustained attention and working memory after the multitasking training due to training-induced enhancements in the prefrontal activity in older adults. Based on the findings by Anguera and colleagues (2013), training-induced changes were expected in older adults in the AX-CPT because both tasks require attentional and working-memory mechanisms for successful context updating and conflict processing.

If task-switching training leads to improved cognitive control processes and results in enhanced temporal efficiency in older adults:

Prediction 13a: Cue-locked neural activity will reflect larger cognitive engagement in proactive control (i.e., larger context effects in P3 amplitudes) in the training groups after the training, compared to the young control group.

Prediction 13b: Target-locked neural activity will reflect higher efficiency of reactive control (i.e., smaller context effects in N450 amplitudes) in the training groups after the training, compared to the young control group.

Prediction 13c: Frontal neural activity will be modulated in the training groups after the training, compared to the young control group.

3.6 Far Transfer Effects of Cognitive Control Training to Working Memory and Interference Control

Interference control is assumed to be impaired in older adults, which is reflected in age-related differences in delayed-recognition tasks that include interfering stimuli (e.g., Clapp & Gazzaley, 2012). It was presumed that task-switching training exercises mechanisms of working memory and interference control because the training tasks required the ability to focus on task-relevant information and inhibit task-irrelevant information (Braver & Cohen, 2000;

Diamond, 2013; Grange & Houghton, 2014; Morton et al., 2011). Furthermore, the WMC task was assumed to demand neural circuits in the prefrontal cortex that were also activated during task switching (Fabiani & Friedman, 1995; Kok, 2001; Pinal, 2014; Polich, 2007). Based on the theoretical framework and empirical evidence in delayed-recognition tasks, a general reduction in the inhibition deficit for distracting stimuli in older adults was expected.

3.6.1 Far transfer effects to behavioral performance.

Task-switching training studies confirmed far transfer effects in older adults to dissimilar cognitive control tasks that measured interference control, such as the Stroop task and the Flanker task (Gaál & Czigler, 2017; Karbach, 2008; Karbach & Kray, 2009).

Prediction 14: Far transfer effects (i.e., reduced latencies and decreased error rates for interfering stimuli) will be evident in the training groups after the training, compared to the young control group.

3.6.2 Far transfer effects to ERPs.

Anguera and colleagues (2013) demonstrated neural far transfer effects of their multitasking training to a delayed-recognition task in older adults. The findings showed training-induced enhancement in the frontal activity in the older brain after the multitasking training. Based on these results, training-induced neural changes in older adults were expected in the WMC task.

If task-switching training leads to improved working memory and interference control in older adults:

Prediction 15: Interference-locked neural activity will reflect more efficient working memory and interference control (i.e., decreased N170 and P3 amplitudes for distractor stimuli) in the training groups after the training, compared to the young control group.

Additional note. Finally, the difference in amount of far transfer effects between the task-switching training group and the single-task training group is an open question. The pure task-switching training was expected to exercise specific cognitive control processes, whereas single-task training was expected to result in more general training effects (e.g., Karbach & Kray, 2009). Therefore, the following applies to all previous research questions of far transfer as well as to research questions of near transfer to ERPs:

Prediction 16: Assuming that pure task-switching training and single-task training differ in their demands on cognitive control processes, transfer effects will vary between the task-switching training group and the single-task training group.

II. Empirical Part

4. Method

4.1 Participants

Recruitment. In order to examine age-related differences in this study, two major age groups were recruited; 31 younger adults, aged from 18 to 30 years, and 72 older adults, aged from 60 to 80 years. Older adults were recruited by means of newspaper articles, and younger adults were recruited by means of on-campus posters and social media. Eight older adults did not complete their participation in the study, which resulted in a final sample size of 64 older adults and 31 younger adults. All participants received monetary compensation for their attendance. Older adults received 8€ per hour, and younger adults could choose between financial compensation and course credit (Versuchspersonenstunden).

Ethics. A proposal about the study procedure was posed by the IRTG (International Research Training Group) and approved by the ethical board. Participation was on a voluntary basis, and a written informed consent was signed by the participants at the beginning of the first session.

Descriptive data. Table 1 shows the descriptive data and the statistical results of the psychometric tests for the final sample. According to self-report, all participants were German native speakers and right-handers, had normal or corrected-to-normal vision, did not suffer from a neurological or psychological disorder, and did not take any medication that might affect their cognitive abilities. Moreover, none of the exclusion criteria for EEG or fMRI examinations was fulfilled. To ensure the representativeness of the age samples, two psychometric tests were used to measure age-related differences in performance parameters of fluid and crystalline intelligence: the Digit Symbol Substitution Test (DSST, adapted from Wechsler, 1982) and the Spot-a-Word Test (e.g., Baltes, Mayer, Helmchen, & Steinhagen-Thiessen, 1999, for a detailed description of the psychometric tests, see chapter 4.3.1). In line with the two-component model of life span cognition (e.g., Baltes, Mayer et al., 1999, see chapter 2.1.2), older adults achieved lower scores in the DSST compared to younger adults, $F(1, 92) = 64.61$, $p < .001$, $\eta_p^2 = .41$, confirming an age-related decline in processing speed and inductive reasoning. In contrast, older adults showed higher scores in the Spot-a-Word Test compared to younger adults, $F(1, 92) = 51.96$, $p < .001$, $\eta_p^2 = .36$, demonstrating a more comprehensive vocabulary.

Table 1: Descriptive Data and Statistics of the Final Study Sample: Mean values (and Standard Deviations).

	Age Group	
Statistics	Younger Adults	Older Adults
n	31	64
Mean age	22.9 (2.74)	69.38 (4.45)
Age range	18-28	61-80
Male/female	13/18	33/31
DSST Test Score	61.97 (11.19)	44.17 (9.45)
Spot-a-Word Test Score	22.29 (3.52)	27.56 (3.33)

Note. DSST = Digit Symbol Substitution Test

4.2 Overview of the Study Design

The training study lasted six weeks and was divided into three phases: pretest, training, and posttest (see Figure 3). At pretest and posttest, participants performed a cognitive test battery, including three transfer tasks that measured specific cognitive control abilities. At pretest, participants additionally performed two psychometric tests that examined fluid intelligence (by means of the DSST) and crystallized intelligence (by means of the Spot-a-Word-Test).

The pretest–training–posttest design allowed a direct comparison of task performance and ERPs between pretest (baseline) and posttest. In order to interpret transfer effects of the cognitive control training, the transfer tasks were identical for pre- and posttest. The pre- and posttest session consisted of two sessions, respectively; the first one served for the measurement of ERPs by means of EEG techniques, and the second one included fMRI techniques. Since the focus of this study is on temporal measures using ERPs, the fMRI sessions will not be considered further. After the pretest sessions, older adults performed a four-week cognitive control training with eight training sessions (training group), whereas younger adults did not receive any cognitive training (control group). In order to examine the influence of training-specific characteristics on transfer effects, the training group was further divided into two subgroups; one group only practiced mixed-task blocks (task-switching training group) and the other group only practiced one cognitive task at a time (single-task training group).

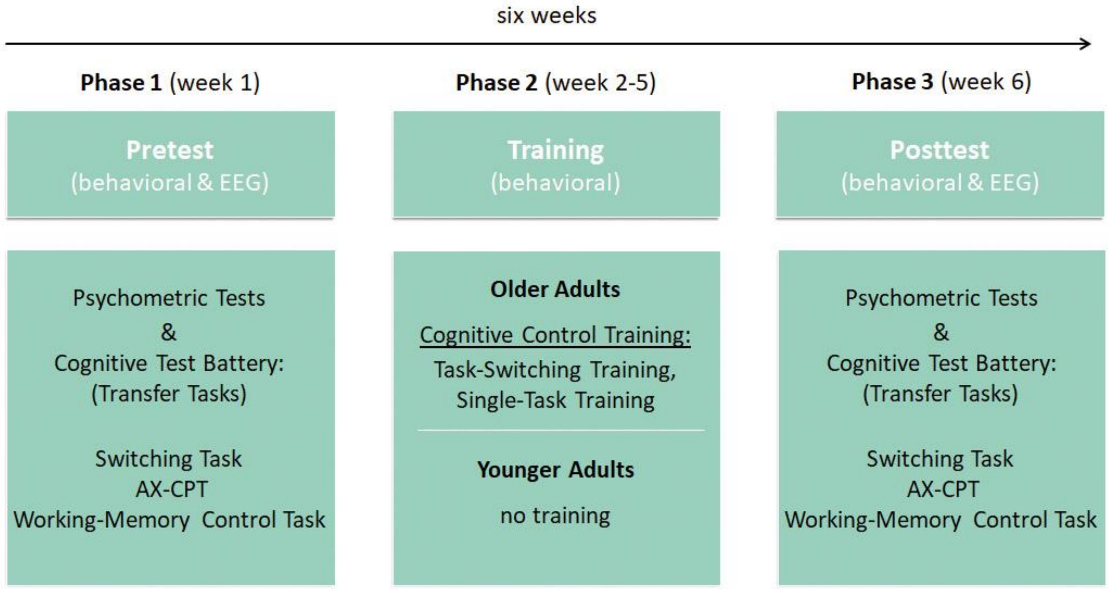

Figure 3. Study design. *Note.* DSST = Digit Symbol Substitution Test; AX-CPT = AX-Continuous Performance Task.

4.3 Measures

The following section provides a detailed description of the assessment for the pre- and posttest. The focus is on the cognitive test battery that was conducted for measuring the generalization of training benefits to behavioral performance and ERPs in contextual similar (near transfer) and dissimilar (far transfer) cognitive control tasks.

The tasks at pre- and posttest were computerized (except for the DSST), and EEG was recorded during the cognitive test battery. Task instructions and stimuli were presented on a 24 inch color monitor, and behavioral responses were recorded by keyboard or by two buttons on a response pad. The programming software was E-Prime Standard Version 2 (Psychology Software Tools, 2010).

4.3.1 Psychometric tests.

Digit Symbol Substitution Test. The DSST measured processing speed in form of a brief paper-pencil test that was adapted from the Hamburg Wechsler

Intelligence Test for adults (Wechsler, 1982). The test displayed an array of number-symbol mappings for the numbers 1 to 9. After a quick practice phase, participants had to fill in the blank spaces underneath a random sequence of 126 numbers with the corresponding symbols. Participants had to proceed as quickly as possible within the testing time of 90 seconds. The test score was calculated as the total number of correct symbols.

Spot-a-Word Test. The spot-a-word test measured vocabulary and was adapted from the Multiple Choice Knowledge Test-B (MWT-B, Lehrl, 1977). Participants were presented with sets of five words and had to identify one meaningful word out of four pronounceable non-sense alternatives. Responses were given by pressing a corresponding button on the keyboard. After three practice runs, a total of 35 word sets were presented successively. There was no time limit for the individual runs, but testing time was restricted to five minutes. The test score was calculated as the total number of correct items and was displayed on the screen at the end of the test.

4.3.2 Cognitive test battery.

The transfer tasks of the cognitive test battery demanded several processes of cognitive control, including task switching (measured by a switching task), context processing (measured by the AX-CPT), and working memory and interference control (measured by the WMC task). Task instructions were presented in advance, and each task was trained in practice blocks that could be repeated until the instructions were well understood. Participants were encouraged to respond as quickly and as accurately as possible at all time, and performance feedback in terms of mean latency and accuracy was given at the end of every task block.

Switching task.

Paradigm. The switching task was based on the cued task-switching paradigm (e.g., Logan et al., 2007) and measured the cognitive processes during two categorization tasks (task A and B) that were either performed in single-task blocks or mixed-task blocks (see Figure 4). The conceptual distinction between the task blocks was important in order to unravel the cognitive costs that typically occur in task switching (e.g., Kray & Lindenberger, 2000, see chapter 2.1.3).

In the single-task blocks, only one task had to be performed (task A or task B). In order to solve the task, a stimulus-response mapping for the particular task had to be maintained in working memory throughout the entire task block. In the mixed-task blocks, a switch between the two tasks A and B had to be performed. Therefore, stimulus-response mappings had to be reconfigured throughout the task block. Task switches were indicated by an informative cue prior to the target stimulus. While the identity of the cue was not relevant during the single-task blocks, it had to be attended during the mixed-task blocks in order to activate the appropriate stimulus-response mapping.

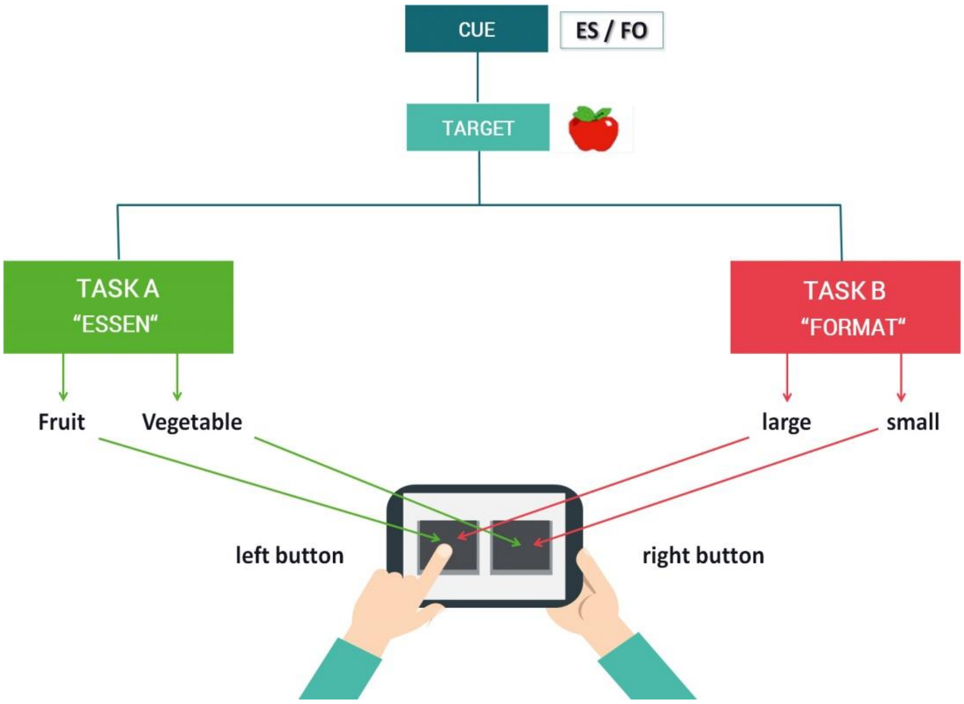

Figure 4. Task-switching scheme with exemplary stimulus-response assignments.

Tasks and stimulus material. Target stimuli were presented as food items on the computer screen, and task A and B were simple classification tasks for the targets. Participants had to categorize the item as either fruit or vegetable (Essensaufgabe), or as small or large in size (Formataufgabe). Responses were given with two buttons on the response pad. Target stimuli were 16 fruit and 16 vegetable pictures adapted from the Snodgrass and Vanderwart's pictorial set (Rossion & Portois, 2004). The targets were ambiguous in order to evoke interference. Therefore, every food item was available in small size (90 × 90 pixels) and large size (220 × 220 pixels). To solve the task correctly, participants had to concentrate on the currently relevant target attribute while suppressing the irrelevant one. Further interference was induced by the stimulus-response mappings to the keys on the response pad. For example, the left key was associated with the response for the attributes 'fruit' and 'large picture', and the right key was associated with the response for the attributes 'vegetable' and 'small picture' (see Figure 4). Thus, participants had to keep both assignments in mind and switch between them. Switching between the tasks was indicated by the cue stimulus, represented by the letters ES (for 'Essensaufgabe') and FO (for 'Formataufgabe'). Cues were 176 × 126 pixels in size and presented in the center of the screen. The stimulus material was identical for all participants at pre- and posttest, but posttest items differed from pretest items in order to hamper retest effects. The assignments of the task sets were counterbalanced across the subjects.

The switching task had two types of task blocks that were alternating. In single-task blocks, participants performed only one task (task A or B) throughout the entire block. Trials within the single-task blocks were referred to as single trials. In mixed-task blocks, participants had to randomly switch between task A and B by paying close attention to the cue information. Trials within the mixed-task blocks were either non-switch trials, meaning one task had to be performed two times in a row (AA or BB), or switch trials, meaning a switch between the tasks had to be performed (AB or BA).

Task procedure. Participants performed eight task blocks, consisting of four single-task blocks and four mixed-task blocks. EEG was recorded for the main experiment, which lasted about 25 minutes. Uncertainties regarding the identification and categorization of target stimuli were clarified in the beginning.

The sequence of task blocks in the main experimental was kept constant for every participant, consisting of two initial single-task blocks, followed by two mixed-task blocks. After a quick break, the same course was performed again. Each experimental block included 40 trials, resulting in a total number of 320 trials for the experiment. Mixed-task blocks consisted of 20 switch and 20 non-switch trials that were presented in a random sequence.

Single-task and mixed-task blocks involved an equal number of response types (left or right response key), task types ("Essensaufgabe" and "Formataufgabe"), and stimulus types (large sized fruit, small sized fruit, large sized vegetable, small sized vegetable).

Trial procedure. Trials started with a 300 ms fixation cross. The cues were visible for 800 ms. After a second 1,000 ms fixation cross, the target stimulus was presented until a response was made, but not longer than 1,800 ms. Responses had to be made within the time window, otherwise, the trial was excluded from the further analysis. The inter-trial interval (ITI) between two consecutive trials lasted 500 ms.

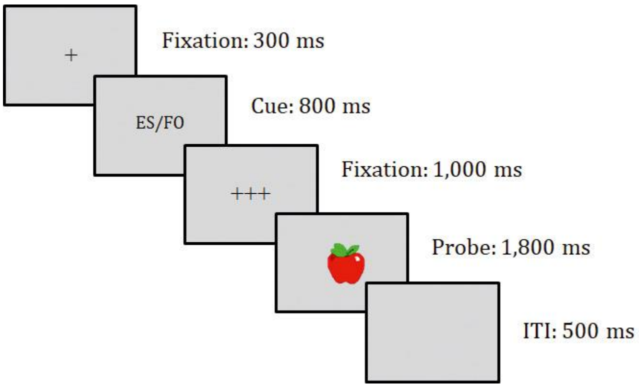

Figure 5. Trial procedure of the switching task.

AX–Continuous Performance task.

Paradigm. The AX-Continuous Performance task (AX-CPT; Braver et al., 2001, 2005; Lenartowicz et al., 2010; Schmitt, Ferdinand, & Kray, 2014) was designed to investigate cognitive processes of selection, maintenance, and updating of contextual information (Braver et al., 2001). The AX-CPT used in this study was adapted from Schmitt, Ferdinand, and Kray (2014) and included pictures instead of letters as target stimuli (cf. Lenartowicz et al., 2010) in order to facilitate the visual processing of the items, especially for older adults.

The modified version of the AX-CPT included two trial types, which allowed the investigation of cognitive costs caused by varying demands on context processing. In context-independent (c-indep) trials, correct responses to the target stimulus did not rely on the previous cue information because the stimulus-response mapping was identical for the four possible cue-target combinations (see Fig. 6, right side). In context-dependent (c-dep) trials, the correct response to the target relied on the preceding cue. To cause interference, the correct stimulus-response mapping was exactly reversed for the cue-target combinations in context-dependent trials (see Figure 6, left side). Thus, participants had to focus attention on the cue information in order to reconfigure the stimulus-response mapping, if required.

In the main experiment, all task blocks contained alternating c-dep and c-indep trials, putting high demands on context updating. This means that both attentional and inhibitory processes were evoked, as participants had to activate the relevant stimulus-response mapping while inhibiting the irrelevant mapping.

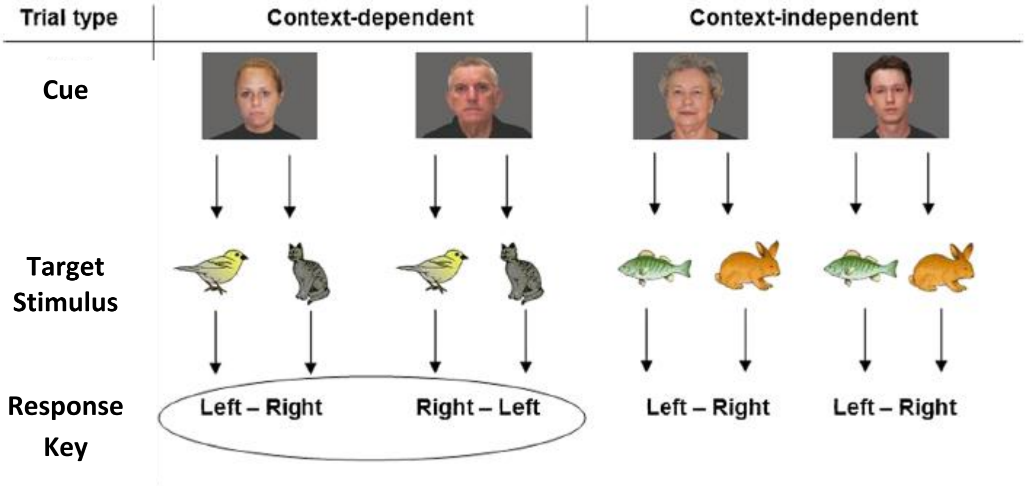

Figure 6. Inherent structure of the modified AX-CPT by Schmitt, Ferdinand, and Kray (2014).

Task and stimulus material. Stimulus material differed between the pre- and posttest session, but was identical for all participants within each session. Cue stimuli were four color photographs of neutral faces that were adapted from the lifespan database of adult facial stimuli (Minear & Park, 2004). Cue identities were either the face of a young man, a young woman, an old man, or an old woman. Target stimuli at pretest were color pictures of a bird, a cat, a fish, and a rabbit that were adapted from the Snodgrass and Vanderwart's object pictorial set (Rossion & Pourtois, 2004)[4]. All stimuli were presented in a 3.5 x 5.5 cm frame on a gray background. Responses to target stimuli were given with two buttons on the response pad.

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[4] For the posttest session, a picture of a rat, raccoon, frog, and kangaroo were chosen as targets stimuli.

Figure 6 shows one example for the assignment of cues, targets, and response keys in the AX-CPT. Correct responses to the target stimuli in the c-indep trials (fish and rabbit) were made with the same set of keys. Participants had to press the left button after the presentation of the fish and the right button after the presentation of the rabbit, regardless of the preceding cue (young man or old woman). Hence, in c-indep trials, the correct response to the target was independent of the cue-identity. In c-dep trials, however, correct responses to the targets (bird and cat) were dependent upon the cue-identity (young woman and old man). In this example, participants had to press the left key if the photo of the young woman was followed by the bird and the right button if the same cue was followed by the cat. For targets following the photo of the old man, the response keys were exactly reversed.

The assignments of cues to targets and targets to response-keys in both c-indep and c-dep trials were counterbalanced across the subjects, and the two cues for the trial conditions were always paired as followed: young man/old woman or old man/young woman.

Task procedure. The modified AX-CPT included 160 trials that were distributed over four task blocks. Context processing was manipulated on a trial-to-trial basis by mixing c-dep and c-indep trials with the same frequency within the task blocks. Visual instructions were given on the screen before each task block as a reminder, and a break was included after two task blocks. Testing time of the main experiment lasted about 15 minutes.

Trial procedure. Trials started with a 250 ms fixation cross, followed by the cue, which was displayed for 750 ms. After a second 750 ms fixation cross, the target was presented for a maximum of 3,600 ms. Responses had to be executed within the 3,600 ms time window, otherwise, the trial was excluded from the further analysis. An ITI of 500 ms separated two consecutive trials.

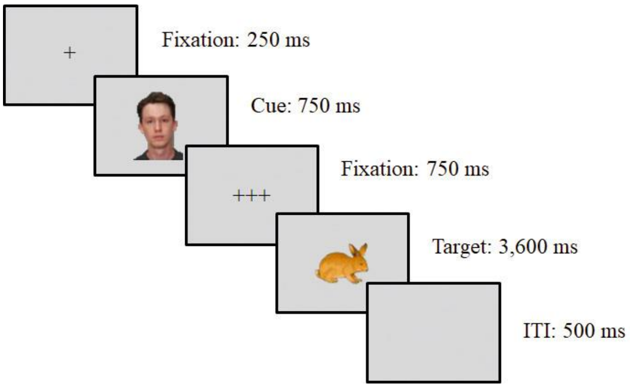

Figure 7. Trial procedure of the AX-CPT.

Working-Memory Control task.

Paradigm. The Working-Memory Control (WMC) task was based on the delayed-recognition task paradigm (e.g., Clapp et al. 2009, see chapter 2.1.3). In each run, participants had to memorize a picture of a landscape over a certain time delay in order to make a match/non-match decision when the target stimulus was presented. Furthermore, participants were confronted with interfering stimuli during the delay period. (Clapp & Gazzaley, 2012).

Two types of interfering stimuli were selected to evoke processes of either interruption or distraction. Interrupter stimuli were used to focus attention on a secondary classification task. Distractor stimuli represented irrelevant task information, and participants were asked to ignore them. Clapp and Gazzaley (2012) proposed that two different cognitive mechanisms of interference control were triggered by the interfering stimuli. Interrupter stimuli required processes of enhanced attention, whereas distractor stimuli demanded processes of suppression. To separate these cognitive control mechanisms, interrupter and distractor stimuli were used in different task blocks. A third control task of passive viewing was included to provide a baseline measurement of neural activity (cf. Clapp & Gazzaley, 2012).

Task and stimulus material. The stimulus material was identical for all participants, in both the pre- and posttest session. Two hundred forty eight grayscale photographs of neutral male and female faces from a large age range (124 female, 124 male) and 176 landscapes were provided by the Gazzaley Lab (e.g., Gazzaley et al., 2008). Face stimuli were edited in Photoshop CC 2015 (Adobe Systems) to remove any potential non-facial cues (cf. Clapp & Gazzaley, 2012). The stimuli were non-repeated across all trials for all task blocks, and were presented as 225 x 225 pixeled landscapes and as 330 x 224 pixeled faces on a gray background at the center of the screen.

Participants had to perform three different task blocks (see Figure 8). In the interrupter task, participants had to remember a landscape (first stimulus). After that, a face appeared (second stimulus) that required a judgement of gender identification (secondary task). Participants were asked to respond to either a female or a male face with a button press, otherwise, no response had to be performed. The target gender was counterbalanced across the subjects, but the probability of catch trials was only 4%. The face stimulus was followed by a landscape (third stimulus), which represented the target stimulus and had to be classified as match (landscape stimulus seen before in that particular trial) or non-match (unseen landscape). The distractor task was identical to the interrupter task, except for the absence of a secondary task. Instead of responding to the face, participants had to ignore the stimulus. The stimulus-response mappings for the distractor and interrupter task were counterbalanced across the subjects. In the passive view, participants were asked to passively view the landscape and the face stimulus, and to respond to a target arrow pointing left or right. The stimulus-response mapping for the passive view was kept constant for all participants (left key on the response pad for arrows pointing to the left, right key for arrows pointing to the right) in order to prevent an irregular distribution of potential errors.

Task procedure. The main experiment lasted about 35 minutes and included two runs of three task blocks (one block of interrupter task, distractor task, and passive view) with 32 trials per block (192 trials in total). The sequence of stimuli within the task blocks was random, and the sequence of the task blocks within the runs was counterbalanced across the participants.

Trial procedure. Trials started with a 200 ms fixation cross. A first landscape stimulus was presented for 800 ms, followed by a first 2,600 ms delay. Afterwards, a face stimulus appeared for 800 ms, followed by a second delay that lasted 2,800 ms. The target stimulus was presented for 1,800 ms, followed by a 500 ms delay. A 1,300 ms ITI marked the end of the trial.

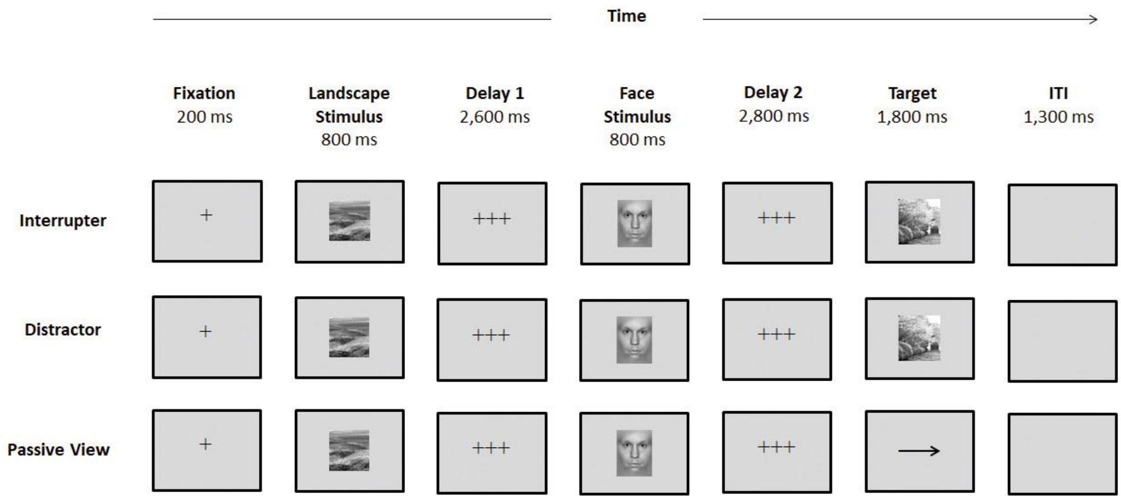

Figure 8. Trial procedure of the WMC task.

4.4 Study Procedure

Pre-study preparations. Candidates were asked to provide personal data and clinical information over the phone. A first briefing on the course of the study was provided, and after analyzing the personal data, suitable candidates were invited for the pretest session.

Pretest and posttest sessions. The sessions took place in the EEG laboratory of the Psychology work unit "Sprache, Lernen und Handlung" at Saarland University. Two test investigators were present for the EEG sessions that lasted about three hours. Participants were briefed on the EEG procedure, signed a consent form, and completed a demographic questionnaire. Testing started with the psychometric measures of processing speed (by means of the DSST) and vocabulary (by means of the Spot-a-Word Test, see chapter 4.3.1).

EEG was recorded for the cognitive test battery, including the switching task, the AX-CPT, and the WMC task. The recording lasted about one and a half hours in total with regular breaks. For that time, participants were seated in a separate EEG chamber in the laboratory.

Task-switching training. The cognitive control training for older adults was based on the cued task-switching paradigm (e.g., Logan et al., 2007). In order to examine the impact of different types of training (task-switching training and single-task training), older adults were split into two training groups, matched on age, gender, and the baseline performance in the switching task (by means of cognitive costs, see chapter 5.1).

Training groups. The single-task training group was trained in single-tasks blocks only, whereas the task-switching training group performed eight training sessions of mixed-task blocks.

Training tasks and stimuli. The training tasks and stimulus material varied between the sessions (see Figure 9). Cue and target stimuli were identical for all participants throughout the training, but instructions differed between the training groups. A total number of 128 items were selected from the Snodgrass and Vanderwart's pictorial set (Rossion & Portois, 2004) and from Clipart Sets available at the "Sprache, Lernen & Handlung" database. Tasks A and B consisted of 32 target stimuli each, and the material was available in two task dimensions (semantic and perceptual dimension).

There were two possible stimulus-response mappings per session of single-task training and four possible mappings per session of task-switching training. The assignments were counterbalanced across the participants in both training groups. Furthermore, the assignment of task A and B to the stimuli and task types, respectively, was counterbalanced across the participants in each session.

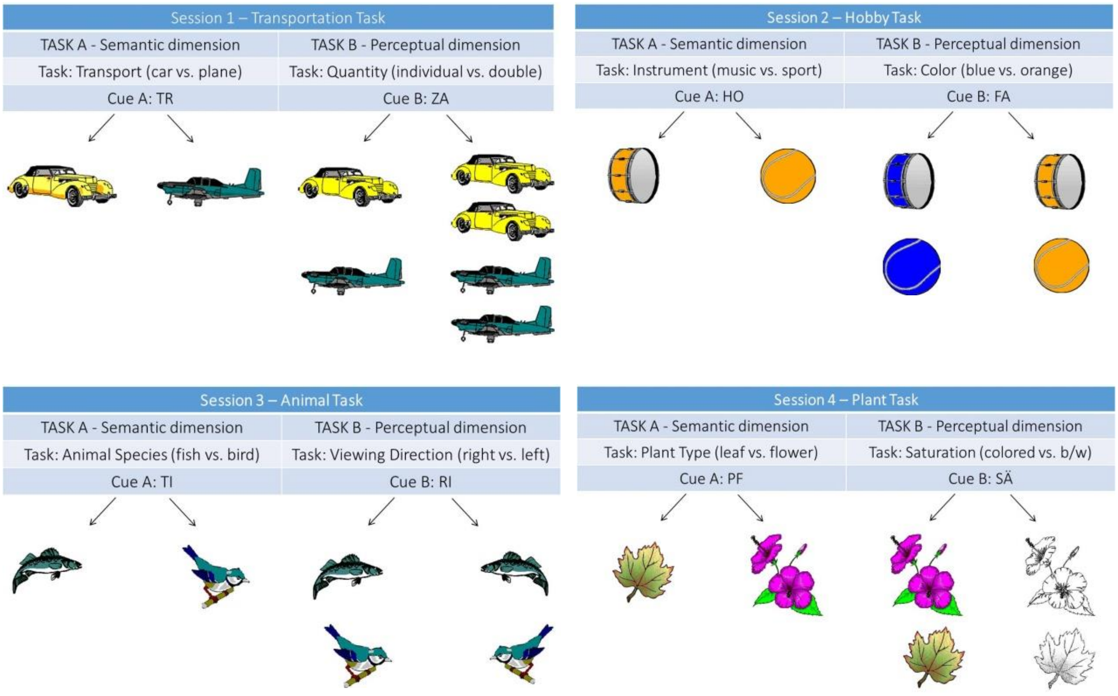

Figure 9. Stimulus material and tasks for the eight training sessions[5].

Training procedure. The training sessions were carried out at the Saarland University. Trainings were computerized and lasted for about 45 minutes. Participants of the single-task training group and task-switching training group were trained separately. Each training program contained 10 task blocks of 40 trials each, resulting in a total number of 400 trials per session. The single-task training group performed five single-task blocks of task A and five single-task blocks of task B in an alternating sequence. The task-switching training group performed ten mixed-task blocks.

Stimulus material and detailed task instructions were presented before the practice blocks. Responses were given with two buttons on the keyboard. Participants completed the training in a self-paced manner, and performance feedback was included at the end of every training block.

Trial procedure. The trial procedure was identical to the switching task used in the pre- and posttest session (see chapter 4.3.2).

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[5] Task labels and cues were presented in german language (1.Transport-Aufgabe: Transportmittel(TR) & Zahl(ZA), 2.Hobby-Aufgabe: Hobby(HO) & Farbe(FA), 3.Tier-Aufgabe: Tierart(TI) & Blickrichtung(RI), 4.Pflanzen-Aufgabe: Pflanzenart(PF) & Sättigung(SÄ), 5.Kleidungs-Aufgabe: Kleidungsstück(KL) & Muster(MU), 6.Gelände-Aufgabe: Terrain(TE) & Orientierung(OR), 7.Objekt-Aufgabe: Objekt(OB) & Luminanz(LU), 8.Leute-Aufgabe: Geschlecht(GE) & Haarfarbe(HA)).

4.5 EEG Recording

For the reliable derivation of EEG signals, participants were seated in a separate EEG-chamber that was noise-protected and electrically shielded. EEG and electro-ocular activity (EOG) were recorded using the Brain Vision Recorder software (Brain Products, Munich, Germany). The signal was derived from 59 Ag-AgCl active electrodes, arranged in the extended international 10-20 system (Jasper, 1958). The electrodes were attached to elastic caps (Acticap, Brain Products, Munich, Germany), and impedances were kept below 20 kΩ. The ground electrode was placed at the AFz position, and the reference electrode was placed at the left mastoid. In order to correct for ocular artifacts, vertical and horizontal eye movements were tracked by EOG. Therefore, electrodes were placed above and below the right eye for recording vertical movements, and at both outer canthi for recording horizontal eye movements. During recording, EEG and EOG were filtered online (250 Hz) and converted analog-to-digital (sample rate = 500 Hz). After the EEG session, data was band-pass filtered offline from 0.01-30 Hz and referenced to the link mastoid electrode. Before the data analysis, eye movements were corrected by means of a linear regression (cf. Gratton, Coles, & Donchin, 1983). Trials including uncorrectable eye artifacts were rejected before data averaging. The EEG was further screened for artifacts at all electrodes, and trials containing artifacts of technical nature or muscular tension were excluded. Finally, EEG data was transferred into SPSS (IBM SPSS Statistics 22) for statistical analyses.

4.6 Data Processing & Extreme Values

This chapter will provide a brief overview of the processing procedure for behavioral and neural data. Detailed statistical analyses will be described in the results chapter because the statistical variables and procedures differed between the cognitive tasks. In general, behavioral data was computed using the software E-Prime and SPSS. EEG data was processed with EEProbe and Brain Vision Analyzer, and analyzed in SPSS. The data was vector-normalized to control for age-related differences in the distribution of electrodes (McCarthy & Wood, 1985). Statistical variables were analyzed using analyses of variances (ANOVA). If necessary, F values were corrected for nonsphericity with the Greenhouse-

Geisser procedure (Keselman & Rogan, 1980). The overall level of significance for the statistical analyses was 5%, marginal significance was 10%. Effect sizes using eta squared (η_p^2) and Cohen's *d* are reported to provide standardized values of measurements with respect to the sample size (Lakens, 2013).

Extreme values in behavioral data. A preliminary data screening for extreme values in the training and transfer data resulted in the exclusion of one participant from all subsequent analyses[6].

Extreme values in ERP data. Due to uncorrectable artifacts in the EEG recording, some participants had to be excluded from the statistical analysis. This exclusion resulted in a final sample of 90 subjects for the switching task, 91 subjects for the AX-CPT, and 88 subjects for the WMC task.

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[6] Data was marked as extreme value and excluded from further analyses if scores exceeded -/+ 3 SD in more than one training session as well as in the pre- or posttest session.

5. Results

The results will be presented in five sections. The first part describes the matching procedure that was used to assign the participants of old age to the training groups. The second part reports the training results. Part three addresses near transfer effects to a similar switching task, and part four and five focus on far transfer effects to two dissimilar cognitive control tasks.

5.1 Matching of the Training Groups

Older adults were assigned to two training groups (task-switching training and single-task training) before the intervention. The matching procedure was based on the performance at pretest in order to control for baseline differences between the groups. Matching referred to the scores of the DSST as well as to the cognitive costs in the switching task (for a description of the tasks, see chapter 4.3). Differences in the baseline performance were controlled for each matching variable separately. Control analyses were carried out by means of a one-way ANOVA with the between-subjects factor Training Group (task-switching training, single-task training). There were no significant differences in the matching variables between the training groups at pretest. Results for the matching procedure are presented in Table 2.

Table 2: Means (M) and Standard Deviations (SD) for Perceptual Speed (DSST score), Vocabulary (Spot-a-Word Test Score), and Cognitive Costs in the Training Groups at Pretest.

	Training Group					
Matching Criteria	Task-Switching Training (n = 30)		Single-Task Training (n = 34)		Statistical Values	
	M	*SD*	*M*	*SD*	*F*	*p*
DSST score	46.30	9.71	42.29	8.94	2.95	.09
General Switch Costs (Latencies)	123	96	123	93	.00	.98
General Switch Costs (Error Rates)	5.20	7.91	6.17	6.61	.28	.60
Specific Switch Costs (Latencies)	25	46	21	59	.09	.77
Specific Switch Costs (Error Rates)	3.54	5.92	2.78	4.94	.31	.58

5.2 Training Data

In order to interpret transfer effects after cognitive trainings, participants should show performance improvements in the trained tasks due to the continuous exercise of cognitive mechanisms (e.g., Klauer, 2000).

Data analysis was based on latency scores (mean RT for correct responses) and error rates. Experimental trials faster than 100 ms were excluded from the statistical analysis (= 0.16% of trials in the task-switching training group and = 0.11% of trials in the single-task training group), as well as practice blocks and start trials (to control for restart costs, cf. Allport & Wylie, 2000).

The use of different training stimuli and tasks over the eight training sessions resulted in a variability of training difficulty throughout the intervention. Therefore, a linear improvement in performance over the whole training period was not expected, but linear training gains within each session were presumed (cf. Pereg et al., 2013). For the examination of training effects, each training session was divided into four time units (quartiles), consisting of 100 experimental trials, respectively. A repeated ANOVA with the between-subjects factor Training Group (task-switching training, single-task training) and the within-subjects factor Quartile (1, 2, 3, 4) was performed. Results for mean latencies and error rates are displayed in Figure 10. An overview of the statistical data is provided in Table 4 (see Appendix).

Latencies. Results revealed a significant quartile × training group interaction, $F(1, 61) = 13.81$, $p < .001$ $\eta_p^2 = .19$. A linear decrease in mean RT from quartile 1 to 4 was found in the task-switching training group, $F(1, 28) = 74.59$, $p < .001$ $\eta_p^2 = .73$, and in the single-task training group, $F(1, 33) = 78.54$, $p < .001$ $\eta_p^2 = .70$.

Accuracy. The statistical analyses based on error rates also revealed a significant quartile × training group interaction, $F(1, 61) = 27.24$, $p < .001$, $\eta_p^2 = .31$. Both training groups showed a linear decrease in error rates from quartile 1 to 4, but effects were more pronounced in the task-switching training group, $F(1, 28) = 38.48$, $p < .001$, $\eta_p^2 = .58$, than in the single-task training group, $F(1, 33) = 3.84$, $p < .10$, $\eta_p^2 = .10$.

Figure 10. Mean RT (ms, left panel) and error rates (%, right panel) as a function of training group (task-switching training, single-task training) and quartile (1-4). Error bars refer to standard errors of the mean.

Specific Switch Costs. A further repeated ANOVA for the specific switch costs in mean latencies was carried out for the task-switching training group, but did not reach significance[7]. A screening of the raw training data did not show a

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[7] Statistical data of the specific switch costs are attached in the Appendix (Table 4).

distinct pattern of changes in the costs within the training sessions. Overall, specific switch costs were low from the beginning of the session and tended to decline until quartile 3, before rising again in quartile 4 (quadratic effect for quartile, $p < .05$, see Figure 34).

Summary. The cognitive intervention was efficient, as participants of the task-switching training group and the single-task training group improved their performance in the respective tasks within the sessions. Mean RT scores and error rates were reduced as a result of the task practise in both groups with larger improvements in the task-switching training group regarding the accuracy scores. However, there were no significant changes in the specific switch costs in the task-switching training group within the training sessions.

5.3 Near Transfer Effects of Cognitive Control Training to Task Switching

The following section addresses near transfer effects of the cognitive control training to a similar switching task and is split into four parts. In the first part, age-related differences in the switching task at pretest are reported to account for consistency with previous studies. The second part focuses on near transfer effects of the cognitive control training to behavioral performance. Age-related differences at pretest and near transfer effects to cue- and target-locked event-related potentials are described in part three and four. A general description of the data processing will be given in advance, whereas detailed statistical procedures are presented at the beginning of each section.

Data processing & data analysis of behavioral performance. Data analysis was based on latency scores (mean RT for correct responses) and error rates. Experimental trials below the RT score of 100 ms were excluded from the statistical analysis (pretest: 2.75% of the trials in older adults and 0.28% of the trials in younger adults, posttest: 0.68% of the trials in older adults and 0.19% of the trials in younger adults), as well practice blocks and start trials. Statistical analyses based on latencies were performed using mean RT scores and log-transformed RT scores, and differences in results will be reported in references[8].

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[8] To control for age-related differences in the baseline performance, natural logarithms of RT scores were calculated (cf. Karbach, 2008).

General and specific switch costs in the switching task were investigated by means of a priori contrasts. Therefore, a repeated contrast was defined for the factor Trial Type (cf. Bühner & Ziegler, 2009). The first contrast compared the performance between single trials and non-switch trials and reflected general switch costs (Trial Type Contrast 1). The second contrast compared the performance between non-switch trials and switch trials and reflected specific switch costs (Trial Type Contrast 2). For the investigation of baseline differences between the training groups, an additional contrast was defined for the factor Study Group, comparing the performance of the task-switching training group against the single-task training group at pretest (cf. Bühner & Ziegler, 2009). Pre-existing differences between the training groups will be reported in references.

Pre-processing & data analysis of event-related potentials. In line with previous studies, ERP analyses of the switching task were restricted to the midline electrodes Fz, Cz, and Pz, where P3 effects were most pronounced (Gajewski & Falkenstein, 2012; Karayanidis et al., 2011). Time intervals for cue- and target-locked potentials started 200 ms before stimulus presentation and ended 1000 ms after stimulus onset. EEG data of the practice blocks and start trials was excluded from the statistical analysis.

In line with the methodical procedure by Karayanidis and colleagues (2011), differential effects in the P3 between the trial types were examined by means of a priori contrasts for the Factor Trial Type. A repeated contrast compared P3 amplitudes between single and non-switch trials, hereafter referred to as mixing cost effect (Trial Type Contrast 1), as well as between non-switch and switch trials, hereafter referred to as switch cost effect (Trial Type Contrast 2). An additional repeated contrast was defined for the factor Electrode in order to investigate the distribution of P3 amplitudes over the midline electrodes. The contrast compared P3 amplitudes between the frontal and the central electrode (Electrode Contrast 1), and between the central and the parietal electrode (Electrode Contrast 2). Baseline differences in P3 amplitudes between the training groups were analyzed by means of an additional contrast for the factor Study Group (see above).

5.3.1 Age-related differences in behavioral performance in the switching task.

To investigate the task performance of older and younger adults at pretest, a two-way ANOVA with the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factor Trial Type (single, non-switch, switch) was performed for mean latencies and error rates. ANOVA results are demonstrated in Figure 35 (see Appendix), and the statistical data for mean latencies and error rates is summarized in Table 5 (see Appendix).

Latencies. Results showed a significant age group × trial type interaction for Trial Type Contrast 1, $F(1, 92) = 6.11$, $p < .05$, $\eta_p^2 = .06$[9], indicating that general switch costs were larger in older adults compared to younger adults. Post-hoc comparisons showed that both age groups responded slower in non-switch trials than single trials (older adults: $t(62) = -9.97$, $p < .001$, $d_z = 1.27$, younger adults: $t(30) = -6.16$, $p < .001$, $d_z = 1.11$). Age-related differences in specific switch costs remained not significant ($p = .62$).

Accuracy. There was no age-related difference in general switch costs ($p = .16$). However, a significant age group × trial type interaction for Trial Type Contrast 2 was found, $F(1, 92) = 9.81$, $p < .01$, $\eta_p^2 = .10$, indicating that older adults made more errors in switch trials compared to non-switch trials, $t(62) = -4.52$, $p < .001$, $d_z = .57$, whereas younger adults did not show significant specific switch costs ($p = .71$).

Summary. In line with the previous literature on task switching (e.g., Gaál & Czigler, 2015), results for latencies and error rates emphasized the older adults' poorer performance in the switching task compared to the younger age group. It should be noted that cognitive costs were generally low at pretest for both age groups when compared to previous studies (cf. Karbach, 2008, see chapter 6.3.1).

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[9] The significant interaction for Trial Type Contrast 1 disappeared when analyzing log-transformed RT data ($p = .40$). For the discussion, see chapter 6.3.1.

5.3.2 Near transfer effects to behavioral performance in the switching task.

In order to examine training-induced changes in age-related differences in the switching task, a three-way ANOVA with the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest) and Trial Type (single, non-switch, switch) was performed. Scores for mean latencies, error rates, and cognitive costs are summarized in Table 6 (see Appendix). Figure 11 demonstrates the changes in cognitive costs on the level of mean RT from pretest to posttest for each study group.

Latencies. Results for latencies revealed a marginal significant session × study group interaction, $F(2, 91) = 3.10$, $p < .10$, $\eta_p^2 = .10$, demonstrating reduced mean RT scores at posttest with larger effects in the task-switching training group, $F(1, 28) = 31.59$, $p < .001$, $\eta_p^2 = .53$, and the single-task training group, $F(1, 33) = 33.45$, $p < .001$, $\eta_p^2 = .50$, compared to the young control group, $F(1, 30) = 17.11$, $p < .001$, $\eta_p^2 = .36$. The session × trial type contrast 2 × study group interaction gained significance, $F(2, 91) = 3.75$, $p < .05$, $\eta_p^2 = .08$, due to reduced specific switch costs in the young control group compared to older adults, $F(1, 30) = 8.93$, $p < .01$, $\eta_p^2 = .23$. No training-induced changes in specific switch costs were present in the task-switching training group ($p = .87$) and in the single-task training group ($p = .37$). Although the higher-order interaction for trial type contrast 1 was not significant ($p = .26$), a larger reduction in general switch costs emerged in the task-switching training group (-50%) compared to the single-task training group (-19%) and the young control group (-32%, see Figure 11).

Accuracy. Session interacted with study group, $F(2, 91) = 5.09$, $p < .01$, $\eta_p^2 = .10$, indicating a reduction in error rates at posttest for the task-switching training group, $F(1, 28) = 8.72$, $p < .01$, $\eta_p^2 = .24$, and the single-task training group, $F(2, 33) = 5.51$, $p < .05$, $\eta_p^2 = .14$, but not for the young control group ($p =$ 23). The higher-order interactions for cognitive costs remained not significant (all $p > .11$).

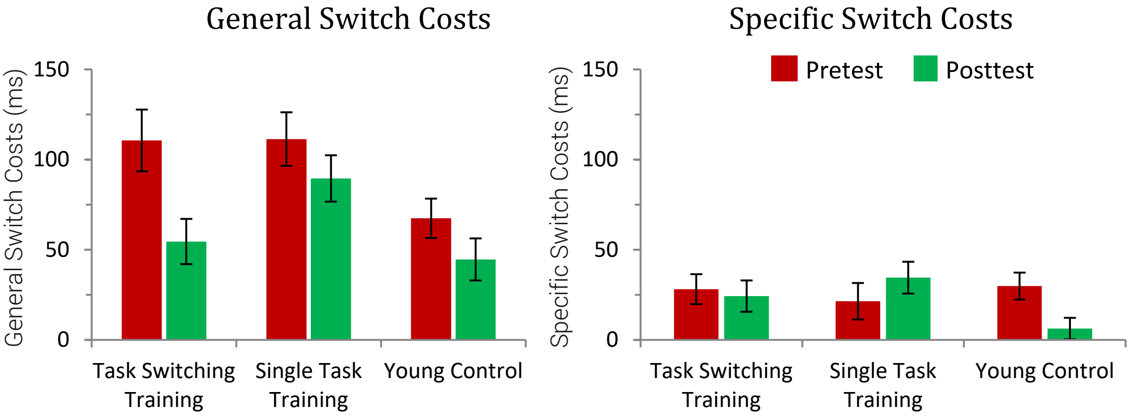


Figure 11. General switch costs (left panel) and specific switch costs (right panel) on the level of mean RT as a function of study group (task-switching training, single-task. training, young control) and session (pretest, posttest). Error bars refer to standard errors of the mean.

Summary. Behavioral results demonstrated that both training groups responded faster and made fewer errors in the switching task after the training. Near transfer effects to cognitive costs were less prominent in the overall ANOVA. However, general switch costs on the level of mean latencies were reduced within the study groups, especially in the task-switching training group. Against the expectations, a significant reduction in specific switch costs on the level of mean latencies was only found in the young control group.

5.3.3 Age-related differences in cue-locked ERPs in the switching task

After the visual inspection of the cue-locked grand average waveforms in younger and older adults in the switching task, two time windows were extracted for the statistical analysis of age-related differences in the P3. In line with previous results by Karayanidis and colleagues (2011), differential effects in P3 amplitudes between the trial types were evident in an early time window (300 to 500 ms after cue onset) and in a late time window (500 to 700 ms after cue onset). Grand average waveforms at pretest are depicted in Figure 12.

In order to investigate age-related differences at pretest, a three-way ANOVA with the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factors Trial Type (single trials, non-switch trials, switch trials) and Electrode (Fz, Cz, Pz) was performed. Differential effects between single and non-switch trials as well as between non-switch and switch trials were examined by means of priori contrasts for the factor Trial Type. Differential effects between the frontal and the central electrodes, and between the central and the parietal electrodes were examined by means of a priori contrasts for the factor Electrode. Detailed results for age-related differences in the cue-locked P3 at pretest are displayed in Figure 13 (early time window) and Figure 14 (late time window).

Switching Task – Cue-locked Event-related Potentials

Older Adults Younger Adults

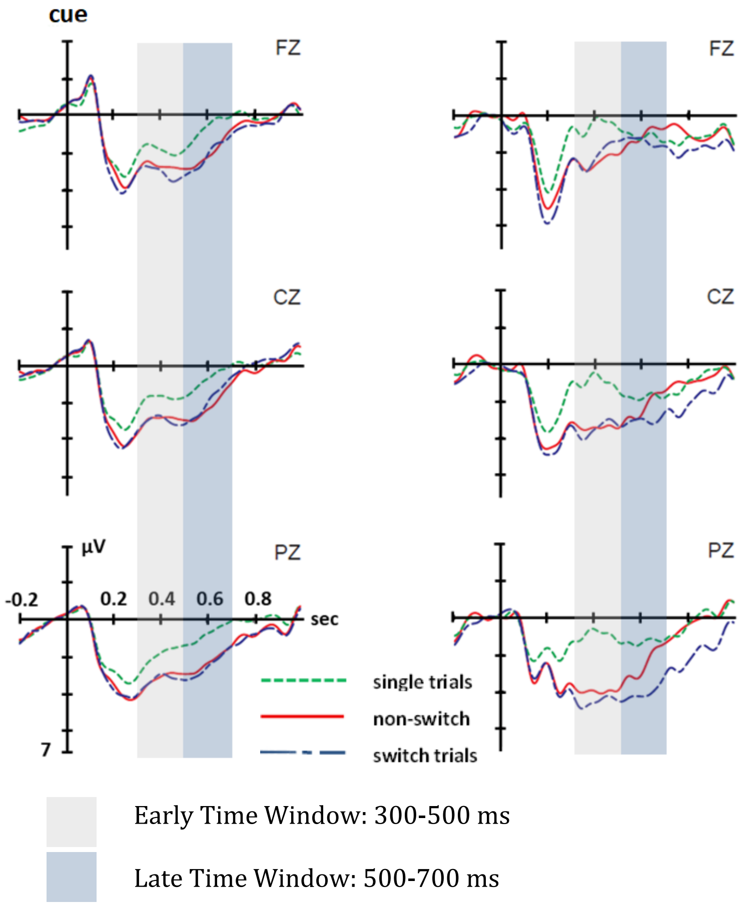


Figure 12. Cue-locked grand average waveforms for single, non-switch, and switch trials at midline electrodes (Fz, Cz, Pz) in older and younger adults at pretest.

Cue-locked early time window. Results showed a mixing cost effect in older adults with larger amplitudes for non-switch trials compared to single trials, $F(1, 60) = 23.20$, $p < .001$, $\eta_p^2 = .28$, and in younger adults, $F(1, 28) = 39.25$, $p < .001$, $\eta_p^2 = .58$. Trial type interacted with age group, $F(1, 88) = 7.98$, $p < .01$, $\eta_p^2 = .08$, showing that the mixing cost effect was smaller in older adults due to significantly larger amplitudes for single trials compared to the young age group, $F(1, 88) = 15.61$, $p < .001$, $\eta_p^2 = .15$.

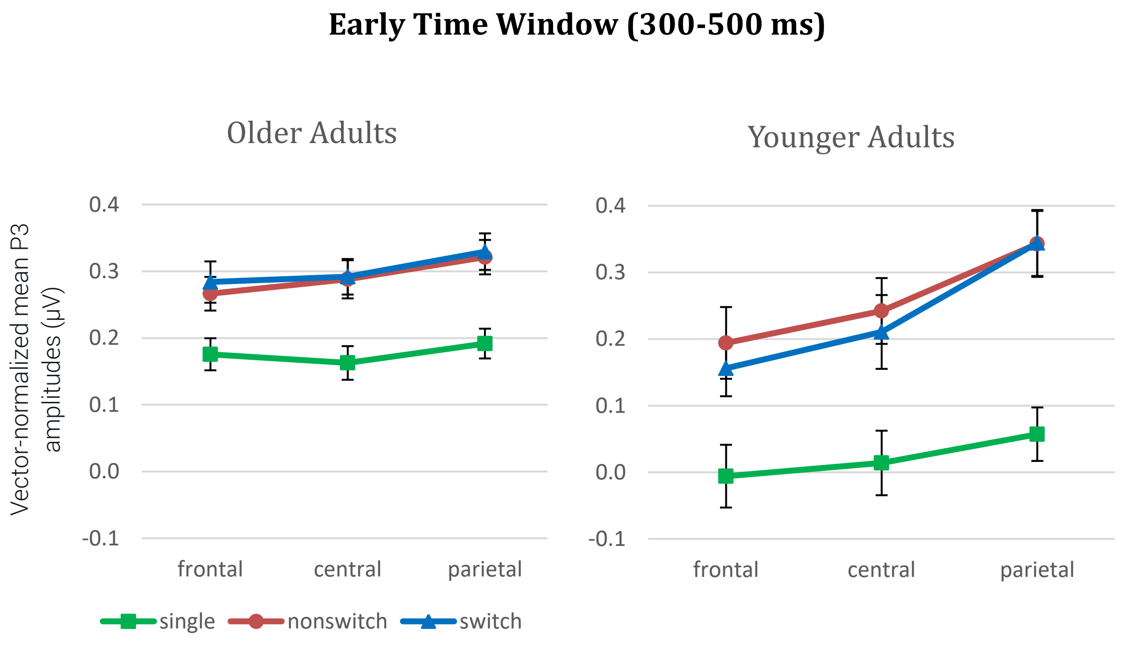


Figure 13. Cue-locked mean P3 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Cue-locked late time window. Trial type contrast 1 interacted with age group, $F(1, 88) = 4.71$, $p < .05$, $\eta_p^2 = .05$, indicating that the mixing cost effect persisted in the late time window, but only in the old age group, $F(1, 60) = 32.12$, $p < .001$, $\eta_p^2 = .35$. Furthermore, electrode interacted with age group, $F(1, 88) = 8.16$, $p < .01$, $\eta_p^2 = .09$, demonstrating larger P3 amplitudes at the central electrode compared to the frontal electrode, but only in younger adults, $F(1, 28) = 9.83$, $p < .01$, $\eta_p^2 = .26$. Although the higher-order interaction for trial type contrast 2 was not significant ($p = .24$), a switch cost effect was visible in the young age group at the parietal electrode ($\eta_p^2 = .24$).

Late Time Window (500-700 ms)

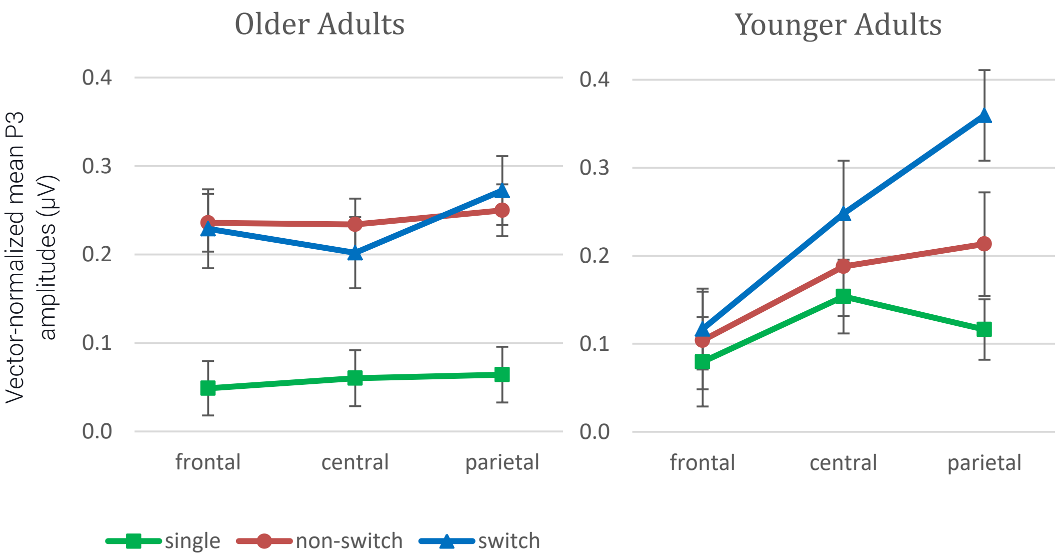


Figure 14. Cue-locked mean P3 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Summary. In line with previous findings (e.g., Karayanidis et al., 2011), age-related differences in the cue-locked P3 amplitude were evident between single and non-switch trials (mixing cost effect). In the early time window, the mixing cost effect was more pronounced in the young age group due to enhanced amplitudes for single trials in the old age group. Moreover, older adults showed a prolonged mixing cost effect in the later time window. Younger adults showed increasing P3 amplitudes over the midline electrodes, whereas older adults showed a more evenly distributed scalp distribution in the P3.

5.3.4 Near transfer effects of cognitive control training to cue-locked ERPs in the switching task.

A four-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest), Trial Type (single trials, non-switch trials, switch trials), and Electrode (Fz, Cz, Pz) was carried out to investigate training-induced changes in the early and later course of the P3 after the cue presentation. An overview of the cue-locked waveform patterns is displayed in Figure 36 (see Appendix).

Cue-locked early time window. Higher-order interactions of interest were (marginal) significant for session × trial type contrast 1 × study group, $F(2, 87) = 3.19$, $p < .05$, $\eta_p^2 = .07$, session × electrode contrast 1 × study group, $F(2, 87) = 2.84$, $p < .10$, $\eta_p^2 = .06$, and session × trial type contrast 1 × electrode contrast 2 × study group, $F(2, 87) = 4.01$ $p < .05$, $\eta_p^2 = .08$. To understand the nature of the interactions, post-hoc analyses were carried out for each study group separately. Figure 15 displays the vector-normalized mean P3 amplitudes in the early time window at pre- and posttest at the midline electrodes in each study group. The associated statistical data is summarized in Table 7 (see Appendix).

In the task-switching training group, a significant interaction between the factors session, trial type contrast 1 and electrode contrast 2 was found, $F(1, 27) = 3.53$ $p < .10$, $\eta_p^2 = .12$. At pretest, P3 amplitudes for non-switch trials were larger compared to single trials (mixing cost effect) at the central and parietal electrode, $F(1, 27) = 17.80$ $p < .001$, $\eta_p^2 = .40$. At posttest, the mixing cost effect was no longer present at the central electrode, but still pronounced at the parietal electrode, $F(1, 27) = 7.30$ $p < .05$, $\eta_p^2 = .21$, albeit smaller compared to the pretest. This result was due to a significant decrease of P3 amplitudes in non-switch trials at the central electrode after the training, $F(1, 27) = 4.35$ $p < .05$, $\eta_p^2 = .14$.

No meaningful interactions were significant in the single-task training group (all $p > .20$).

In younger adults, P3 amplitudes increased for single trials, but the effect was only marginal significant, $F(1, 28) = 3.91$ $p < .10$, $\eta_p^2 = .12$.

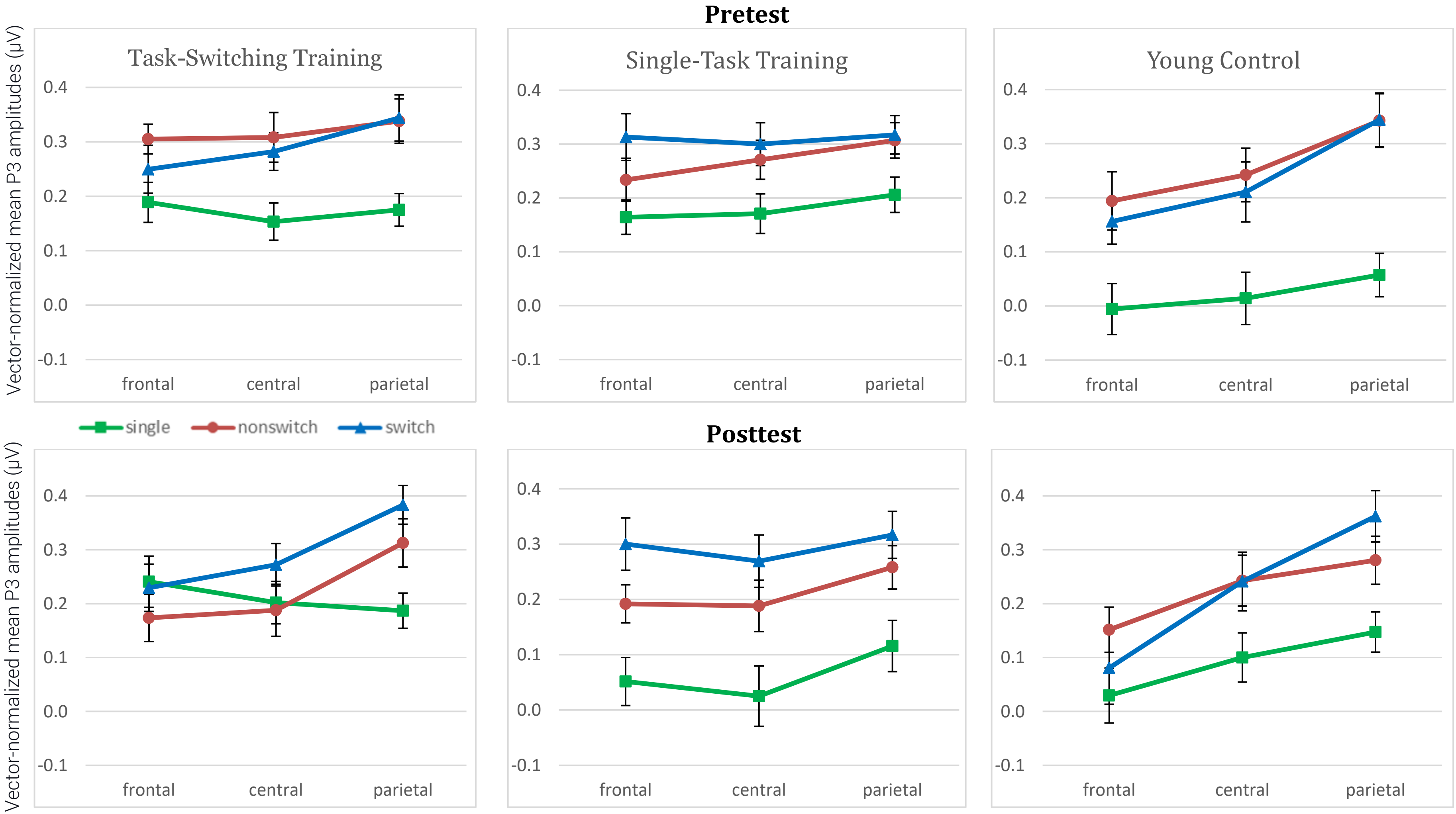


Figure 15. Cue-locked mean P3 amplitudes (early time window: 300-500 ms after cue onset) of vector-normalized data in each study group at pretest and posttest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Cue-locked late time window*.* Higher-order interactions including both the factors session and study group did not reach significance (all $p > .17$). The session × trial type interaction was significant for trial type contrast 1, $F(1, 87) = 5.97$, $p < .05$, $\eta_p^2 =.06$, and trial type contrast 2, $F(1, 87) = 4.32$, $p < .05$, $\eta_p^2 = .05$, showing that mean amplitudes for non-switch trials were reduced at posttest, $F(1, 89) = 11.80$, $p < .01$, $\eta_p^2 = .12$. Figure 16 displays the vector-normalized mean P3 amplitudes in the late time window at pre- and posttest at the midline electrodes for each study group. The statistical data can be found in Table 8 (see Appendix).

Summary. In the early time window, the task-switching training group showed a selective reduction of P3 amplitudes for non-switch trials at the central electrode after the training. In the late time window, mean P3 amplitudes for non-switch trials were reduced, however, no significant difference between the study groups was found.

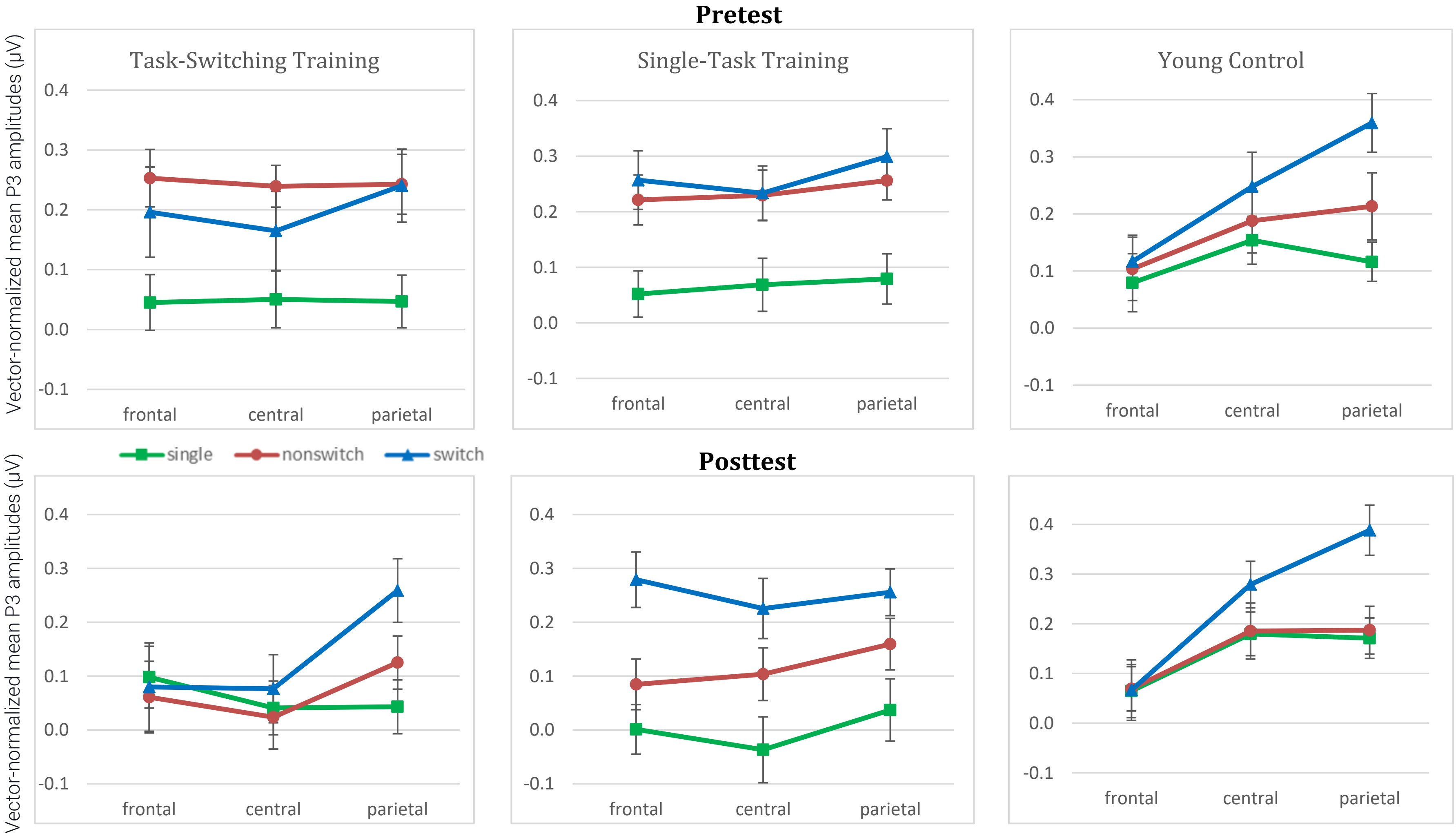


Figure 16. Cue-locked mean P3 amplitudes (late time window: 500-700 ms after cue onset) of vector-normalized data in each study group at pretest and posttest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

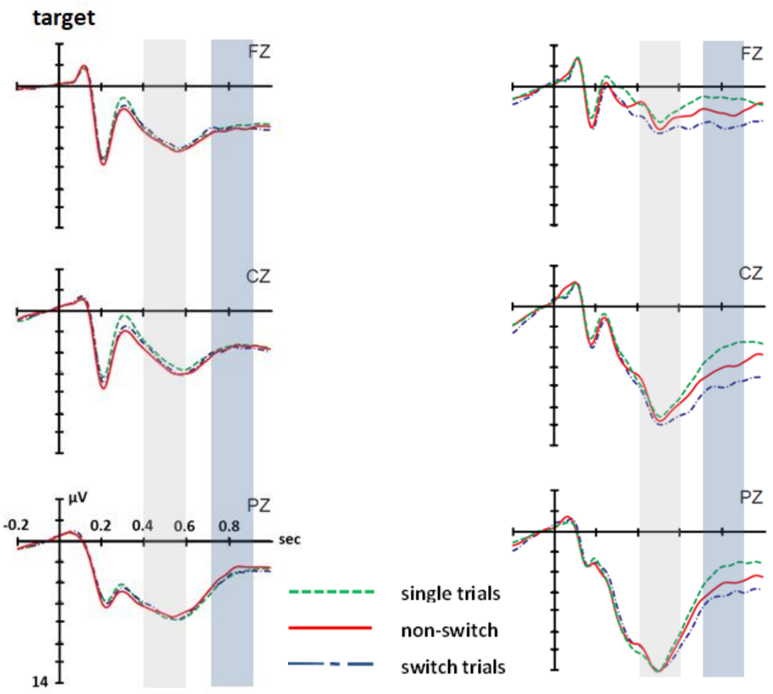
5.3.5 Age-related differences in target-locked ERPs in the switching task.

After the visual inspection of the target-locked grand average waveforms in younger and older adults in the switching task, two time windows were extracted for the analysis of age-related differences in the P3 (early time window: 400-600 ms, late time window: 700-900 ms after target onset, see Figure 17).

In order to investigate age-related differences in the target-locked P3 at pretest, a three-way ANOVA with the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factors Trial Type (single trials, non-switch trials, switch trials) and Electrode (Fz, Cz, Pz) was performed. Differential effects between the trial types and between the electrodes were examined by means of a priori contrasts (see chapter 5.3.3). Results for age-related differences are displayed in Figure 18 (early time window) and Figure 19 (late time window).

Switching Task – Target-locked event-related potentials

Older Adults Younger adults



▨ Early time window: 400-600 ms

▨ Late time window: 700-900 ms

Figure 17. Target-locked grand average waveforms for single, non-switch and switch trials at midline electrodes (Fz, Cz, Pz) for older and younger adults at pretest.

Target-locked early time window. ANOVA results revealed significant interactions between electrode contrast 1 × age group, $F(1, 88) = 44.21$, $p < .001$, $\eta_p^2 = .33$, trial type contrast 1 × electrode contrast 1 × age group, $F(1, 88) = 3.46$, $p < .10$, $\eta_p^2 = .04$, trial type contrast 1 × electrode contrast 2 × age group, $F(1, 88) = 4.64$, $p < .05$, $\eta_p^2 = .05$, and trial type contrast 2 × electrode contrast 2 × age group, $F(1, 88) = 3.75$, $p < .10$, $\eta_p^2 = .04$. In order to understand the nature of the higher-order interactions, post-hoc analyses were performed for both age groups separately.

In older adults, main P3 amplitudes described a u-shaped distribution with larger amplitudes at the frontal electrode compared to the central electrode, $F(1, 60) = 5.64$, $p < .05$, $\eta_p^2 = .09$, and with larger amplitudes at the parietal electrode compared to the central electrode, $F(1, 60) = 34.99$, $p < .001$, $\eta_p^2 = .37$. Furthermore, differential effects in amplitudes between single and non-switch trials (mixing cost effect) were present. The mixing cost effect was more pronounced at the central electrode, with larger P3 amplitudes for non-switch trails than for single trials compared to the frontal electrode, where amplitudes of the single and non-switch trials converged, $F(1, 60) = 5.63$, $p < .05$, $\eta_p^2 = .09$. Moreover, there was a significant difference in the mixing cost effect between the central and the parietal electrode, $F(1, 60) = 13.48$, $p < .01$, $\eta_p^2 = .18$. Younger adults showed increasing P3 amplitudes from the frontal to the central electrode, $F(1, 28) = 94.04$, $p < .001$, $\eta_p^2 = .77$, and from the central to the parietal electrode, $F(1, 28) = 15.30$, $p < .01$, $\eta_p^2 = .35$. Moreover, a more pronounced switch cost effect, with larger P3 amplitudes for switch trials than for non-switch trials was found at the central electrode compared to the parietal electrode, $F(1, 28) = 3.63$, $p < .10$, $\eta_p^2 = .12$.

Early Time Window (400-600 ms)

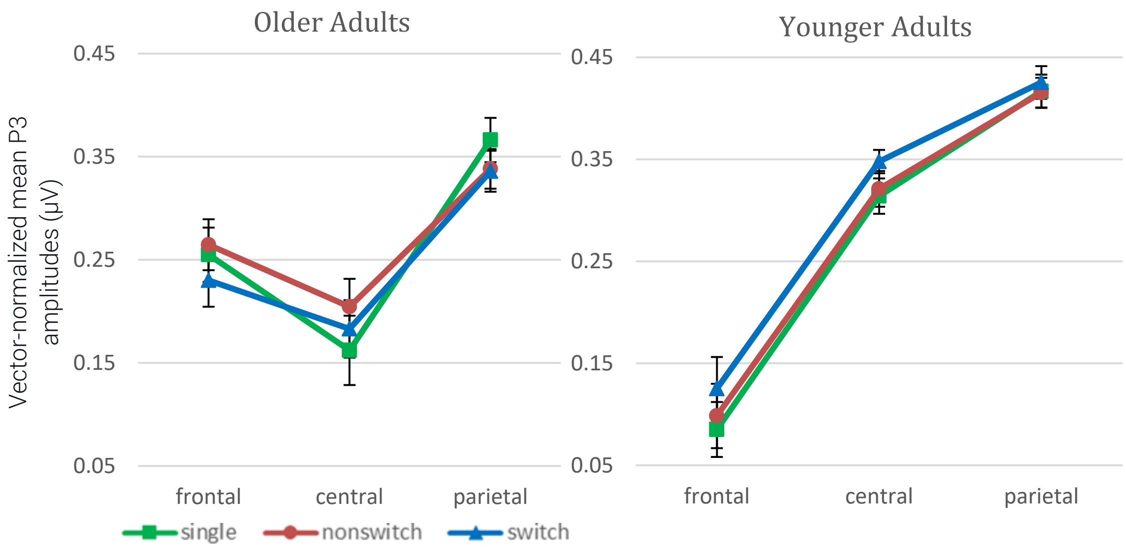


Figure 18. Target-locked mean P3 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Target-locked late time window. Trial type contrast 1 interacted with age group, $F(1, 88) = 7.53$ $p < .01$, $\eta_p^2 = .08$, providing evidence that overall P3 amplitudes were larger for non-switch trials than for single trials (mixing cost effect) in the young age group, $F(1, 28) = 9.48$, $p < .01$, $\eta_p^2 = .25$. A mixing cost effect was also present in older adults, but only at the parietal electrode, $F(1,60) = 4.19$, $p < .05$, $\eta_p^2 = .07$. Electrode contrast 1 and 2 interacted with age group, (Contrast 1: $F(1, 88) = 35.70$, $p < .001$, $\eta_p^2 = .29$, Contrast 2: $F(1, 88) = 3.18$, $p < .10$, $\eta_p^2 = .04$), showing that P3 amplitudes were smaller at the central electrode than at the frontal electrode in older adults, $F(1, 60) = 3.57$, $p < .10$, $\eta_p^2 = .06$. In younger adults, this effect was reversed, $F(1, 28) = 59.95$, $p < .001$, $\eta_p^2 = .68$. Younger adults showed a switch cost effect with larger P3 amplitudes for switch trials than for non-switch trials, $F(1, 28) = 3.71$, $p < .10$, $\eta_p^2 = .12$, whereas older adults did not.

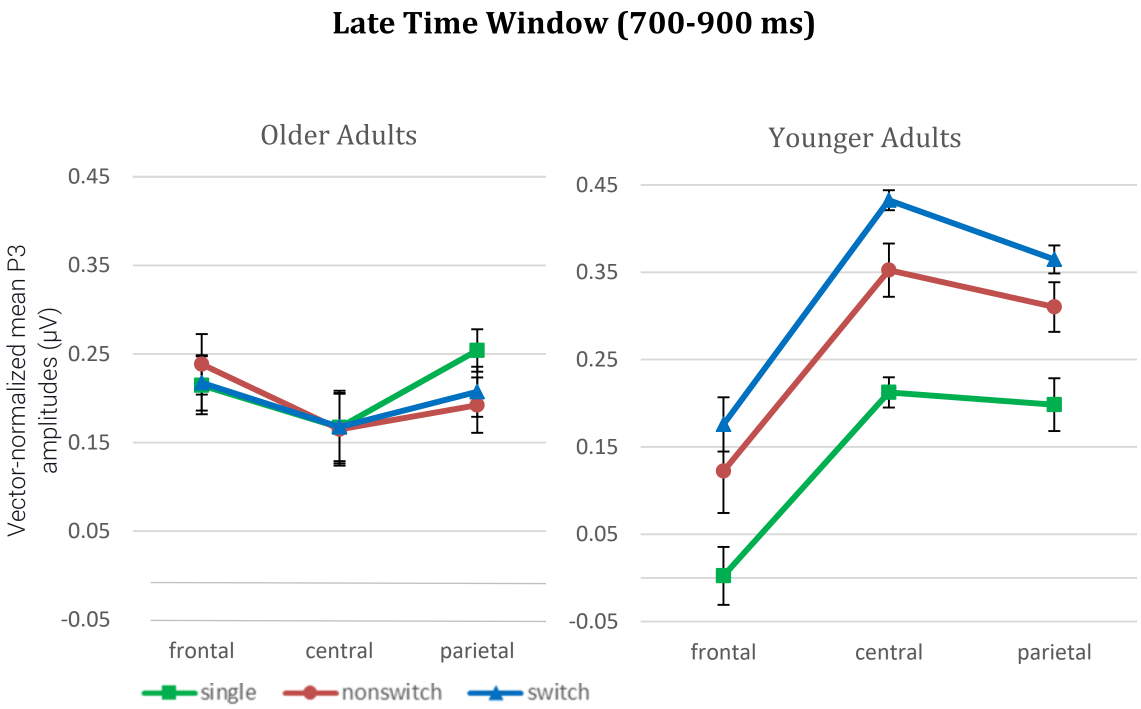


Figure 19. Target-locked mean P3 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Summary. In the early time window, older adults showed a u-shaped scalp distribution of P3 amplitudes with enhanced frontal activity and a mixing cost effect at the central electrode. In younger adults, P3 amplitudes were rising from the frontal to the parietal electrode, and a switch cost effect was evident at the central electrode. In the late time window, older adults showed enhanced frontal activity and a mixing cost effect at the parietal electrode. In younger adults, a linear increase in P3 amplitudes from the frontal to the central electrode was found. Furthermore, the young age group showed a mixing cost effect and a switch cost effect in overall amplitudes.

5.3.6 Near transfer effects of cognitive control training to target-locked ERPs in the switching task.

In order to investigate near transfer effects in the target-locked P3, a four-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest), Trial Type (single trials, non-switch trials, switch trials), and Electrode (Fz, Cz, Pz) was carried out. An overview of the target-locked waveform patterns is displayed in Figure 37 (see Appendix).

Target-locked early time window. Session interacted with study group, $F(1, 87) = 5.73$, $p < .05$, $\eta_p^2 = .06$. Furthermore, a significant three-way interaction for session × electrode contrast 1 × study group, $F(2, 87) = 4.55$, $p < .05$, $\eta_p^2 = .10$, as well as a four-way interaction for session × trial type contrast 1 × electrode contrast 2 × study group, $F(2, 87) = 3.40$, $p < .05$, $\eta_p^2 = .07$, was obtained. To untangle the higher order interactions, separate post-hoc analyses were carried out for each study group separately. Figure 20 displays the vector-normalized mean P3 amplitudes for each study group in the early time window at the midline electrodes at pre- and posttest. The statistical data can be found in Table 9 (see Appendix).

In the task-switching training group, session interacted significantly with electrode contrast 1, $F(1, 27) = 6.72$, $p < .05$, $\eta_p^2 = .20$, pointing out that mean P3 amplitudes were increased after the training, $F(1, 27) = 4.67$, $p < .01$, $\eta_p^2 = .15$, with largest effects at the central electrode, $F(1, 27) = 8.34$, $p < .01$, $\eta_p^2 = .24$.

A training-induced change in the mixing cost effect was evident in the single-task training group. At pretest, a hybrid interaction for the mixing cost effect was found between the central and the parietal electrode, $F(1, 32) = 9.56$, $p < .01$, $\eta_p^2 = .23$, confirming a significant mixing cost effect at the central electrode, $F(1, 32) = 34.17$, $p < .001$, $\eta_p^2 = .52$. At posttest, the mixing cost effect was no longer present ($p = .31$). Furthermore, the session × electrode 1 interaction showed that overall P3 amplitudes were larger at the frontal electrode compared to the central electrode at pretest, $F(1, 32) = 4.49$ $p < .05$, $\eta_p^2 = .12$. After the training, no difference in amplitudes was found between the electrodes due to a significant decrease in amplitudes at the frontal electrode, $F(1, 32) = 6.57$, $p < .05$, $\eta_p^2 = .17$, and a significant increase in amplitudes at the central electrode, $F(1, 32) = 6.84$, $p < .05$, $\eta_p^2 = .18$.

No effects of interest were significant in the young age group (all $p > .30$)

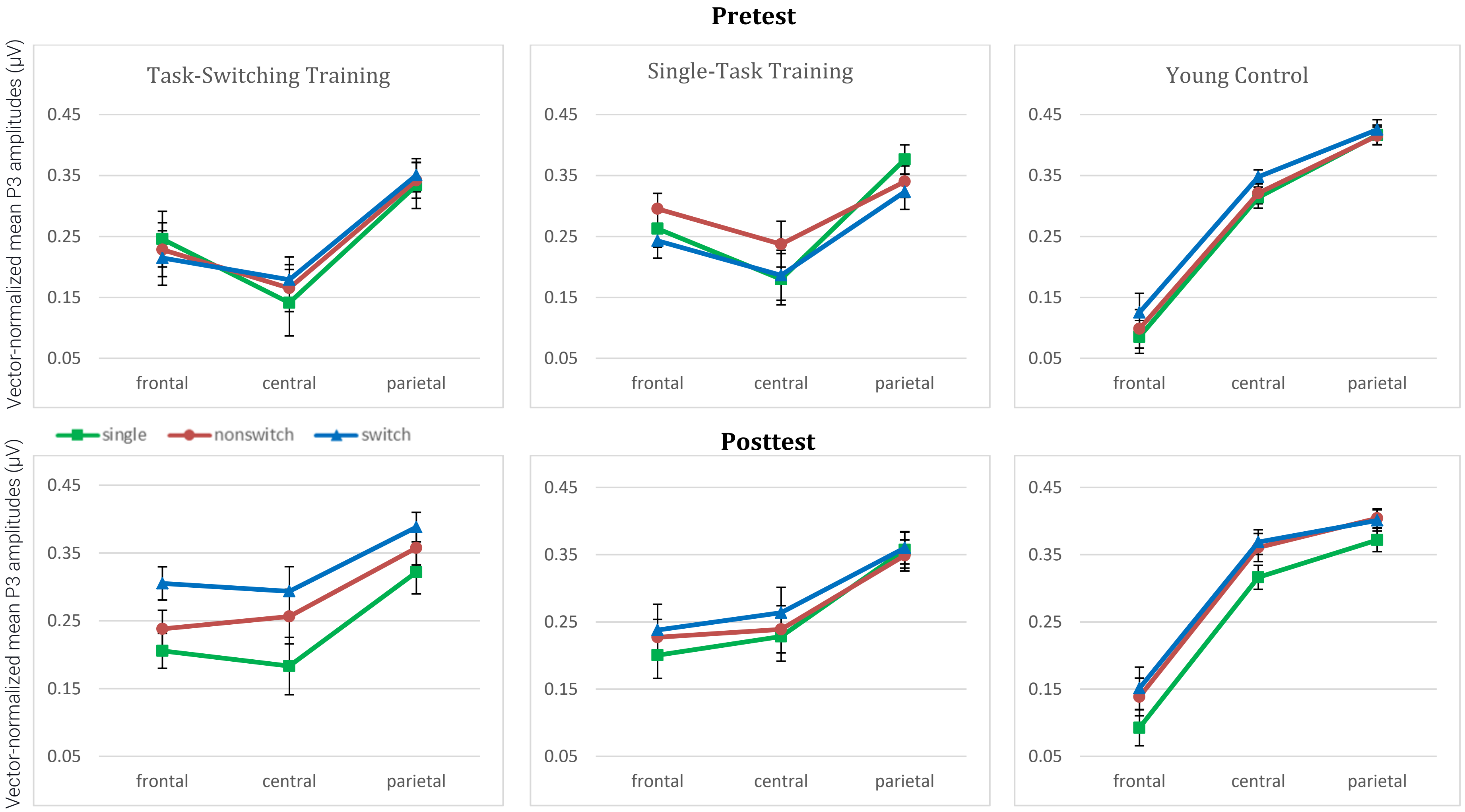


Figure 20. Target-locked mean P3 amplitudes (early time window: 400-600 ms after cue onset) of vector-normalized data in each study group at pretest and posttest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

Target-locked late time window. Session interacted with study group, $F(1, 87) = 15.49$, $p < .001$, $\eta_p^2 = .15$. Moreover, the session × electrode contrast 2 × study group interaction gained significance, $F(1, 87) = 4.90$, $p < .05$, $\eta_p^2 = .10$. Finally, a significant four-way interaction for session × trial type contrast 1 × electrode contrast 2 × study group was obtained, $F(2, 87) = 3.11$ $p < .10$, $\eta_p^2 = .07$. Separate post-hoc analyses were carried out for each study group in order to interpret the higher-order interactions. Figure 21 displays the vector-normalized mean P3 amplitudes for each study group in the late time window at the midline electrodes at pre- and posttest. The statistical data can be found in Table 10 (see Appendix).

In the task-switching training group, overall P3 amplitudes increased after the training, $F(1, 27) = 13.16$, $p < .01$, $\eta_p^2 = .33$.

In the single-task training group, a hybrid interaction was found for the mixing cost effect between the central and the parietal electrode at pretest, $F(1, 32) = 6.68$, $p < .05$, $\eta_p^2 = .17$, however, its dissolution resulted in a non-significant result (all $p > .15$). Furthermore, overall P3 amplitudes were increased after the training at the central electrode, $F(1, 32) = 4.68$, $p < .05$, $\eta_p^2 = .13$.

In the young control group, frontal P3 amplitudes were larger at posttest, $F(1, 28) = 8.24$, $p < .01$, $\eta_p^2 =.23$.

Summary. In the task-switching training group, early target-locked P3 amplitudes were larger at the central electrode, and overall late P3 amplitudes were increased after the training. In the single-task training group, mean amplitudes increased at the central electrode in both time windows, which resulted in a significant attenuation of an early mixing cost effect at the Cz after the training. Moreover, frontal P3 amplitudes decreased in the early time window in this training group.

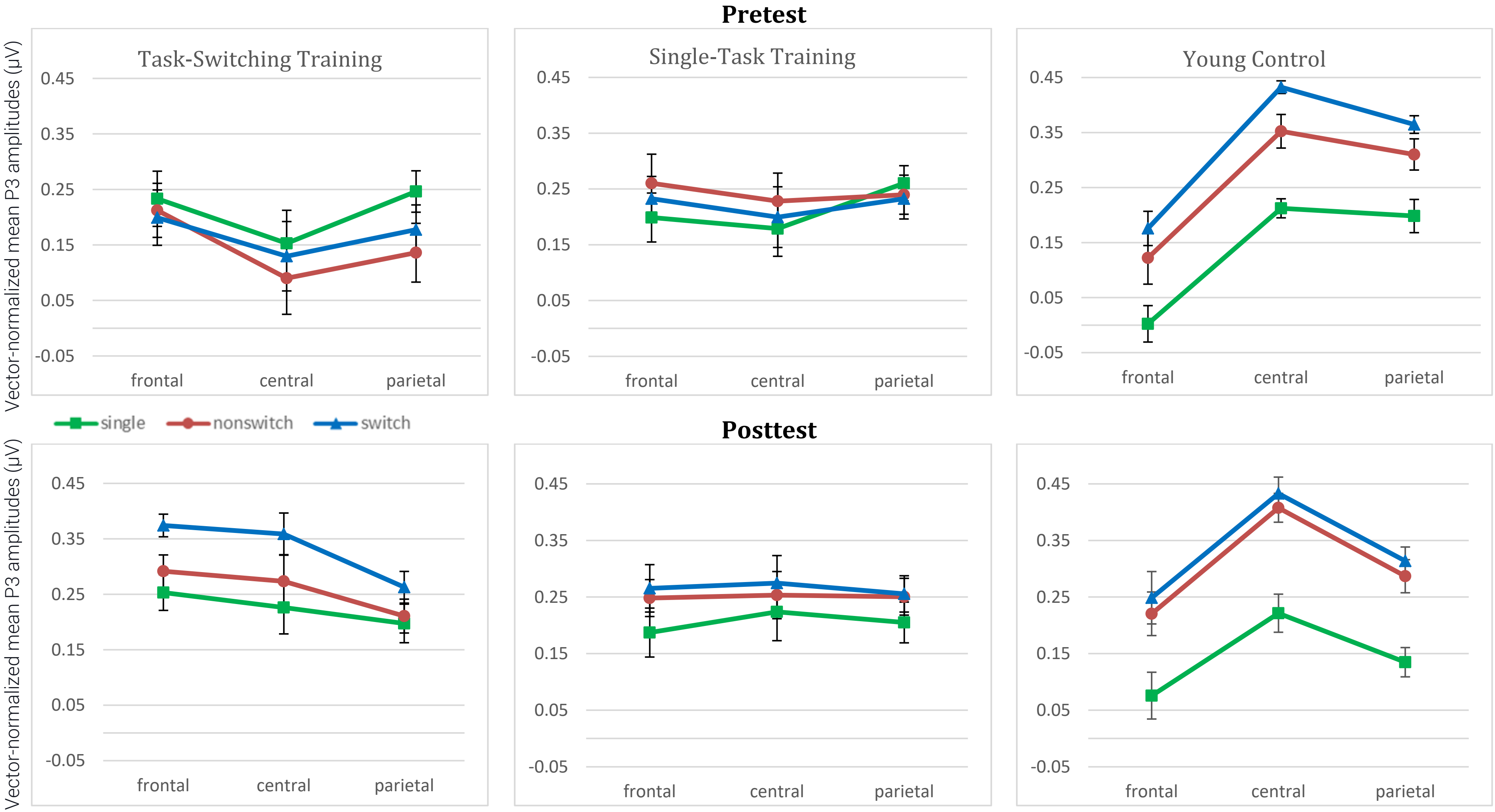


Figure 21. Target-locked mean P3 amplitudes (late time window: 700-900 ms after cue onset) of vector-normalized data in each study group at pretest and posttest as a function of trial type (single, non-switch, switch) and electrode (Fz, Cz, Pz). Error bars refer to standard errors of the mean.

5.4. Far Transfer Effects of Cognitive Control Training to Context Processing

Besides near transfer effects of the cognitive control training to a similar switching task, far transfer effects to context updating and conflict detection were expected because both training and transfer tasks exercised these mechanisms (e.g., Schmitt, Ferdinand, & Kray, 2014). In accordance with the preceding section, results in the AX-CPT are covering age-related differences in the baseline performance at pretest, as well as training-induced changes in task performance and ERPs, respectively. Data processing of task performance and ERPs is presented in advance.

Data processing & analysis of behavioral performance. The statistical analysis was based on latency scores (mean RT for correct responses) and error rates. Experimental trials below the RT score of 100 ms were excluded from the statistical analysis (pretest: 0.26% of the trials in older adults, and 0.02% of the trials in younger adults, posttest: 0.11% of the trials in older adults, and 0.02% of the trials in younger adults), as well as practice blocks and start trials. Statistical analyses based on latency were performed using mean RT scores and log-transformed RT scores, and differences in results will be reported in references.

Context effects were defined as differences in performance between context-dependent trials and context-independent trials (cf. Schmitt, Ferdinand, & Kray, 2014, see chapter 2.1.5). In accordance with the data processing of the switching task, pre-existing differences between the training groups were investigated by means of a contrast for the factor Study Group (see chapter 5.3).

Pre-processing & data analysis of event-related potentials. Cognitive processes of context updating and conflict detection are associated with the occurrence of the P3 after cue and the N450 after target onset in the AX-CPT (Lenartowicz et al., 2010; Schmitt, Ferdinand, & Kray, 2014; Schmitt, Wolff et al., 2014). In line with the study by Schmitt, Ferdinand, and Kray (2014), statistical analyses of ERPs were based on mean amplitudes. EEG data of the practice blocks and start trials was excluded from the statistical analysis. EEG recording was cue- and target-locked for a time interval lasting from 200 ms prior to stimulus onset to 800 ms thereafter. As peak latencies of the components differed among sessions and age groups, different time windows were extracted for the statistical analyses. Cue-locked P3 amplitudes in the older age group were analyzed in a 470-670 ms time window at pretest and in a 400-600 ms time window at posttest. In the younger age group, a 440-640 ms time window was selected at pretest, and a 460-660 ms time window was selected at posttest. Target-locked N450 amplitudes in the older age group were analyzed in a 450-650 ms time window at pretest and in a 400-600 ms time window at posttest. In the younger age group, a 350-550 ms time window was selected at pretest and posttest. Based on the visual inspection of the waveforms, the midline electrodes Fz, Cz, and Pz were investigated. In order to examine the scalp distribution of amplitudes, a repeated contrast was defined for the factor Electrode. Baseline differences in amplitudes between the training groups were analyzed, and pre-existing differences will be reported in references (see chapter 5.3).

5.4.1 Age-related differences in behavioral performance in the AX-CPT.

In order to investigate the task performance of older and younger adults at pretest, a two-way ANOVA with the between-subjects factor Age Group (younger, older adults) and the within-subjects factor Trial Type (c-indep, c-dep) was performed for mean latencies and error rates. Statistical data is summarized in Table 11 (see Appendix).

Latencies. Mean latencies for c-dep trials were larger than for c-indep trials in both age groups (older adults: $F(1, 62) = 122.52$, $p < .001$, $\eta_p^2 = .66$, younger adults: $F(1, 30) = 46.48$, $p < .001$, $\eta_p^2 = .61$). This context effect was larger in older adults compared to younger adults, $F(1, 92) = 20.83$, $p < .001$, $\eta_p^2 = .19$. Furthermore, age-related differences in mean latencies were more pronounced for context-dependent trials, $F(1, 92) = 61.37$, $p < .001$, $\eta_p^2 = .40$, than for context-independent trials, $F(1, 92) = 52.33$, $p < .001$, $\eta_p^2 = .36$.

Accuracy. Error rates were larger for the context-dependent condition than for the context-independent condition in both older adults, $F(1, 62) = 41.86$, $p < .001$, $\eta_p^2 = .40$, and younger adults, $F(1, 30) = 19.10$, $p < .001$, $\eta_p^2 = .39$. In line with the results for mean latencies, the context effect was larger in the old age group compared to the young age group, $F(1, 92) = 11.24$, $p < .01$, $\eta_p^2 = .11$. Age-related differences in error rates were significant for context-dependent trials, $F(1, 92) = 18.01$, $p < .001$, $\eta_p^2 = .16$, but not for context-independent trials (p = .21).

Summary. Results for age-related differences at pretest were in line with previous studies on context updating in the AX-CPT (e.g., Schmitt, Ferdinand, & Kray, 2014). Age-related differences were generally more pronounced for context-dependent trials than for context-independent trials, showing the older adults' poorer performance in task conditions that require context updating. Moreover, significant context effects occurred in both age group, but were larger in older adults.

5.4.2 Far transfer effects to behavioural performance in the AX-CPT.

A three-way ANOVA with the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest) and Trial Type (c-indep, c-dep) was performed. Scores for mean RT, error rates, and context effects are summarized in Table 12 (see Appendix). Figure 22 displays changes in context effects for mean RT and error rates in the study groups from pre- to posttest.

Latencies. The ANOVA results reached (marginal) significance for all main factors and higher-order interactions (all $p < .07$[10]). In order to understand the nature of the interactions, post-hoc analyses were performed for each study group separately. At posttest, mean latencies were significantly reduced in all study groups (task-switching training group: $F(1, 28) = 60.73$, $p < .001$, $\eta_p^2 = .68$, single-task training group: $F(1, 33) = 17.81$, $p < .001$, $\eta_p^2 = .35$, young control group: $F(1, 30) = 39.23$, $p < .001$, $\eta_p^2 = .57$). A reduced context effect was found in the task-switching training group, $F(1, 28) = 15.76$, $p < .001$, $\eta_p^2 = .36$, but not in the single-task training group (p = .15) after the training. In the young control group, the context effect was reduced as well, $F(1, 30) = 5.19$, $p < .05$, $\eta_p^2 = .15$, but the effect was less pronounced than in the task-switching training group.

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[10] An additional analysis of the log-transformed RT data resulted in a non-significant three-way interaction (p = .20).

Accuracy. Overall error rates were reduced from pretest to posttest, $F(1, 91) = 9.84$, $p < .01$, $\eta_p^2 = .10$. Although the three-way interaction remained not significant ($p = .34$), there was a training-specific decreased context effect in the task-switching training group ($\eta_p^2 = .22$).

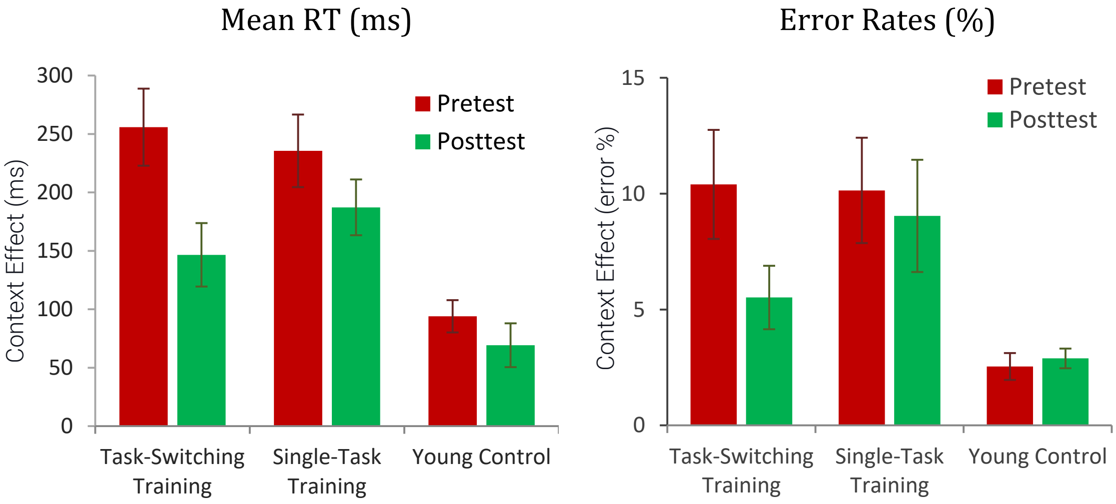


Figure 22. Context effects on the level of mean RT (left panel) and error rates (right panel) as a function of study group (task-switching training, single-task training, young control) and session (pretest, posttest). Error bars refer to standard errors of the mean.

Summary. Overall mean latencies and error rates were reduced after the training. Moreover, a training-induced decrease in context effects was found in the task-switching training group, but not in the single-task training group.

5.4.3 Age-related differences in cue-locked ERPs in the AX-CPT.

Grand average waveforms among older and younger adults at pretest showed a positivity in both age groups that peaked around 500 ms after cue onset. In line with previous findings, a context effect in P3 amplitudes was clearly visible in younger adults, but not in older adults (e.g., Schmitt, Ferdinand, & Kray, 2014, see Figure 23). Furthermore, P3 amplitudes were most pronounced at the parietal electrode in younger adults, but not in older adults.

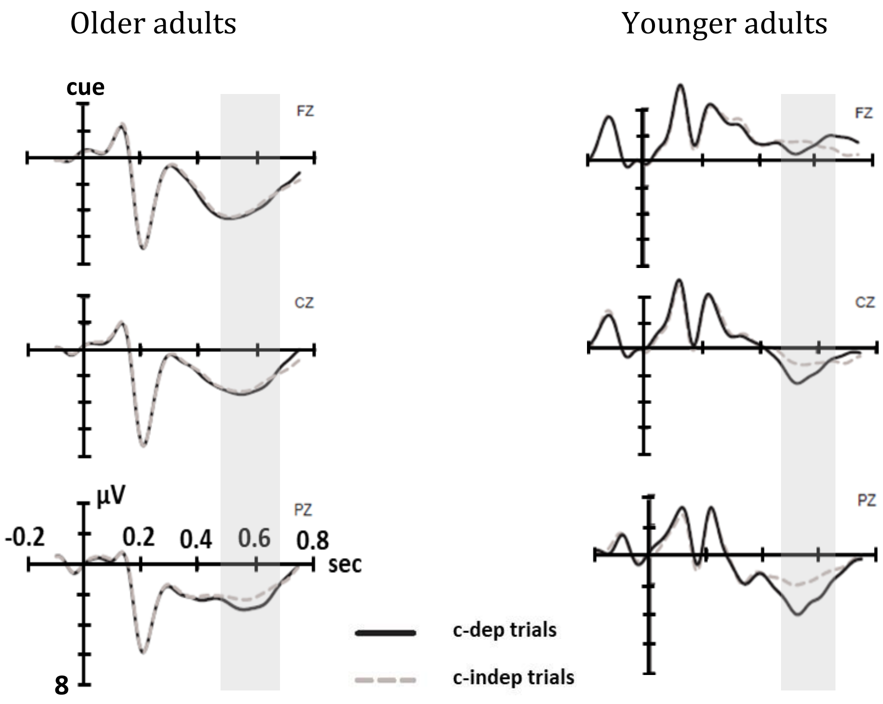


Figure 23. Cue-locked grand average waveforms for c-indep and c-dep trials at midline electrodes (Fz, Cz, Pz) in older and younger adults at pretest.

In order to examine age-related differences in cue-locked P3 amplitudes at pretest, a three-way ANOVA including the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factors Trial Type (c-indep, c-dep) and Electrode (Fz, Cz, Pz) was performed. Results are illustrated in Figure 24, and the statistical data is displayed in Table 13 (see Appendix).

Age group interacted with trial type, $F(1, 89) = 4.15$ $p < .05$, $\eta_p^2 = .05$, and electrode, $F(1.6, 144) = 68.93$, $p < .001$, $\eta_p^2 = .44$, confirming age-related differences in context effects and amplitude distributions. Post-hoc analyses showed that P3 amplitudes were larger for context-dependent trials than for context-independent trials in younger adults, $F(1, 30) = 8.80$, $p < .01$, $\eta_p^2 = .23$. Furthermore, there was a linear increase of mean amplitudes from the frontal to the central electrode $F(1, 30) = 84.95$, $p < .001$, $\eta_p^2 = .74$, as well as from the central to the parietal electrode, $F(1, 30) = 17.84$, $p < .001$, $\eta_p^2 = .37$. In contrast, P3 amplitudes in older adults did not differ between the context conditions ($p = .56$) and decreased significantly from the frontal to the central electrode, $F(1, 59) = 37.52$, $p < .001$, $\eta_p^2 = .39$.

AX-CPT Cue-locked time window

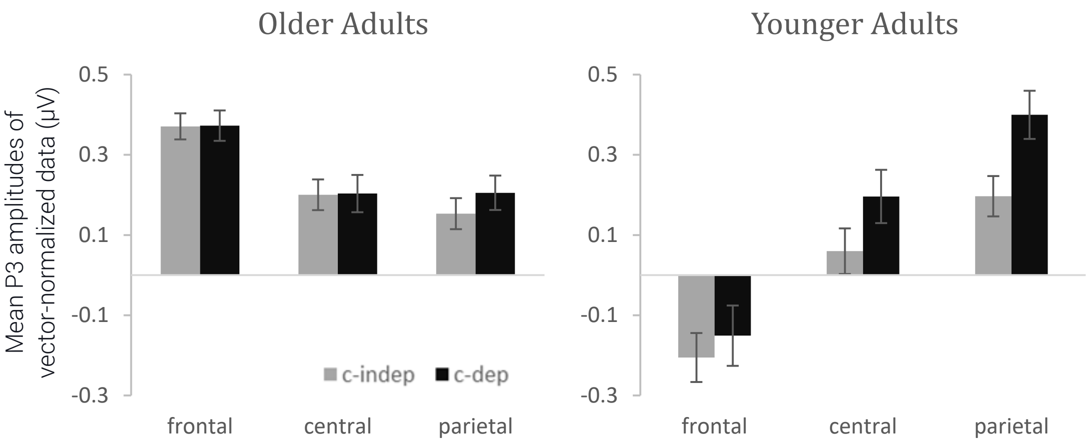


Figure 24. Cue-locked mean P3 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (c-indep, c-dep) and electrode (frontal, central, parietal). Error bars refer to standard errors of the mean.

Summary. Age-related differences were found in amplitudes and scalp distribution of the P3 component. Younger adults showed a context effect with rising amplitudes from the frontal to the parietal electrode, whereas older adults showed no context effect and a rather flattened distribution of P3 amplitudes that were larger at the frontal electrode than at centro-parietal electrodes.

5.4.4 Far transfer effects to cue-locked ERPs in the AX-CPT.

In order to analyze far transfer effects, a three-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest), Trial Type (c-indep trials, c-dep trials), and Electrode (Fz, Cz, Pz) was performed. The cue-locked waveform patterns are illustrated in Figure 38 (see Appendix).

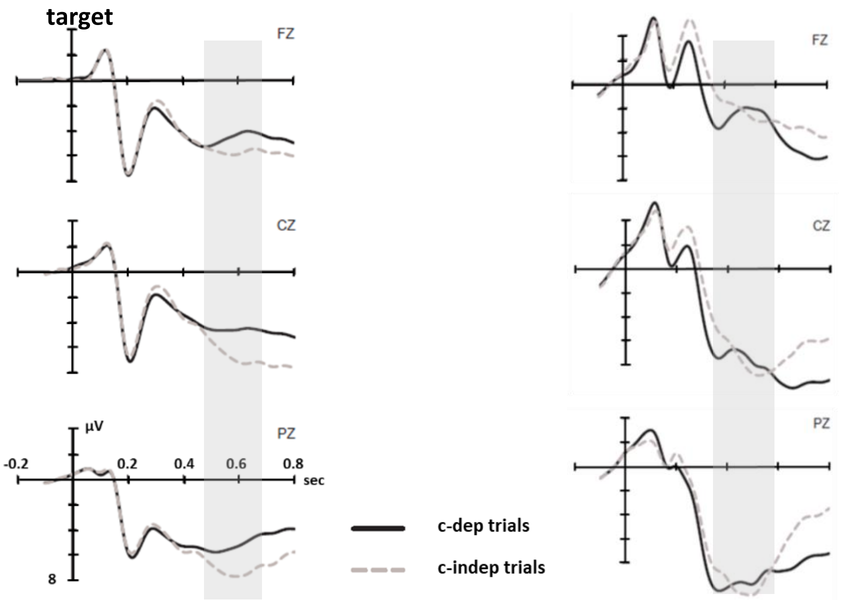
The ANOVA showed significant main effects for the factors study group, trial type, as well as significant electrode × study group and trial type × electrode interactions (all $p < .05$). Further interactions including the factors Session and Study Group remained not significant. Mean P3 amplitudes are listed in Table 14 (see Appendix).

Summary. There were no significant training-induced changes in age-related differences regarding P3 amplitudes in the cue-locked time window.

5.4.5 Age-related differences in target-locked ERPs in the AX-CPT.

Figure 25 displays the waveform pattern in the target-locked time window. Effects between the context conditions were present in both age groups, peaking around 600 ms in older adults and around 400 to 600 ms in younger adults after target onset at the parietal electrode.

For the statistical analysis of age-related differences at pretest, a three-way ANOVA was carried out, including the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factors Trial Type (c-indep, c-dep) and Electrode (Fz, Cz, Pz). Detailed results are illustrated in Figure 26.



Older adults

Younger adults

Figure 25. Target-locked grand average waveforms for c-indep and c-dep trials at midline electrodes (Fz, Cz, Pz) in older and younger adults at pretest.

Results revealed significant interactions for trial type × age group, $F(1, 89) = 9.05$, $p < .01$, $\eta_p^2 = .10$, and electrode contrast 1 × age group, $F(1, 89) = 33.73$, $p < .001$, $\eta_p^2 = .28$. Post-hoc analyses showed a context effect in older adults with larger N450 amplitudes for context-dependent trials than for context-independent trials, $F(1, 59) = 18.32$, $p < .001$, $\eta_p^2 = .24$ [11], whereas younger adults did not show a context effect ($p = .57$). Overall amplitudes did not differ between the three midline electrodes in older adults, but younger adults showed more negative amplitudes at the central electrode compared to the frontal electrode, $F(1, 30) = 71.76$, $p < .001$, $\eta_p^2 = .71$.

AX-CPT Target-locked time window

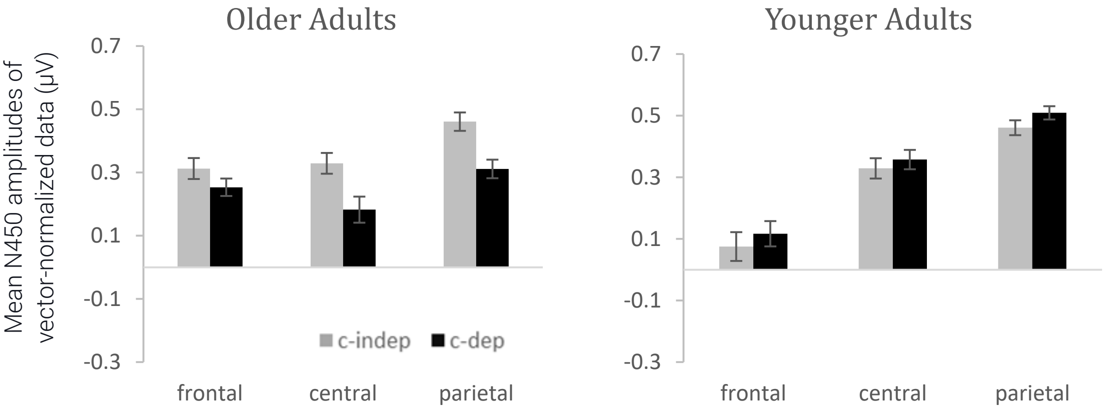


Figure 26. Target-locked mean N450 amplitudes of vector-normalized data in older and younger adults at pretest as a function of trial type (c-indep, c-dep) and electrode (frontal, central, parietal). Error bars refer to standard errors of the mean.

Summary. A context effect in N450 amplitudes was only found in older adults. Moreover, the distribution of amplitudes was more flattened across the midline electrodes in the old age group compared to the young age group.

5.4.6 Far transfer effects to target-locked ERPs in the AX-CPT.

A three-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest), Trial Type (c-indep trials, c-dep trials), and Electrode (Fz, Cz, Pz) was performed. Figure 39 displays the target-locked waveform patterns at pretest and posttest (see Appendix).

The ANOVA revealed a marginal significant session × electrode contrast 2 × study group interaction, $F(2, 88) = 2.72$, $p < .10$, $\eta_p^2 = .06$. Further interactions including the factors Session and Study Group remained not significant. In order

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[11] Differences in the amplitudes at pretest were marginal significant between the training groups, $K = -.07$, $p < .10$.

to entangle the three-way interaction, separate analyses were carried out for each study group. Mean N450 amplitudes are listed in Table 14 (see Appendix).

The task-switching training group showed a significant interaction between the factor session and electrode contrast 2, $F(1, 27) = 7.83$ $p < .01$, $\eta_p{}^2 = .23$, showing that mean N450 amplitudes decreased by approximately 50% at the central electrode after the training. The decrease was mostly due to reduced N450 amplitudes in the context-dependent trials and led to a reduction of the context effect at Cz (see Figure 27).

No significant effects of interest were found in the single-task training group.

Younger adults showed a significant session × electrode contrast 2 interaction, $F(1, 30) = 11.18$, $p < .01$, $\eta_p{}^2 = .27$, due to larger mean N450 amplitudes at the parietal electrode at posttest.

Summary. The task-switching training group showed smaller N450 amplitudes at the central electrode after the training, whereas the single-task group did not show any training-induced changes.

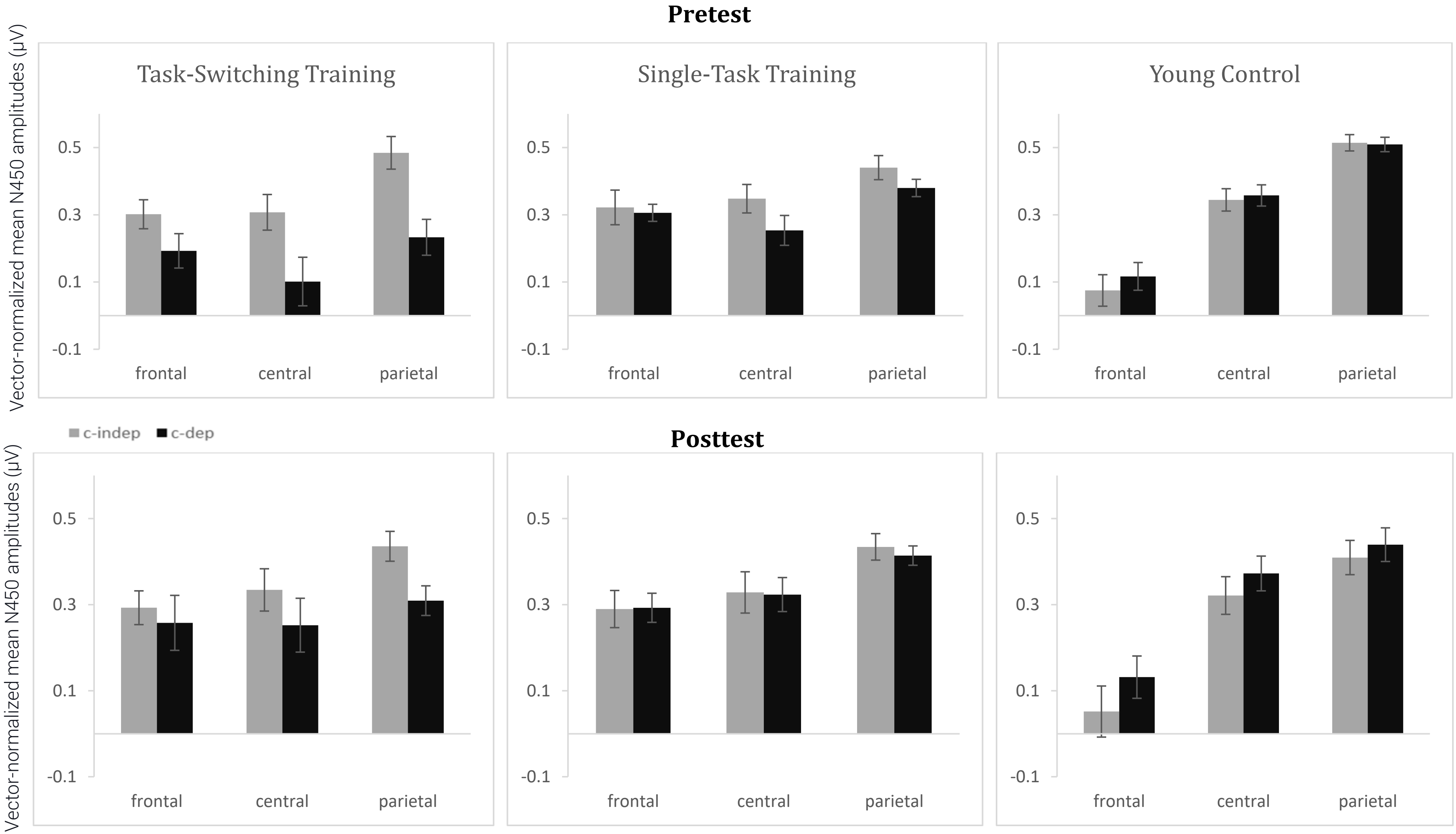

Figure 27. Target-locked mean N450 amplitudes of vector-normalized in each study group at the midline electrodes (Fz, Cz, Pz) at pretest and posttest. Error bars refer to standard errors of the mean.

5.5 Far Transfer Effects of Cognitive Control Training to Working Memory and Interference Control

Given the fact that cognitive control involves working-memory functions (e.g., Miller & Cohen, 2001), it was expected that the training intervention, which exercised processes of maintenance and inhibition, affects task performance and neural activity in the WMC task. Far transfer effects are presented in four parts, covering age-related differences in the WMC task at pretest, as well as training-induced changes in task performance and ERPs, respectively. Data processing of behavioral performance and ERPs is presented in advance.

Data processing & analysis of behavioral performance. The statistical analysis of task performance in the WMC task was based on latency scores (mean RT for correct responses) and error rates. Experimental trials below the RT score of 100 ms were excluded from further analyses (pretest: 2.67 % of the trials in older adults and 0.94 % of the trials in younger adults, posttest: 1.48 % of the trials in older adults and 0.40 % of the trials in younger adults), as well as practice blocks and start trials. Statistical results based on latency were calculated using mean RT scores and log-transformed RT scores, and differences in results will be reported in references.

For the statistical analysis of interference costs in the WMC task, three a priori contrasts were defined for the Factor Trial Type. A repeated contrast compared scores of task performance in distractor trials against passive view trials, reflecting inhibition costs that were induced by a distracting stimulus, and is hereafter referred to as Trial Type Contrast 1. The second contrast compared scores of performance in interrupter trials against passive view trials, reflecting interruption costs induced by the secondary task, and is hereafter referred to as Trial Type Contrast 2. An additional contrast was defined to compare the performance between distractor trials and interrupter trials (Trial Type Contrast 3). Differences in the baseline performance between the task-switching training group and the single-trial training group were examined by means of a contrast for the factor Study Group (see chapter 5.3).

Pre-processing & data analysis of event-related potentials. Analyses of the ERP data were based on mean amplitudes of the N170 and the P3. Both components were linked to cognitive enhancement, maintenance, and inhibition of task information in association with the working-memory system (e.g., Clapp & Gazzaley, 2012; Miller, Deouell, Dam, Knight, & D'Esposito, 2008). EEG data in the practice blocks and the start trials were excluded from the statistical analyses. In line with previous studies, EEG was recorded for the interfering face stimulus, starting from 200 ms before stimulus onset to 800 ms post-stimulus onset (e.g., Clapp & Gazzaley, 2012). Interrupter trials that required a button response to the interrupting face stimulus were excluded from further analyses due to the interaction with motor responses. EOI for the N170 analyses were the parietal electrodes P7, P8, PO7, and PO8. EOI for the P3 analyses were the midline electrodes Fz, Cz, and Pz. The visual inspection of the grand average waveforms among older and younger adults led to the examination of two time window for the statistical analyses (N170: 130-230 ms, P3: 400-600 ms after stimulus onset).

Differential interference effects between the trial types were investigated by means of a priori contrasts for the factor Trial Type within the ANOVA. Neural activity associated with inhibition was defined as differences in amplitudes between distractor trials and passive view (Trial Type Contrast 1). Neural activity associated with enhancement was defined as differences in mean amplitudes between interrupter trials and passive view (Trial Type Contrast 2). An exploratory contrast was defined to compare the neural activity between distractor trials and interrupter trials (Trial Type Contrast 3). Baseline differences in the ERPs between the training groups were calculated by means of a contrast for the factor Study Group, and pre-existing differences will be reported in references (see chapter 5.3).

5.5.1 Age-related differences in the behavioral performance in the WMC task.

A two-way ANOVA including the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factor Trial Type (distractor trials, interrupter trials, passive view) was performed for mean latencies and error rates. Statistical data of the baseline performance is summarized in Table 15 (see Appendix).

Latencies. ANOVA results showed a significant main effect for age group, $F(1, 92) = 59.14$, $p < .001$, $\eta_p^2 = .39$, demonstrating general slower responses in older adults compared to younger adults. Further main effects gained significance for the trial type contrasts 1 and 2. In both age groups, responses were slower for distractor trials than passive view, $F(1, 92) = 365$, $p < .001$, $\eta_p^2 = .80$, and slower for interrupter trials than passive view, $F(1, 92) = 509$, $p < .001$, $\eta_p^2 = .85$. There was no significant age × trial type interaction ($p = .68$)[12].

Accuracy. Results for error rates revealed a significant trial type × age group interaction, $F(1.7, 158) = 15.84$, $p < .001$, $\eta_p^2 = .15$. Age-related differences in error rates were evident between interrupter trials and distractor trials, as older adults showed substantially larger error rates in interrupter trials compared to distractor trials, $F(1, 62) = 18.02$, $p < .001$, $\eta_p^2 = .23$, whereas younger adults only showed marginal significant effects between the trial types, $F(1, 30) = 3.62$, $p < .10$, $\eta_p^2 = .11$. In line with the results for latencies, both age groups made significantly more errors in distractor trials compared to the passive view (older adults: $F(1, 62) = 55.62$, $p < .001$, $\eta_p^2 = .47$, younger adults: $F(1, 30) = 40.40$, $p < .001$, $\eta_p^2 = .57$), and more errors in interrupter trials than in the passive view (older adults: $F(1, 62) = 144.6$, $p < .001$, $\eta_p^2 = .65$, younger adults: $F(1, 30) = 52.52$, $p < .001$, $\eta_p^2 = .64$).

Summary. Age-related differences were present in overall mean latencies, as older adults responded slower in the WMC task. Interference costs were found in both age groups on the basis of mean latencies and error rates with slower responses and higher error rates for interrupter trials and distractor trials, respectively, compared to the passive view. However, only older adults made significantly more errors in interrupter trials than in distractor trials.

5.5.2 Far transfer effects to behavioral performance in the WMC task.

A three-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest) and Trial Type (distractor trials,

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[12] The analysis of log-transformed data resulted in a significant age × trial type interaction, $F(1.6, 144) = 9.96$, $p < .001$, $\eta_p^2 = .10$. Post-hoc comparisons showed substantial differences between interrupter and distractor trials, $F(1, 62) = 31.05$, $p < .001$, $\eta_p^2 = .33$ in older adults, whereas effects were only marginal in younger adults, $F(1, 30) = 3.62$, $p < .10$, $\eta_p^2 = .11$.

interrupter trials, passive view) was performed. Scores of mean RT and error rates are displayed in Table 16, and Figure 40 shows training-induced changes in performance for interrupter trials and distractor trials in each study group (see Appendix).

Latencies. Session interacted with study group, $F(2, 91) = 4.65$, $p < .05$, $\eta_p^2 = .09$, showing that reduced latencies were most pronounced in the task-switching training group, $F(1, 28) = 30.43$, $p < .001$, $\eta_p^2 = .52$, and in the single-task training group, $F(1, 33) = 42.05$, $p < .001$, $\eta_p^2 = .56$, compared to the young control group, $F(1, 30) = 8.54$, $p < .01$, $\eta_p^2 = .22$ after the training. Further higher-order interactions remained not significant (all $p > .67$)[13].

Accuracy. All main effects and higher-order interaction gained significance (all $p < .01$). To entangle the interactions, post-hoc analyses were performed for each study group separately. Participants of the task-switching training group showed reduced error rates for distractor trials, $F(1, 28) = 7.62$, $p < .05$, $\eta_p^2 = .21$, and for interrupter trials, $F(1, 28) = 10.42$, $p < .01$, $\eta_p^2 = .27$. Error rates were also reduced in the single-task group, but effect sizes were smaller for both distractor trials, $F(1, 33) = 4.83$, $p < .05$, $\eta_p^2 = .13$, and interrupter trials, $F(1, 33) = 5.71$ $p < .05$, $\eta_p^2 = .15$. There was no effect in error rates in the young control group ($p = .28$).

Summary. Older adults generally responded faster and made fewer errors after the cognitive training intervention. Of importance was the reduction in error rates for trials that included interfering stimuli with larger effects for the task-switching training group than for the single-task training group.

5.5.3 Age-related differences in ERPs in the WMC task.

N170. Grand average waveforms in older and younger adults at pretest are displayed in Figure 28. Older adults showed a larger negativity at the parietal electrodes compared to younger adults. Furthermore, N170 amplitudes appeared larger for interrupter trails compared to other trial types in both age groups.

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[13] The analysis of log-transformed data showed further significant interactions for trial type × study group, $F(2.8, 130) = 4.67$, $p < .01$, $\eta_p^2 = .09$, and session × trial type, $F(1.6, 142) = 3.70$, $p < .05$, $\eta_p^2 = .04$.

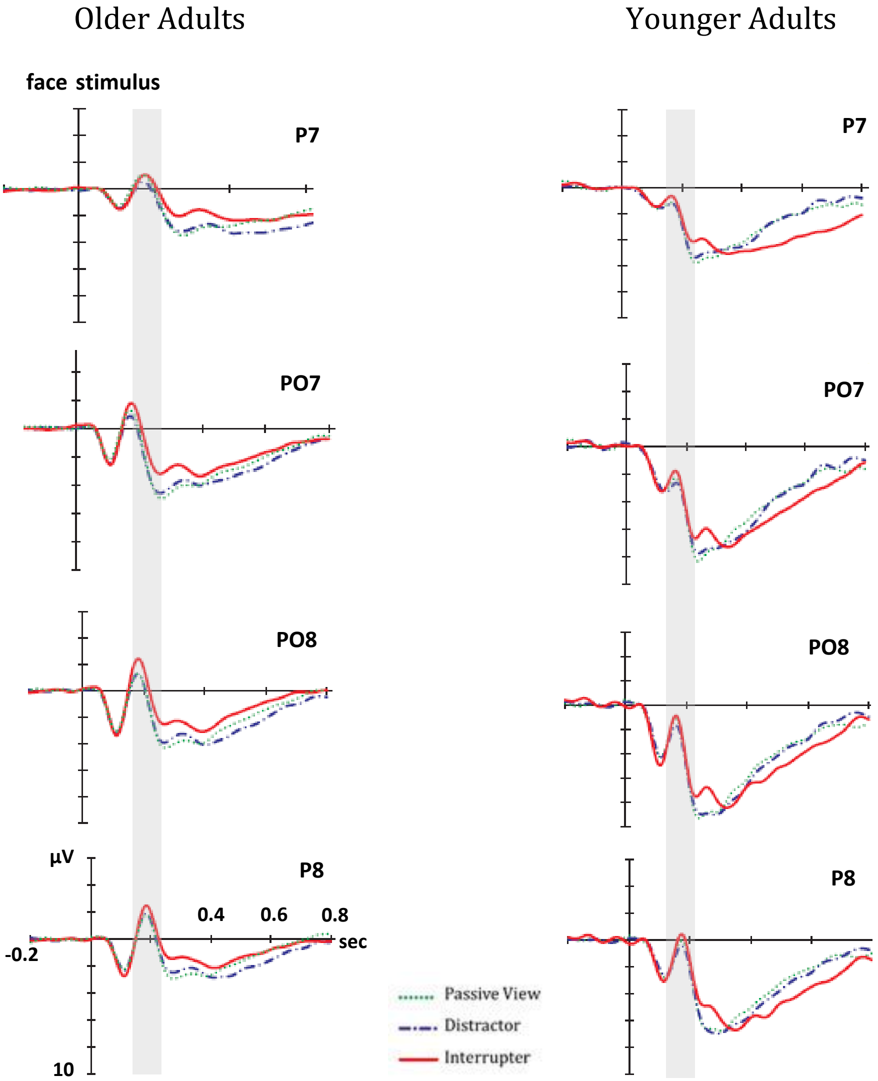

Figure 28. Grand average waveforms locked to the interfering face stimulus for distractor trials, interrupter trials, and passive view at parietal electrodes in older and younger adults at pretest.

The analysis of age-related differences in the N170 at pretest was performed my means of a two-way ANOVA with the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factor Trial Type (distractor trials, interrupter trials, passive view). Results of the statistical analysis are displayed in Figure 29.

The ANOVA resulted in significant main effect for age group, $F(1, 86) = 20.24$, $p < .001$, $\eta_p^2 = .20$, demonstrating that older adults showed overall larger N170 amplitudes. Furthermore, trial type contrast 2 gained significance, $F(1, 86) = 8.67$, $p < .01$, $\eta_p^2 = .09$, showing that mean N170 amplitudes were larger for interrupter trials than for the passive view in both age groups. The trial type × age group interactions remained not significant (all $p > .55$).

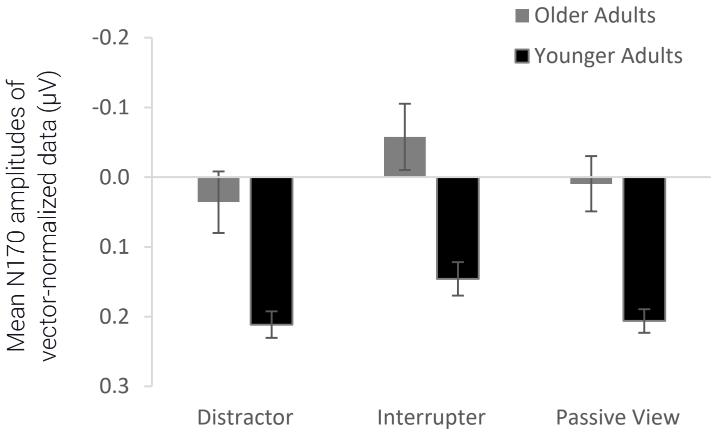

Figure 29. Mean N170 amplitudes of vector-normalized data at pretest as a function of age group (older adults, younger adults) and trial type (distractor, interrupter, passive view).

P3. Grand average waveforms including the P3 at the midline electrodes at pretest are displayed in Figure 30. P3 amplitudes appeared to increase from the frontal to the parietal electrode in younger adults, whereas older adults showed a more even distribution across the midline electrodes. Amplitudes were noticeably larger for interrupter trials than for distractor trials and the passive view. Differential effects between the trial types were visible in both age groups, although it seemed that effects between distractor trials and the passive view were larger in the old age group.

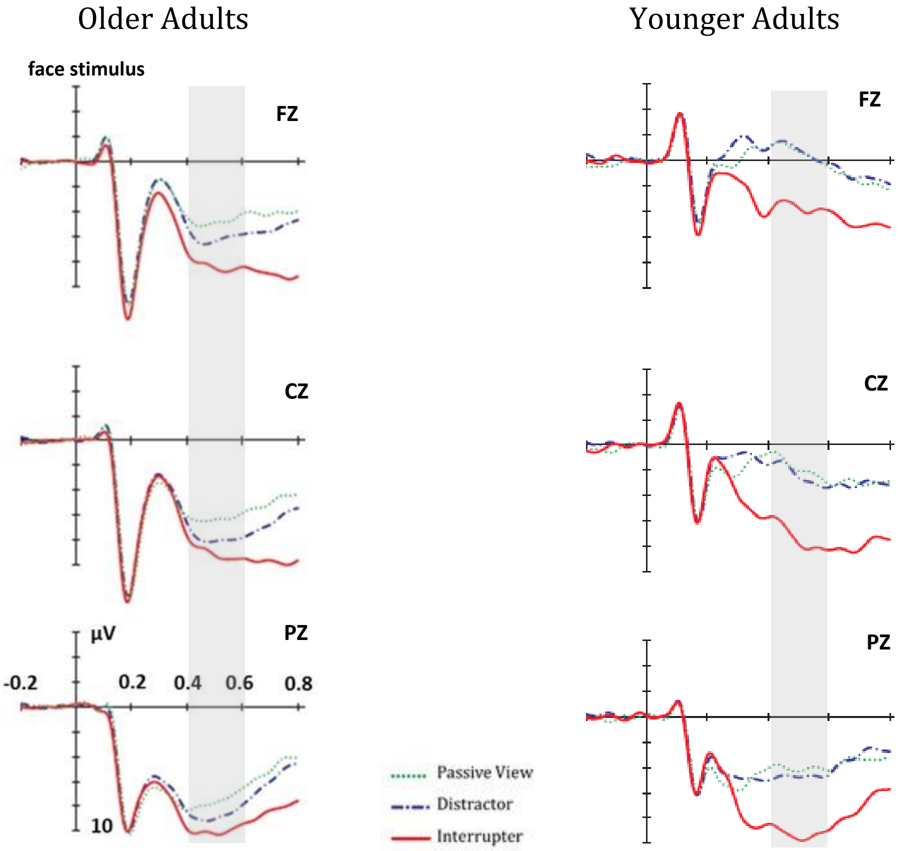

Figure 30. Grand average waveforms locked to the interfering face stimulus for distractor trials, interrupter trials, and passive view at midline electrodes in older and younger adults at pretest.

Age-related differences in P3 amplitudes at pretest were analyzed by means of a three-way ANOVA, including the between-subjects factor Age Group (older adults, younger adults) and the within-subjects factors Trial Type (distractor trials, interrupter trials, passive view), and Electrode (Fz, Cz, Pz). Differential effects between the trial types as well as baseline differences between the training groups were investigated in accordance with the N170 analysis (see above). ANOVA results are displayed in Figure 31.

The results revealed significant main effects for all factors (all $p < .001$). Moreover, significant three-way interactions were found for the factors trial type (contrast 2 and 3), electrode (contrast 1), and age group. Post-hoc analyses showed that P3 amplitudes were larger for interrupter trials than for passive view in both age groups, but effects were larger in younger adults ($F(1, 28) = 58.78$, $p < .001$, $\eta_p^2 = .68$) compared to older adults ($F(1, 58) = 19.23$, $p < .001$, $\eta_p^2 = .25$). Moreover, the differential effect was more pronounced at the individual electrodes Fz, $F(1, 28) = 39.00$, $p < .001$, $\eta_p^2 = .58$, and Cz, $F(1, 28) = 53.95$, $p <$

.001, $\eta_p^2 = .66$, in younger adults compared to older adults (Fz: $F(1, 58) = 32.18$, $p < .001$, $\eta_p^2 = .36$, Cz: $F(1, 58) = 12.38$, $p < .01$ $\eta_p^2 = .18$). Of further interest was the significant difference between distractor trials and interrupter trials. In younger adults, P3 amplitudes were larger for interrupter trials than for distractor trials at all midline electrodes, $F(1, 28) = 41.71$, $p < .001$, $\eta_p^2 = .60$. In contrast, older adults showed larger amplitudes for interrupter trials than for distractor trials only at Fz, $F(1, 58) = 7.29$, $p < .01$, $\eta_p^2 = .11$, but not at Cz ($p = .53$). The P3 distribution showed increasing amplitudes from the frontal to the central electrode with larger effects in younger adults, $F(1, 28) = 79.25$, $p < .001$, $\eta_p^2 = .74$, compared to older adults, $F(1, 58) = 24.14$, $p < .001$, $\eta_p^2 = .29$.

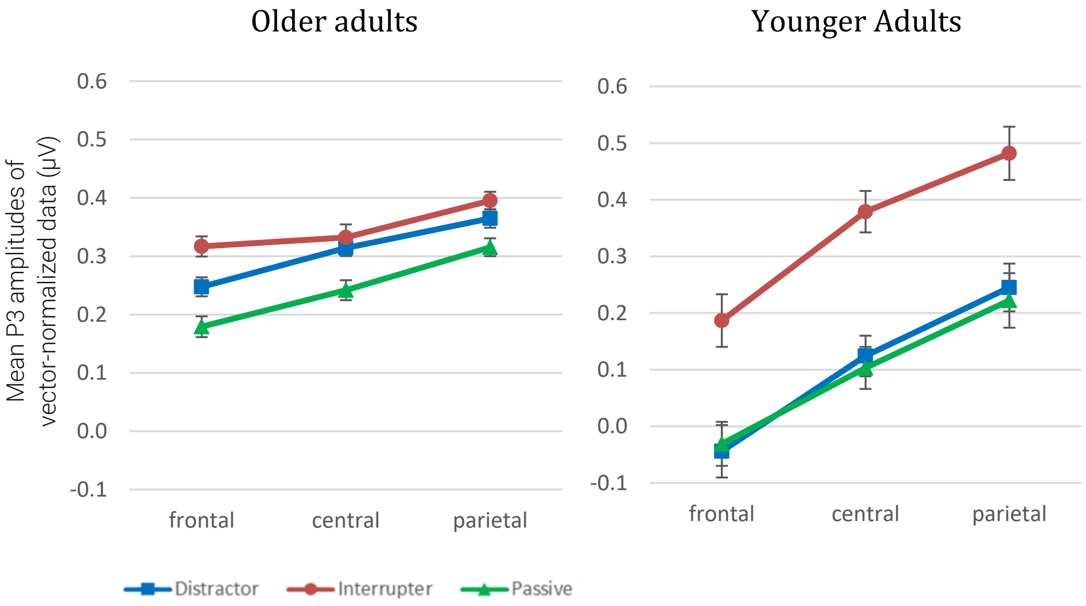

Figure 31. Mean P3 amplitudes of vector-normalized data at pretest as a function of age group (older adults, younger adults) and trial type (distractor trials, interrupter trials, passive view).

Summary. Age-related differences were found in the N170, as older adults showed larger mean amplitudes than younger adults. For both N170 and P3, amplitudes were larger for interrupter trials than for the passive view in both age groups. This interrupter effect was greater in younger adults compared to older adults in P3 amplitudes. Moreover, amplitudes were larger for interrupter trials than for distractor trials in younger adults. In older adults, this result pattern was only significant at the frontal electrode. Lastly, P3 amplitudes were larger for distractor trials than for passive view only in older adults, however, this tendency should not be interpreted, as the higher-order interaction remained not significant.

5.5.4 Far transfer effects to ERPs in the WMC task.

N170. In order to investigate training-induces changes in N170 amplitudes, a three-way ANOVA including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest) and Trial Type (distractor trials, interrupter trials, passive view) was performed. Figure 41 displays the waveform pattern after the onset of the interfering stimulus at the parietal electrodes, and the mean N170 amplitude scores are summarized in Table 17 (see Appendix).

Significant main effects were found for the factors trial type, $F(2, 170) = 23.22$, $p < .001$, $\eta_p^2 = .22$, and study group, $F(2, 85) = 17.21$, $p < .001$, $\eta_p^2 = .29$. Further effects remained not significant (all $p > .20$).

P3. Changes in P3 amplitudes were investigated by means of a four-way ANOVA, including the between-subjects factor Study Group (task-switching training, single-task training, young control) and the within-subjects factors Session (pretest, posttest), Trial Type (distractor trials, interrupter trials, passive view), and Electrode (Fz, Cz, Pz). Figure 42 displays the waveform pattern at the midline electrodes after the onset of the interfering face stimulus at pretest and posttest, and the mean P3 amplitude scores are summarized in Table 17 (see Appendix).

All main effects were significant (all $p < .01$). Of particular interest was the (marginal) significant three-way interaction between the factors session, trial type contrast 2, and study group, $F(2, 85) = 2.79$, $p < .10$, $\eta_p^2 = .06$. A significant four-way interaction was found for the factors session, trial type contrast 3, electrode contrast 1, and study group, $F(2, 85) = 2.67$, $p < .10$, $\eta_p^2 = .06$. In order to understand the nature of the higher-order interactions, post-hoc analyses were performed for each study group separately. Figure 32 displays the vector-normalized mean P3 amplitudes in the study groups at pretest and posttest.

In the task-switching training group, P3 amplitudes for interrupter trials increased, $F(1, 27) = 5.09$, $p < .05$, $\eta_p^2 = .06$, whereas amplitudes for the passive view decreased, $F(1, 27) = 7.14$, $p < .05$, $\eta_p^2 = .21$, from pretest to posttest. Due to the ascending activity for interrupter trials, a significant difference in P3 amplitudes emerged between distractor trials and interrupter trials at the central electrode, $F(1, 27) = 4.41$, $p < .05$, $\eta_p^2 = .14$.

No significant interactions were found in the single-task training group. The young control group showed reduced P3 amplitudes for interrupter trials at the frontal electrode at posttest, $F(1, 28) = 6.41$, $p < .05$, $\eta_p^2 = .19$.

Summary. The statistical analysis of N170 amplitudes revealed no training-induced difference in the training groups. Mean P3 amplitudes decreased for the passive view and increased for the interrupter trials in the task-switching training group after the cognitive training, which led to a differential effect between distractor and interrupter trials at the parietal electrode.

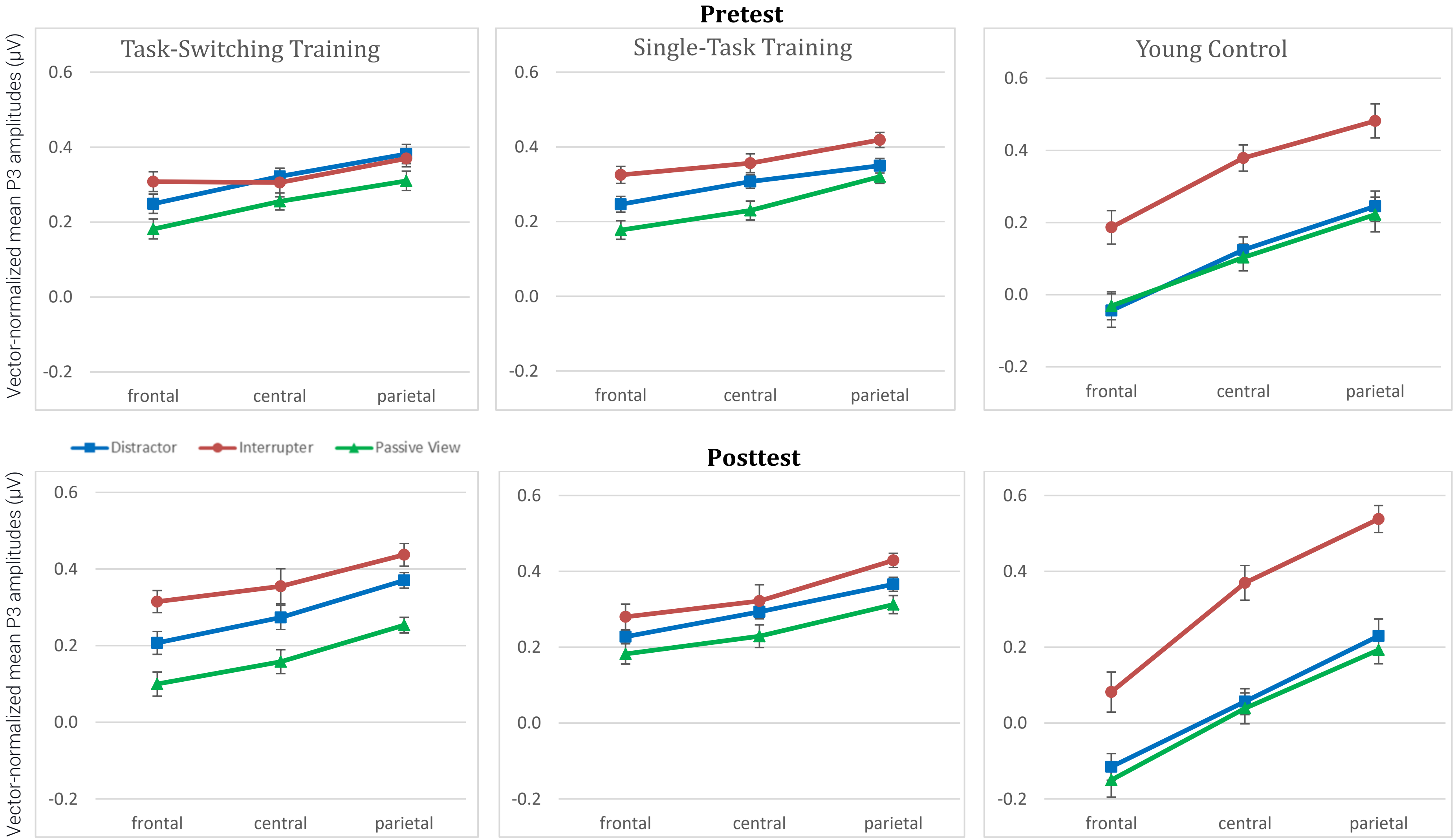

Figure 32. Mean P3 amplitudes of vector-normalized data in each study group at the midline electrodes at pretest and posttest. Error bars refer to standard errors of the mean.

6. Discussion

The final chapter consists of six sections. The first section summarizes the main study goals. A brief discussion of the training data is provided in the second section. The third section discusses age-related differences on the behavioral and neural level in the transfer tasks, building upon recent theories and models of aging and cognitive control. In the fourth section, transfer effects of the cognitive training to task performance and ERPs are discussed in reference to the theoretical and empirical background. The fifth section addresses the limitations of the study methods and interpretations of the outcome, as well as the implications for future research in the field of cognitive control training. Finally, a general conclusion marks the end of the chapter.

6.1 Recap of Main Study Goals and Implementations

The main goal of this study was to reduce older adults' impairments in cognitive control by means of cognitive training. Therefore, older adults were trained in a variable training, either in a pure task-switching setting or in a single-task setting. After the intervention, training gains and transfer effects to similar and dissimilar cognitive control tasks were examined using behavioral performance measures and ERPs. In order to replicate and complement previous findings on age-related differences in cognitive control, a supplementary passive control group of younger adults was recruited. Transfer effects were defined as changes in task performance and ERPs after the training relative to the baseline. The cognitive test battery at pre- and posttest included a switching task (near transfer task) that was similar to the training task and two dissimilar cognitive control tasks (far transfer tasks).

6.2 Discussion of the Training Data

The statistical analysis of the training data verified the efficiency of the cognitive training intervention. Both training groups improved their task performance within each training session. More precisely, responses were faster and error rates were smaller as a function of training. Specific switch costs were expected to decline in the task-switching training group due to the specific exercise in task-set reconfiguration (e.g., Minear & Shah, 2008; Sohn & Anderson, 2001). However, the training data for the task-switching training group showed no changes in specific switch costs between the first and the last quartile of each session. Results demonstrated that averaged specific switch costs decreased from the first to the third quartile of the training session and increased in the last quartile, possibly due to effects of tiredness after 45 minutes of exercise (e.g., Toril, Reales, & Ballesteros, 2014, see Table 4 and Figure 34 in the Appendix).

6.3 Discussion of Age-related Differences

To account for age-related differences in cognitive control, task performance and EPRs were examined at pretest. Differences between the age groups were evident in all transfer tasks and matched with previous findings. Older adults showed poorer task performances and different patterns of brain activity in the switching task, the AX-CPT, and the WMC task compared to younger adults (e.g., Clapp & Gazzaley, 2012; Karayanidis et al., 2011; Schmitt, Ferdinand, & Kray, 2014). A summary of significant age-related differences in ERPs is illustrated in Figure 33.

6.3.1 Age-related differences in task switching.

Age-related differences in task performance. Baseline differences between the age groups in the switching task were expected to be evident in latencies, accuracy, and cognitive costs (e.g., Karbach, 2008; Kray & Lindenberger, 2000; Reimers & Maylor, 2005). Results showed that older adults generally responded slower and made more errors in the switching task compared to younger adults, reflecting age-related cognitive slowing, as well as impaired processes of task-set maintenance and interference control (Gaál & Czigler, 2015; Salthouse, 1996). Furthermore, general switch costs for latencies were larger in the old age group due to impaired cognitive control processes of task-set selection and maintenance (Huff et al., 2015; Karayanidis et al., 2011; Kray & Lindenberger, 2000; Verhaeghen & Cerella, 2002). Moreover, specific switch costs for accuracy were evident in older adults, as they made more errors in switch trials than in non-switch trials, reflecting the age-related decrease in the ability to reconfigure task sets when the predictability of the switch was low (cf. Kray et al., 2002).

It should be noted that cognitive costs were relatively small in the baseline performance compared to other studies (e.g., Karbach, 2008). Older adults in this study showed relatively fast reaction times for non-switch and for switch trials[14].

Age-related differences in ERPs. In task switching, age-related differences appeared in the P3 after cue and target presentation, demonstrating discrepancies in proactive and reactive control modes between the age groups (Karayanidis et al., 2011). Results showed a mixing cost effect with larger P3 amplitudes for non-switch trials than for single trials in both age groups early after cue-presentation, reflecting proactive control mechanisms of advance preparation (Karayanidis et al., 2011). Interestingly, mixing cost effects were more pronounced in the young age group ($\eta_p{}^2$ = .58) than in the old age group ($\eta_p{}^2$ = .28). This result shows on a more effortful advance preparation during single trials in older adult and indicates a less effective proactive control in older adults. Moreover, the mixing cost effect was prolonged in older adults, confirming a more effortful preparation of non-switch trials (Karayanidis et al., 2011). Lastly, only younger adults showed increased cue-locked P3 amplitudes over the midline electrodes, whereas older adults demonstrated enhanced frontal activity, which can be interpreted as compensatory neural recruitment for generally impaired proactive control (e.g., Kopp et al., 2014; West & Travers, 2008).

Results for age-related differences early after target onset differed from previous findings (e.g., Karayanidis et al., 2011). Older adults showed a reversed mixing cost effect at the central electrode, meaning that P3 amplitudes were larger for non-switch trials than for single trials. Younger adults showed no mixing cost effect, but a centrally pronounced switch cost effect with larger amplitudes for switch trials than for non-switch trials, contrary to previous findings (Gajewski et al., 2017; Gajewski & Falkenstein, 2011; Karayanidis et al., 2011; Kieffaber & Hetrick, 2005). It is notable that amplitudes in the early target-locked P3 were larger for trials that elicited higher cognitive demands in both age groups. With practice, however, subjects might have built up stronger neural representations of task sets, which led to enhanced P3 amplitudes (Kok, 2001). Thus, differences in P3 amplitudes between single and non-switch trials in the

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[14] There was a discrepancy in older adults' mean latencies of about 110 ms for non-switch trials and about 420 ms for switch trials between this study and the study by Karbach (2008).

old age group indicate that older adults activated unnecessary reactive control mechanisms when confronted with the target during non-switch trials. Differences between non-switch and switch trials in younger adults imply that they activated processes of task-set reconfiguration early in switch trials after target confrontation (Karayanidis et al., 2001; Mayr, 2001). Findings on amplitude distributions were in line with previous findings and revealed an early centro-parietal focus in younger adults, whereas older adults showed a rather flattened, u-shaped distribution early after target presentation (cf. Kopp et al., 2014). The larger frontal engagement in older adults persisted in the late target-locked time window and can be attributed to compensatory control processes, similar to the findings of the cue-locked data (e.g., Goffaux, 2007). Moreover, mixing cost effects were restricted to the parietal electrode in older adults, whereas younger adults showed both mixing and switch cost effects at all midline electrodes, resembling the findings by Karayanidis and colleagues (2011). In sum, target-locked ERPs indicate that both age groups used reactive control processes, but at different times after target presentation (Eppinger et al., 2007). The lack of switch cost effects in the old age group can be attributed to impaired task-set reconfiguration, which caused older adults to treat non-switch trials like switch trials and to update task sets on a trial-by-trial basis (Karayanidis et al., 2011).

It should be noted that target-locked effects between the task conditions were generally less pronounced compared to previous ERP findings (e.g., Gajewski & Falkenstein, 2011; Karayanidis et al., 2011). The attenuated effects can be caused by generally large variances in the P3 data, especially in switch trials. Falkenstein, Hohnsbein, and Hoormann (1993) assumed that a larger variability in the EEG data results in overall broader and smaller P3 components. The inconsistency in target-locked results can further be attributed to the diversity of neural mechanisms that are reflected in the P3 component (Gajewski et al., 2017). Previous studies demonstrated that the magnitude of the P3 amplitudes was affected by preceding ERP components. Gajewski and Falkenstein (2011) linked effects in the target-locked P3 amplitude to preceding effects in the N2, a component that was not investigated in this study. Furthermore, there is still a disagreement on the validity of P3 amplitudes as a measure of workload (Kok, 2001). Another more general reason for the inconsistency in P3 data is the temporal sensitivity of the component. Therefore, many studies manipulated the time interval between the cue and target stimulus (see chapter 6.5 for a detailed discussion on the P3).

6.3.2 Age-related differences in context processing.

Age-related differences in task performance. Results demonstrated that older adults responded slower in both context conditions and made more errors than younger adults, but only in context-dependent trials, reflecting impairments in context processing (Schmitt, Ferdinand, & Kray, 2014; Schmitt, Wolff, et al., 2014). More importantly, age-related differences were generally more pronounced in context-dependent trials than in context-independent trials, indicating that older adults had more difficulties in the maintenance and updating of context information. Moreover, context effects were found to be larger in older adults, highlighting the impairment of context updating once more (Schmitt, Ferdinand, & Kray, 2014).

Age-related differences in ERPs. Empirical results for age-related differences in the cue-locked P3 were in line with the DMC model (Braver, 2012) and with findings from previous studies (Schmitt, Ferdinand, & Kray, 2014), revealing no context effect and a more evenly distributed P3 amplitude in older adults compared to younger adults. Thus, older adults updated task sets on a trial-by-trial basis due to an inefficient proactive use of the cue information (Paxton, Barch, Storandt, & Braver, 2006; Schmitt, Ferdinand, & Kray, 2014).

In line with previous results on the N450 by Schmitt, Wolff, and colleagues (2014), older adults showed a context effect in the target interval, reflecting reactive control activity. Enhanced reactive control might have been necessary to solve the task because proactive control processes were limited. More specifically, amplitudes were more negative for context-dependent trials than for context-independent trials, caused by larger demands on conflict detection in context-dependent trials. Further age-related differences were evident in the distribution of target-locked amplitudes. In line with ERP results in the switching task, younger adults showed ascending amplitudes from the frontal to the parietal electrodes, whereas older adults showed an equal distribution of amplitudes over the midline electrodes.

It should be noted that most ERP studies investigated target-locked age-related differences in the peak latency rather than the magnitude of the N450 (e.g., Kray et al., 2005). Moreover, it proved difficult to isolate effects of the N450 and the P3 in the target interval because of the temporal overlap of the components (e.g., Eppinger et al., 2007, see chapter 6.5).

6.3.3 Age-related differences in working memory and interference control.

Age-related differences in task performance. In line with the research predictions, older adults showed generally slower responses than younger adults in the WMC task, confirming processes of cognitive slowing and impaired interference control caused by the restricted top-down suppression of task-irrelevant information in old age (Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Salthouse, 1996; Zanto & Gazzaley, 2014). Both age groups showed interference costs in mean latencies between interrupter trials and the passive view, as well as between distractor trials and the passive view. However, age-related differences in interference costs remained not significant. After log-transformation, cognitive costs between interrupter and distractor trials were larger in older adults than in younger adults, indicating a particularly slow processing of interrupter stimuli compared to distractor trials in the old age group. Furthermore, age-related differences were evident in error rates. In accordance with the latency results, the significant age by task condition interaction did not originate from differences in the cognitive costs between interfering stimuli and the passive view, respectively (cf. Clapp & Gazzaley, 2012), but from the age-related difference between distractor and interrupter trials. Results demonstrated larger error rates for interrupter trials than for distractor trials in the baseline performance, but only in the old age group. Overall, results point toward an age-related deficit in the maintenance of task-relevant information, as older adults showed a specifically poor performance in trials with a secondary task.

Age-related differences in ERPs. In line with the research predictions, overall N170 amplitudes at pretest were more negative in older adults, but there was no significant age-related difference between the task conditions, indicating that the neural representation of the tasks were similar in both age groups. Thus, no selective inhibitory deficit in the N170 for distractor stimuli was found in older adults, contrary to previous presumptions (Clapp & Gazzaley, 2012; Gazzaley et al., 2008; Zanto & Gazzaley, 2014).

P3 amplitudes were larger in interrupter trials than in the passive view in both age groups, but effects were larger in the young age group (η_p^2 = .68) compared to the old age group (η_p^2 = .25). It can be assumed that the neural engagement for interrupter trials in the P3 is similar in both age groups, in line with previous results for N170 latencies found by Clapp and Gazzaley (2012). Furthermore, P3 amplitudes were larger for interrupter trials than for distractor trials in younger adults at all electrodes. Older adults showed this differential effect only at the frontal electrode, indicating an equivalent processing style for distractor and interrupter stimuli at the centro-parietal electrodes. In sum, the inhibitory deficit in older adults was not selective for distractor stimuli, but affected both types of interfering stimuli, in contrast to the research predictions.

Summary. Age-related differences were evident in the behavioral and the neural data at pretest. Poorer task performance in older adults confirmed disadvantages in cognitive control processes in all transfer tasks. ERP results in the old age group point toward inefficient proactive control and enhanced reactive control, confirming an age-related shift from proactive to reactive control modes (Braver, 2012; Kopp et al., 2014; Velanova et al., 2006). Whereas proactive mechanisms of selection, maintenance, and updating of task information were restricted, reactive processes of conflict detection remained intact in the old age group (cf. Zanto & Gazzaley, 2014). Additional neural activity in frontal parts of the older brain can be interpreted as coping mechanisms for impaired control processes in centro-parietal areas (Angel et al., 2010; Goffaux, 2007; Goffaux et al., 2008; Park & Reuter-Lorenz, 2009; West & Travers, 2008; Zanto & Gazzaley, 2014). Despite age-related deficits in interference control, the inefficient processing of stimuli was not restricted to be a pure inhibitory deficit of distractors but a general susceptibility to both types of interfering stimuli (Clapp & Gazzaley, 2012).

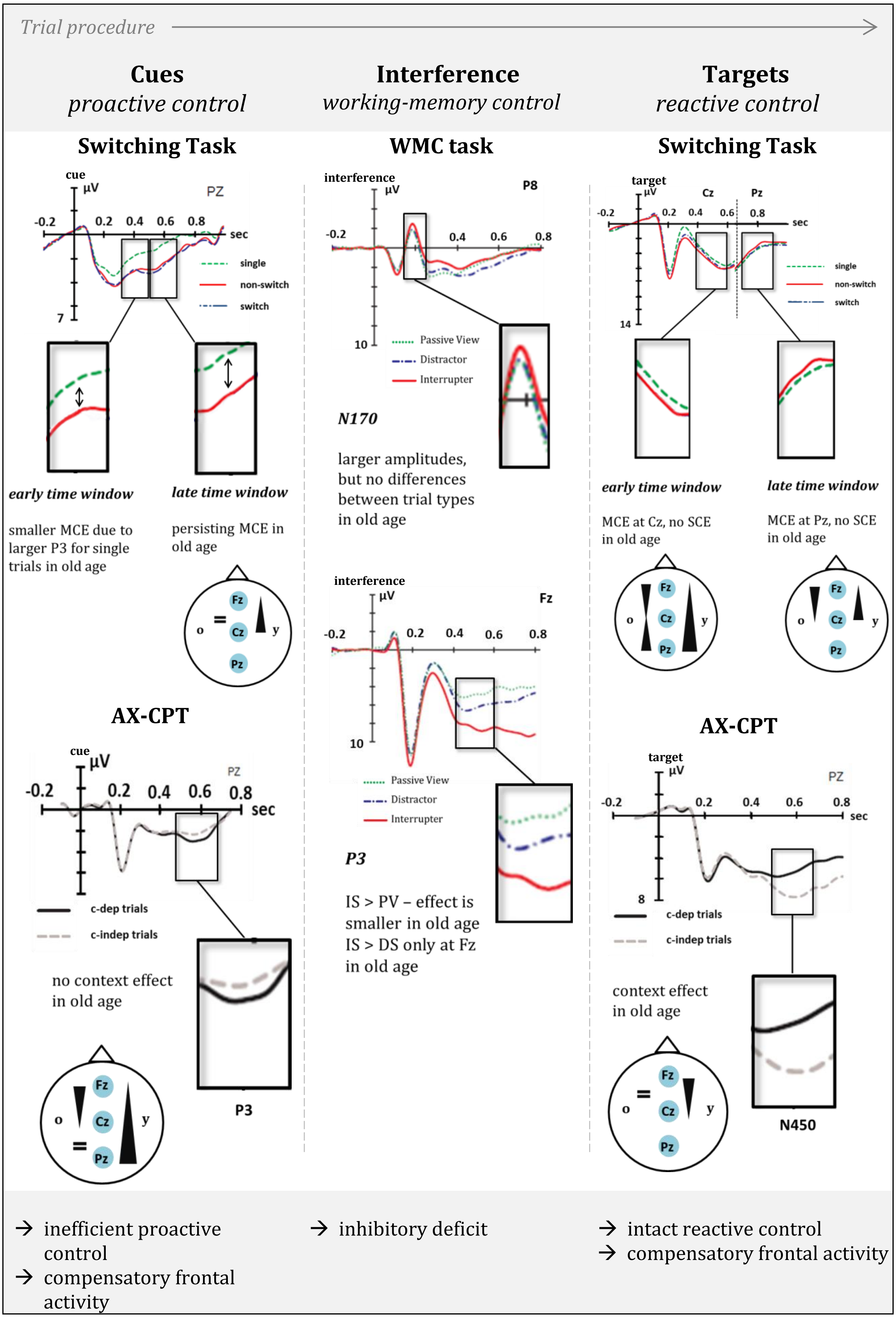

Figure 33. Summary of significant ERP results for the old age group compared to the young age group in the transfer tasks at pretest. MCE = mixing cost effect, SCE = switch cost effect, c-dep = context-dependent, c-indep = context-independent, IS = interrupter stimulus, DS = distractor stimulus, PV = passive view, o = old age, y = young age.

6.4 Discussion of Transfer Effects

The focus of the study lied on the transferability of training effects to untrained cognitive control tasks. Near transfer effects of the cognitive control training to task-switching abilities in a similar switching task were expected. Furthermore, far transfer effects to context updating and conflict detection (in the AX-CPT) and to working memory and interference control (in the WMC task) were investigated.

6.4.1 Near transfer effects.

Near transfer to task performance. In previous studies, near transfer effects of cognitive training were usually reflected in training-induced changes in the cognitive costs (e.g., Karbach, 2008; Karbach & Kray, 2009; Kray & Lindenberger, 2000). Given the unusually low cognitive costs in the baseline performance, changes in cost criteria were limited in this study. Nevertheless, both training groups showed reduced mean latencies and improved accuracy after the training. However, training-induced changes in general switch costs did not differ significantly between the study groups, possibly due to effects in the young control group. Nevertheless, effect sizes for reduced general switch costs within the training groups were larger after task-switching training (η_p^2 = .31) than after single-task training (η_p^2 = .05).

Near transfer to ERPs.

Cue-locked early time window. The task-switching training group showed a selective reduction of amplitudes in the non-switch trials after the training. Moreover, baseline results in the task-switching training group confirmed mixing cost effects at both central and parietal electrodes. After the task-switching training, the effect was attenuated at the central electrode, but it stayed prominent at the parietal electrode, similar to the P3 pattern in younger adults. ERP results can be interpreted as more efficient proactive control after task-switching training due to a reduced cognitive effort in non-switch trials. Moreover, the selective decrease in P3 amplitudes for non-switch trials at the central electrode might reflect a smaller need for compensatory activity, thus, a more parietal focused response preparation after the training. However, training-induced differences in the scalp distribution of overall P3 amplitudes remained not significant in the training groups, showing that older adults still engaged frontal resources.

Cue-locked late time window. General P3 amplitudes for non-switch trials were significantly reduced at posttest. Similar to results in the early cue-locked P3, the selective decrease in non-switch trials can be associated with more efficient proactive processes of task-set maintenance after the cognitive control training. However, higher-order interactions between the study groups remained not significant, therefore, the training effect should be interpreted with caution.

Target-locked early time window. Near transfer effects in the early target-locked P3 varied within the training groups. Mean P3 amplitudes were increased after the task-switching training, especially at the central electrode. Gaál and Czigler (2017) found similar training effects in younger adults and argued that the training builds up more stable representations of the task conditions. If target-locked P3 activity is associated with updating processes of working memory (Donchin & Coles, 1988), larger amplitudes might reflect more efficient working-memory processes for the task implementation.

The single-task training group showed increased amplitudes at the central electrode and decreased amplitudes at the frontal electrode after the training, resembling activity patterns in the young age group. Besides a more efficient representation of the trial types in working memory, this study group showed smaller demands for compensatory frontal activity. Moreover, mixing cost effects were attenuated at the central electrode after the single-task training, suggesting an equal processing of single trials and non-switch trials, hence, a more efficient reactive control.

Target-locked late time window. The task-switching training group showed increased overall P3 amplitudes, and the single-task training group showed increased mean amplitudes at the central electrode. Similar to the results found in the early time window, increased P3 amplitudes might reflect a higher efficiency of reactive control because processes of maintenance were less effortful (Gaál & Czigler, 2017).

6.4.2 Far transfer effects to context processing.

Far transfer to task performance. Older adults improved their task performance, as mean latencies and error rates decreased after the training. Effects of enhanced processing speed were larger in the task-switching training group (η_p^2 = .68) than in the single-task training group (η_p^2 = .35). More importantly, context effects in latencies were significantly reduced, but only after task-switching training. The results imply that the cued task-switching training resulted in more efficient context processing than the single-task training by exercising processes of task-set reconfiguration (Gaál & Czigler, 2017).

Far transfer to ERPs. The cognitive control training did not affect the cue-locked P3 amplitude in the training groups, indicating that older adults still updated task information, even if not necessary. Schmitt, Ferdinand, and Kray (2014) pointed out that older adults rather relied on changes in the identity of the cue, when it comes to the updating and reconfiguration of task sets, regardless of the context condition. The authors investigated the impact of changes in the cue-identity by separating cue-repeat from cue-change trials, and found that older adults constantly updated context information, but especially after a cue change. These "cue-switch" costs compare the performance or neural activity between cue-repeat and cue-change trials (e.g., Grange & Houghton, 2010). However, due to the limited time frame of this study, testing time for the AX-CPT was too short to extract a sufficient number of trials to carry out the analysis based on cue-identity (cf. Luck, 2005).

Training-induced changes were found in amplitudes of the target-locked N450 in the task-switching training group. The reduced N450 amplitudes at the central electrode can be interpreted as more efficient conflict detection after task-switching training. The less effortful reactive control style resembled the activity pattern of younger adults (Schmitt, Wolff, et al., 2014). This means that, instead of enhancing proactive control mechanisms, participants of the task-switching training group were able to improve the efficiency of reactive control.

In the context of target-locked ERPs in the AX-CPT, attention should be drawn to the partial overlap between the N450 and P3 (e.g., West, Jakubek, Wymbs, Perry, & Moore, 2005). The issue of overlapping ERP components will be discussed in chapter 6.5.

6.4.3 Far transfer effects to working memory and interference control.

Far transfer to task performance. Mean latencies were reduced in all task conditions at posttest with significantly larger effects in the training groups (task-switching training group: η_p^2 = .52, single-task training group: η_p^2 = .56) compared to the young control group (η_p^2 = .22), indicating a general attenuation of age-related impairments in processing speed. More importantly, older adults made fewer errors in interrupter and distractor trials compared to younger adults, demonstrating improved interference control after the training. Training-induced effects of improved accuracy tended to be larger in the task-switching training group (η_p^2 = .21 for disrupter trials, η_p^2 = .27 for interrupter trials) than in the single-task training group (η_p^2 = .13 for disrupter trials, η_p^2 = .15 for interrupter trials), indicating that the cued task-switching training might have been beneficial for processes of interference control due to the practice of enhancement and inhibition of task-sets as well as the resolution of ambiguity of task stimuli (Karbach & Kray, 2009). However, training-induced differences between the training groups remained not significant in the statistical analysis.

Far transfer to ERPs. No training-induced effects were evident in the amplitude of the N170. In this case, additional analyses for the N170 latency would have been preferable on account of its proven sensitivity to age-related differences (Clapp & Gazzaley, 2012; Deiber et al., 2010). Furthermore, additional analyses that link training-induced declines in error rates to modulations in N170 latency would have been appropriate (Clapp & Gazzaley, 2012, see chapter 6.5).

Transfer effects to P3 amplitudes were solely found within the task-switching training group. Amplitudes increased for interrupter trials and decreased for the passive view after the training, resulting in a more differentiated activity between the trial types at the central electrode, similar to the waveform pattern of younger adults. The increase in amplitudes for interrupter trials can be interpreted as more efficient processing of intrusive stimuli, which resulted in enhanced working-memory control for the task-relevant information. According to Gazzaley and colleagues (2005), the limited capacity of top-down control is related to the compromised enhancement in neural activity. Thus, increasing amplitudes in the P3 after the task-switching training might reflect improved working memory and interference control.

6.4.4 Summary of transfer effects.

Table 3 provides an overview of near and far transfer effects in the training groups. Near transfer effects in task performance were confirmed, but the type of training did not significantly modulate the amount of the training benefit. Near transfer results in the ERP data revealed differentiated patterns of neural activity in the training groups. Task-switching training resulted in a more efficient proactive maintenance of task sets and a more sophisticated processing of different trial types early after cue presentation. The refined effects in the cue-target interval after task-switching training can be attributed to the enhanced processing of the cue information. The strengthening of mental representations between cue and target stimuli during the training might have resulted in faster and more reliable task-set linking, and the variability of the training eventually facilitated the transferability of the training effect to the untrained switching task (cf. Karbach & Kray, 2009). Furthermore, reactive control processes after target presentation were less effortful after the training due to enhanced working-memory mechanisms that facilitated processes of conflict detection.

Near transfer effects after the single-task training were pronounced in the target interval, demonstrating enhanced reactive control processes. Additionally, demands for compensatory frontal engagement decreased in this training group, which can be attributed to a more efficient resource allocation to reactive control within the fronto-parietal network (Androver-Roig & Barceló, 2010). Previous literature associated effects of single-task training with automated mechanisms of maintenance (e.g. Kramer, Larish, & Strayer, 1995). However, enhanced automatization of cognitive processes alone was not sufficient to induce broad changes in task performance and neural networks, as far transfer results demonstrated. Far transfer effects in task performance were unspecific, and effects in ERPs were not significant after single-task training. Ball and colleagues (2002) proved that transfer effects are process specific, meaning that transfer effects to untrained tasks are more likely when all specific cognitive abilities involved in the transfer task were trained successfully. Therefore, the multidomain task-switching training might have provided a more precise exercise of diverse cognitive control mechanisms that were required in the far transfer tasks. The tendentious advantage of task-switching training over single-task training in far transfer effects indicates that the generalization of enhanced cognitive control processes goes beyond the mere automatization of single-task components (Kramer et al., 1995).

Taken together, far transfer results suggest that underlying cognitive control mechanisms were more efficient after the comprehensive task-switching training compared to the baseline. While the single-task training certainly enhanced the automatization of cognitive processes, it seems that the training did not modify crucial cognitive control mechanisms. However, differences in training-induced changes in the ERP data between the training groups remained not significant in the overall statistical analyses of transfer effects (see chapter 6.5 for a detailed discussion).

Table 3: Summary of Significant Transfer Effects.

Transfer Task	**Task-Switching Training**	**Single-Task Training**	**Young Adults**
Switching Task *behavioral*	Increased processing speed and accuracy (larger effects than in younger adults)	Increased processing speed and accuracy (larger effects than in younger adults)	Increased processing speed and reduced specific switch costs in latencies
Switching Task *ERPs -cues*	Reduced early cue-locked P3 for non-switch trials, attenuated MCE at Cz	no significant effects	Increased mean early cue-locked P3 for single trials
	Reduced mean late cue-locked P3 for non-switch trials	Reduced mean late cue-locked P3 for non-switch trials	Reduced mean late cue-locked P3 for non-switch trials
ERPs -targets	Increased mean early target-locked P3, especially at Cz	Increased mean early target-locked P3 and attenuated MCE at Cz, decreased early target-locked P3 at Fz,	no significant effects
	Increased mean late target-locked P3	Increased mean late target-locked P3 at Cz	Increased mean late target-locked P3 at Fz
AX-CPT *behavioral*	Increased processing speed and accuracy, reduced context effect in latencies (larger effect size than other study groups)	Increased processing speed and accuracy	Increased processing speed and accuracy, reduced context effect in latencies
AX-CPT- *ERPs*	Reduced target-locked N450 at Cz	no significant effects	Increased mean target-locked N450 at Pz
WMC Task *behavioral*	Increased processing speed and accuracy in DS- and IS-trials (largest effect size)	Increased processing speed and accuracy in DS- and IS-trials (larger effect size than YC)	Increased processing speed
WMC Task *ERPs*	Increased P3 for IS-trials and reduced P3 for PV-trials at Cz	no significant effects	Reduced mean P3 for IS-trials at Fz

Note. MCE = mixing cost effect, c-dep = context-independent, DS = distractor stimulus, IS = interrupter stimulus, PV = passive view.

6.5 Study Limitations and Outlook for Future Research

The findings of this study contribute to the present state of neuropsychological research and provide ideas and suggestions for future cognitive training studies with older adults. Difficulties in the methodology of training studies and in the interpretation of transfer effects can hardly be avoided. The first points of discussion include the study groups and design. Despite the thorough matching procedure for the training groups, baseline differences in the neural data seemed to occur between the task-switching training group and the single-task training group. However, a matching procedure on the basis of neural data was impossible for the scope of this study. Another methodical advantage would have been the inclusion of a third group of older adults in form of a waiting control group (Morrison & Chein, 2011). In that case, transfer effects in older adults could be differentiated from retest effects and attributed to the cognitive training. Lastly, the inclusion of a follow-up session would have been meaningful in order to distinguish short-term changes in task performance and neural activity due to repetitive exercise from prolonged effects in underlying cognitive mechanisms (Hasselhorn & Hager, 1996).

The consideration of individual differences between the subjects plays another important role in training studies. Individual differences can affect the training benefits, and empirical results of training effects are highly dependent on the population involved in the study, especially with increasing age (e.g., Gaál & Czigler, 2017; Karbach, 2008). For instance, the subdivision of old age groups into young-old and old-old adults can lead to differences in training benefits, mostly based on the baseline performance in the cognitive task (e.g., Willis & Nesselroade, 1990). Therefore, several studies took the baseline performance in training or transfer tasks as possible covariates into consideration for the statistical analyses of training benefits. With regard to cognitive training, the amplification and the compensation model propose that a high initial performance can either be of advantage or disadvantage for the individual training benefit (Verhaeghen & Marcoen, 1996). In task switching, the compensation model was found to be an appropriate fit for the prediction of subsequent training and transfer effects in older adults (Karbach, 2008; Karbach et al., 2017). Against this background, status–benefit correlations between the baseline performance and transfer effects, respectively, would have been a meaningful addition to the statistical analyses (Klauer, 2001; cf. Karbach, 2008). Besides baseline differences, cognitive traits such as individual learning techniques, working-memory capacity, fluid intelligence, and motivation must be named and considered (Bissig & Lustig, 2007; Herd, Hazy, Chatham, Brant, & Friedman, 2014; Jaeggi, Buschkuehl, Shah, & Jonides, 2014; Kray & Lindenberger, 2000).

The study implemented two types of cognitive control training in order to investigate the impact of the training form on the extent of transfer effects. Besides transfer effects in the AX-CPT performance, differences between the training groups remained not significant. This null result might be due to significant changes in the young control group from pretest to posttest. Moreover, neural differences between the training groups were already evident at pretest. Furthermore, older adults showed generally lower latencies and error rates in the switching task and in the WMC task at pretest compared to previous studies (cf. Karbach, 2008; Clapp & Gazzaley, 2012). Thus, training-induced effects might have been limited due to superior baseline performance.

It is challenging to distinguish the cognitive abilities that improved in each training group by focussing on behavioral results alone. Task switching is a complex paradigm that demands several interacting cognitive processes (e.g., Monsell, 2003), and task-switching trainings are therefore declared as multidomain trainings (e.g., Gajewski & Falkenstein, 2012). The task impurity problem states that a cognitive control task never requires solely one particular control mechanism (Baggetta & Alexander, 2016; Burgess, 1997; Jurado & Rosselli, 2007; Miyake et al., 2000). Therefore, the question arises whether and how the variable task-switching training exercised distinct cognitive control abilities that lead to profound transfer effects in other cognitive control tasks. It was assumed that task-switching training stimulates similar neural networks of cognitive control in the training and the transfer task and facilitates the generalization of training effects (Gaál & Czigler, 2017). By applying EEG techniques, insights in particular ERP components were supposed to reflect distinct processes of cognitive control that cannot be displayed in the behavioral data. However, the examination of ERPs is associated with difficulties, especially in old age groups. Due to the long testing time in this study, subjects tended to show signs of fatigue or loss of concentration (e.g., Lorist et al., 2010). Therefore, EEG data with alpha-waves was excluded from the statistical analyses. Still, the data is not guaranteed to be free from artifacts. Moreover, the manifestation of ERPs can be affected by emotional states, sleep patterns, and other individual characteristics (Polich, 1998; Shackman et al., 2011; Smith, McEvoy, & Gavins, 2002). Besides the challenging control for influencing variables, it is difficult to obtain a sufficient number of clean EEG trials per task condition for the implementation and interpretation of statistical analyses (cf. Luck, 2005). With regard to the limited time frame of the pretest and posttest session, it was important to establish ideal testing conditions, considering the elimination of outside interferences, the maintenance of cognitive arousal, and the preservation of sufficient EEG trials.

Because of the high temporal resolution of EEG measures, numerous studies on task-cueing paradigms manipulated the lengths of delay intervals between cue and target stimuli in order to investigate the effect of preparation time on cognitive costs (for a review, see Kiesel et al., 2010). In this study, cue-target intervals were kept relatively short, which should highlight age-related differences in task performance and ERPs due to the general slowing of cognitive processes in older adults (Cepeda et al., 2011). However, the experimental manipulation of delay intervals would have been desirable to provide a more detailed insight into task-preparatory processes. Furthermore, correlational analyses between neural processes and behavioral performance would have been a valuable addition to the data analysis (cf. Karayanidis et al., 2011).

Aside from methodical complications, the interpretation of EEG data is still a controversial topic. Amplitudes and latencies of ERPs should not be equated with quality and timing of underlying cognitive processes (Luck, 2005). Early on, Donchin and Coles (1988) stressed the distinction between observation and interpretation of the P3 component. This dilemma is still relevant today, and experts established various hypotheses about the manifestation of P3 amplitudes and deriving cognitive mechanisms. Whether higher efficiency in cognitive control processes is reflected in increasing or decreasing P3 amplitudes, varies depending on the underlying neural model and the cognitive task. Gajewski and colleagues (2017) described the P3 as “a conglomerate of diverse neural mechanisms” (p. 11). This means that different cognitive tasks can evoke diverse activity patterns of P3 amplitudes, although they demand similar cognitive mechanisms. Thus, an increase in amplitudes in one task might reflect a similar efficiency in the underlying cognitive process as a decrease of amplitudes in another task (cf. Kok, 2001). Said discrepancy can be found in cognitive tasks that manipulate the intensity of workload between task conditions, for instance (see chapter 2.1.4). Furthermore, the interaction of diverse neural mechanisms during cognitive tasks might be reflected in various, overlapping P3 components. Therefore, multiple peaks and troughs in amplitudes within the sustained positivity can cancel each other out and result in reduced mean P3 amplitudes in a distinct time window (Falkenstein et al. 1993). For instance, Polich and Criado (2006) pointed out that the P3a and P3b subcomponent can overlap in time. Therefore, it is important to consider the distribution of positivity effects, as P3a amplitudes typically occur at fronto-central sites, whereas P3b amplitudes are more pronounced at parietal electrodes (cf. Polich, 2007). Furthermore, this study found a temporal overlap between the P3 and the N450 in the target interval of the AX-CPT. This overlap complicates the interpretation of target-locked results as either increased negativity effects of the N450 or as reduced positivity effects of the P3. The association of N450 effects with neural mechanisms in the ACC suggests the focused investigation of N450 effects at fronto-central electrodes and the additional examination of P3 effects at parietal electrodes (e.g., Kray et al., 2005; Schmitt, Wolff, et al., 2014; Szűcs & Soltész, 2012). Although previous empirical findings on the target-locked P3 are inconsistent, age-related differences have been confirmed in various ERP studies (e.g., Adrover-Roig & Barceló, 2010; West & Travers, 2008).

The scalp distribution of ERPs in old age is a further point of controversy. In previous studies, older adults typically showed rather flattened distributions of P3 amplitudes along with a shift toward enhanced frontal activity compared to younger adults (e.g., Schmitt, Ferdinand, & Kray, 2014). However, there is also contrasting evidence demonstrating that healthy older adults exhibited substantial impairments in the frontal lobe along with decreased activity in the frontal networks (cf. Zanto & Gazzaley, 2014). Hence, it is yet unclear whether the frontal engagement in older adults reflects efficiency in form of additional, compensatory recruitment of frontal networks or inefficiency of cognitive control due to the compromised coordination of several mechanisms (Alperin, Mott, Holcomb & Daffner, 2017; Gaál & Czigler, 2017; O'Connell et al., 2012; West & Travers, 2008).

Although changes in the ERP data from pretest to posttest were evident in the control group, effect sizes were mostly smaller compared to training-induced effects in older adults (cf. Gaál & Czigler, 2017). Differences in younger adults can be attributed to individual variabilities or retest effects. However, they stress the sensitivity of neural data to numerous sources of interference. Therefore, it is instructive to include further analyses of other EEG characteristics for the investigation of training benefits. An additional analysis of maximum peaks of ERP amplitudes avoids the problem of amplitude annulment due to multiple deflections within the selected time windows. Another commonly used method is the correlation of ERP findings with behavioral data (Karayanidis et al., 2010, 2011; Lenartowicz et al., 2010; Verleger, 1997). Because the time windows for the extraction of ERP data differed between pretest and posttest, a difference in the latency of components is presumed. Therefore, an additional analysis of latencies would have been desirable in order to associate with previous studies on age-related differences in cognitive control (e.g., Gazzaley et al., 2008; Karayanidis et al., 2011; Schmitt, Ferdinand, & Kray, 2014). Yet, it would have been difficult to extract peak latencies from the rather broadly distributed components that were found in separate time windows, especially with regard to the relatively small sample size of younger adults.

All the above arguments plead for a cautious interpretation of EEG data. Hence, "there is no perfectly general mean for measuring latent components from observed EPR waveforms" (Luck, 2005, p. 61), but the analysis of well-investigated components such as the N170, the P3, and the N450 in well-known paradigms such as cued task-switching and the AX-CPT is the right method to promote ERP research.

Finally, larger control in scientific experiments raises the question whether effects of cognitive trainings are transferable from the laboratory to everyday life (e.g., Baggetta & Alexander, 2016). To answer this question, training studies included the evaluation of “Timed Instrumental Activities of Daily Living” (Timed IADL) and found significant improvements in everyday activities of older adults after cognitive training (Edwards et al., 2005; Rebok et al., 2014; Willis et al., 2006; Wolinsky, Vander Weg, Howren, Jones, & Dotson, 2015). If research is able to prove the efficiency of scientifically evaluated cognitive control training in older adults’ everyday lives, the consumption of capitalized, unscientific programs would eventually decline.

6.6 Conclusion

The study outcome contributed to the status quo of research by replicating previous findings on age-related differences in cognitive control, on the one hand, and by extending the scope of training and transfer effects in older adults’ cognitive control abilities on the other hand. The training intervention reduced pre-existing age-related differences in cognitive control tasks that are typically attributed to a shift from proactive to reactive control modes in old age (Braver, 2012). In contrast to the predicted reversal of the reactive shift, training-induced changes in the temporal dynamics of older adults demonstrated a higher efficiency of both proactive and reactive control modes after the training (Braver, 2012; Braver et al., 2009). Thus, older adults established a more efficient balance between the control modes, which might be the ideal conditions for successful goal-directed behavior.

The training-induced differences within the training groups provided insights about “what” and “how” cognitive control mechanisms were trained and transferred (cf. Salomon & Perkins, 1989). Single-task training resulted in enhanced automatization of information processing, which facilitated near transfer effects to another switching task. However, training benefits failed to transfer to unfamiliar cognitive control settings. In contrast, the pure task-switching training resulted in differentiated benefits in far transfer tasks due to the specific exercise of cognitive control processes. The tendentious advantage of the task-switching training over the single-task training supports the “prefrontal executive theory” (West, 1996) by attributing the training-induced decline in age-related differences to diverse, but specific neural changes within the PFC after the task-switching training.

Although training-induced ERP effects varied between the midline electrodes, changes in the distribution of neural activity were difficult to assess. Additional analyses of spatial effects would be interesting in order to understand the relationship between temporal and structural training modifications, especially regarding the contribution of the PFC (cf. Clapp et al., 2009; Miller & Cohen, 2001).

To conclude, this study exemplified that cognitive flexibility is still possible in old age and that multidomain trainings are useful for clinical and educational purposes due to their enhancement of several cognitive control abilities. Efficient cognitive control training is able to slow down or prevent typical cognitive impairments that come with age. What remains essential is the continuous evaluation of task-switching training, especially by using progressive imaging techniques. If this endeavour is successful, age-related problems in cognitive control that compromise the quality of life could be a thing of the past.

7. References

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8. Appendix

8.1 Training Data

Table 4: Means (M) and Standard Deviations (SD) for Latencies, Error Rates, and Specific Switch Costs (Mean RT) as a Function of Training Group (Task-Switching, Single-Task) and Quartile (1 to 4).

Mean RT (ms)

	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
Training Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching Training	732	136	695	133	660	121	645	109
Single-Task Training	651	77.6	623	72	611	70	601	69

Accuracy (Error Rates, %)

	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
Training Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching Training	6.85	4.84	4.92	4.10	3.74	3.21	3.28	3.16
Single-Task Training	2.13	1.09	1.68	1.09	1.65	1.10	1.68	1.13

Specific Switch Costs (ms)

	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
Training Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching Training	30.93	29.55	25.10	36.00	20.68	24.34	26.01	21.60

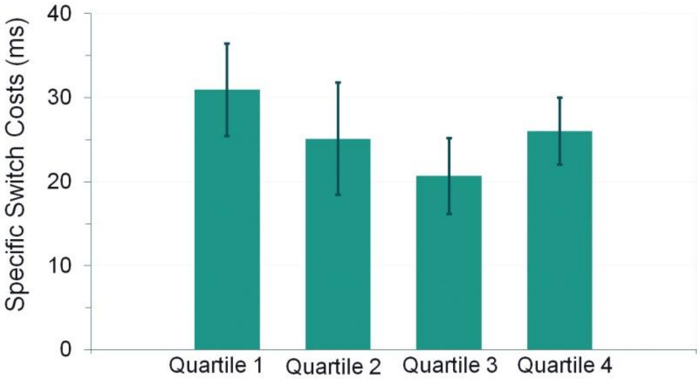


Figure 34. Specific switch costs in mean RT (ms) in the task-switching training group for quartile 1 to 4 across all training session. Error bars refer to standard errors of the mean.

8.2 Switching Task

Table 5: Mean RT, Error Rates, General Switch Costs, and Specific Switch Costs in the Switching Task at Pretest as a Function of Age Group (Younger Adults, Older Adults) and Trial Type (Single, Non-Switch, Switch; for Mean RT and Error Rates).

Mean RT (ms)

	Trial Type						Cognitive Costs			
Age Group	Single		Non-Switch		Switch		General		Specific	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young	543	90	611	115	641	122	67	61	30	41
Old	761	100	872	144	896	160	111	88	152	24

Error Rates (%)

	Trial Type						Cognitive Costs			
Age Group	Single		Non-Switch		Switch		General		Specific	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young	2.60	1.61	4.74	3.68	4.54	2.82	2.14	2.83	-0.20	2.95
Old	6.69	5.07	10.96	10.07	13.87	9.02	4.72	8.12	2.90	5.11

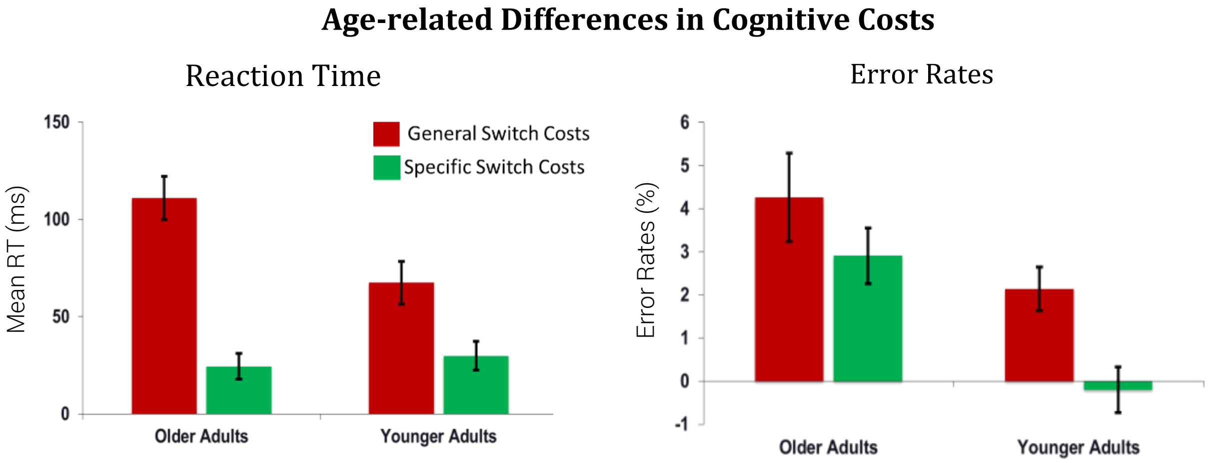


Figure 35. General and specific switch costs in the switching task at pretest based on reaction time (left panel) and error rates (right panel) as a function of age group (older adults, younger adults). Error bars refer to standard errors of the mean.

Table 6: Mean RT (ms), Error Rates (%), and Cognitive Costs (ms) in the Switching Task as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Single, Non-Switch, Switch).

Mean RT (ms)

	Trialtype											
Study Group	Single Trials				Repeat Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	743	108	659	94	854	157	714	138	882	170	738	166
Single-Task	776	92	693	95	888	132	782	140	909	153	817	159
Young Control	543	90	506	81	611	115	551	117	641	122	557	129

Error Rates (%)

	Trialtype											
Study Group	Single Trials				Repeat Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	6.95	5.76	4.49	2.43	10.46	10.78	9.33	5.35	13.51	10.31	7.29	4.51
Single-Task	6.47	4.48	4.46	2.57	11.38	9.56	11.47	6.17	14.17	7.90	10.12	5.76
Young Control	2.60	1.61	2.92	2.33	4.74	3.68	6.31	1.78	4.54	2.82	4.04	3.01

Cognitive Costs (ms)

Study Group	General				Specific			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	111	92.1	55	67.3	28.1	44.6	24.3	46.8
Single-Task	111	86.4	90.0	74.9	21.4	58.9	34.5	51.5
Young Control	67.4	60.9	44.6	65.0	29.9	41.3	6.2	33.1

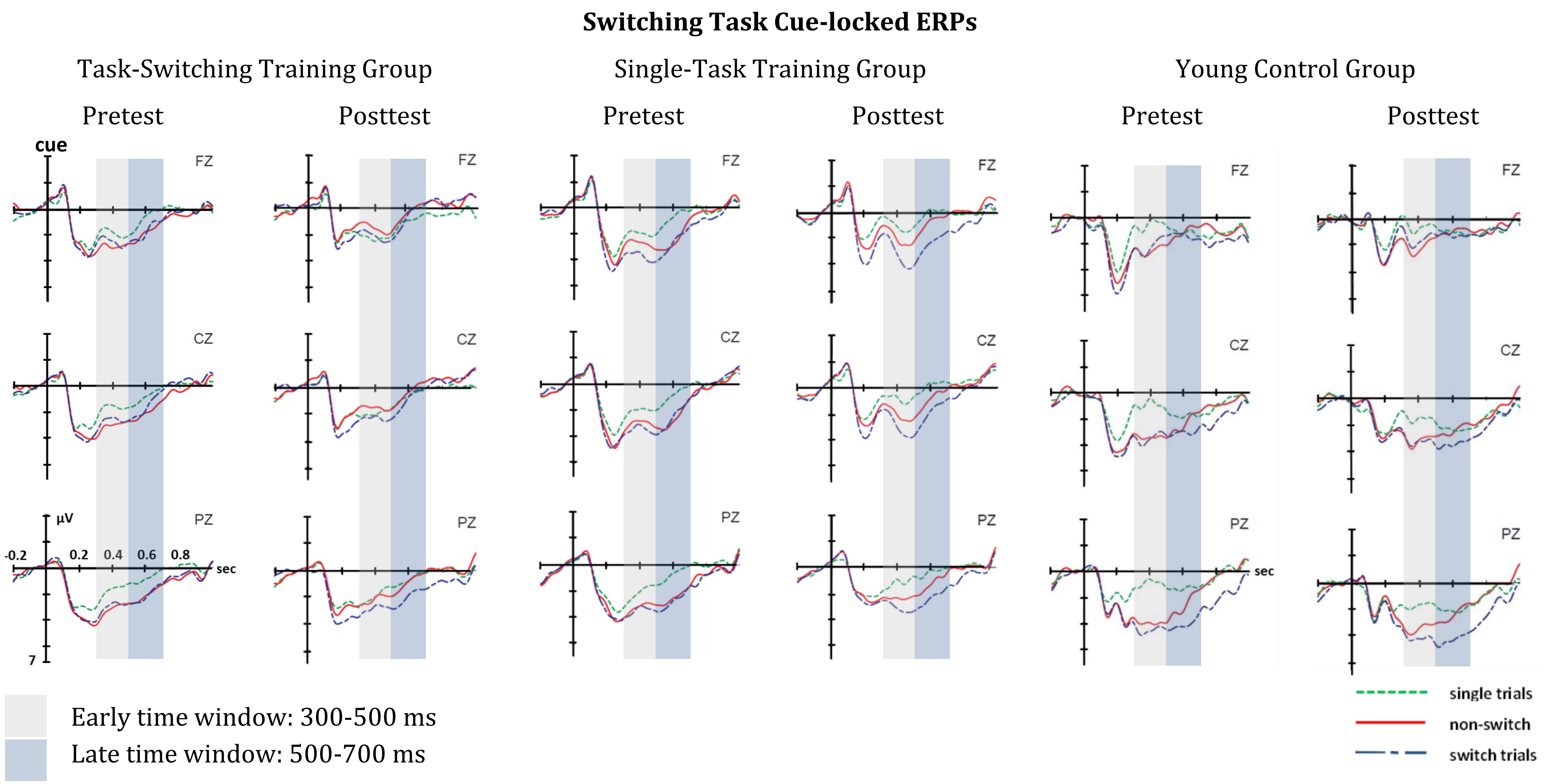


Figure 36. Cue-locked grand average waveforms for single, non-switch, and switch trials at midline electrodes (Fz, Cz, Pz) in the task-switching training group, single-task training group, and young adults at pretest and posttest.

Table 7: Vector-normalized Cue-locked P3 Amplitudes (µV) in the Switching Task in the Early Time Window (300-500 ms after cue-onset) as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Single, Non-Switch, Switch) at the Electrodes Fz, Cz, and Pz.

Cue-locked P3 mean amplitudes (µV) - Early Time Window (300-500 ms after cue-onset)												
Electrode Fz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.189	.195	.241	.208	.305	.144	.174	.232	.250	.233	.229	.232
Single-Task	.164	.183	.052	.250	.234	.231	.192	.198	.313	.249	.300	.271
Young Control	-.006	.254	.030	.362	.194	.290	.152	.226	.156	.226	.080	.362
Electrode Cz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.153	.181	.202	.208	.308	.242	.188	.256	.282	.184	.272	.209
Single-Task	.171	.211	.025	.314	.271	.208	.188	.267	.300	.228	.269	.272
Young Control	.014	.261	.100	.246	.242	.266	.243	.254	.211	.298	.241	.293
Electrode Pz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.175	.159	.187	.176	.338	.216	.312	.237	.344	.225	.383	.190
Single-Task	.206	.188	.116	.266	.307	.190	.258	.225	.317	.205	.317	.244
Young Control	.057	.216	.147	.201	.343	.267	.281	.240	.344	.267	.362	.257

Table 8: Vector-normalized Cue-locked P3 Amplitudes (μV) in the Switching Task in the Late Time Window (500-700 ms after cue-onset) as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest) and Trialtype (Single, Non-Switch, Switch) at the Electrodes Fz, Cz, and Pz.

Cue-locked P3 mean amplitudes (μV) - Late Time Window (500-700 ms after cue-onset)

Electrode Fz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.045	.025	.098	.304	.253	.254	.061	.352	.196	.399	.080	.434
Single-Task	.052	.239	.001	.264	.221	.258	.085	.270	.257	.303	.279	.296
Young Control	.080	.273	.065	.288	.104	.299	.069	.240	.117	.247	.067	.328

Electrode Cz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.050	.251	.41	.264	.239	.018	.024	.312	.165	.350	.077	.335
Single-Task	.067	.247	-.037	.351	.230	.262	.104	.281	.234	.280	.226	.321
Young Control	.154	.226	.180	.237	.188	.303	.186	.304	.248	.324	.279	.252

Electrode Pz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.047	.233	.043	.265	.242	.265	.125	.262	.240	.323	.259	.313
Single-Task	.079	.259	.037	.332	.256	.200	.159	.274	.299	.289	.256	.250
Young Control	.116	.184	.171	.219	.213	.316	.187	.260	.360	.276	.388	.271

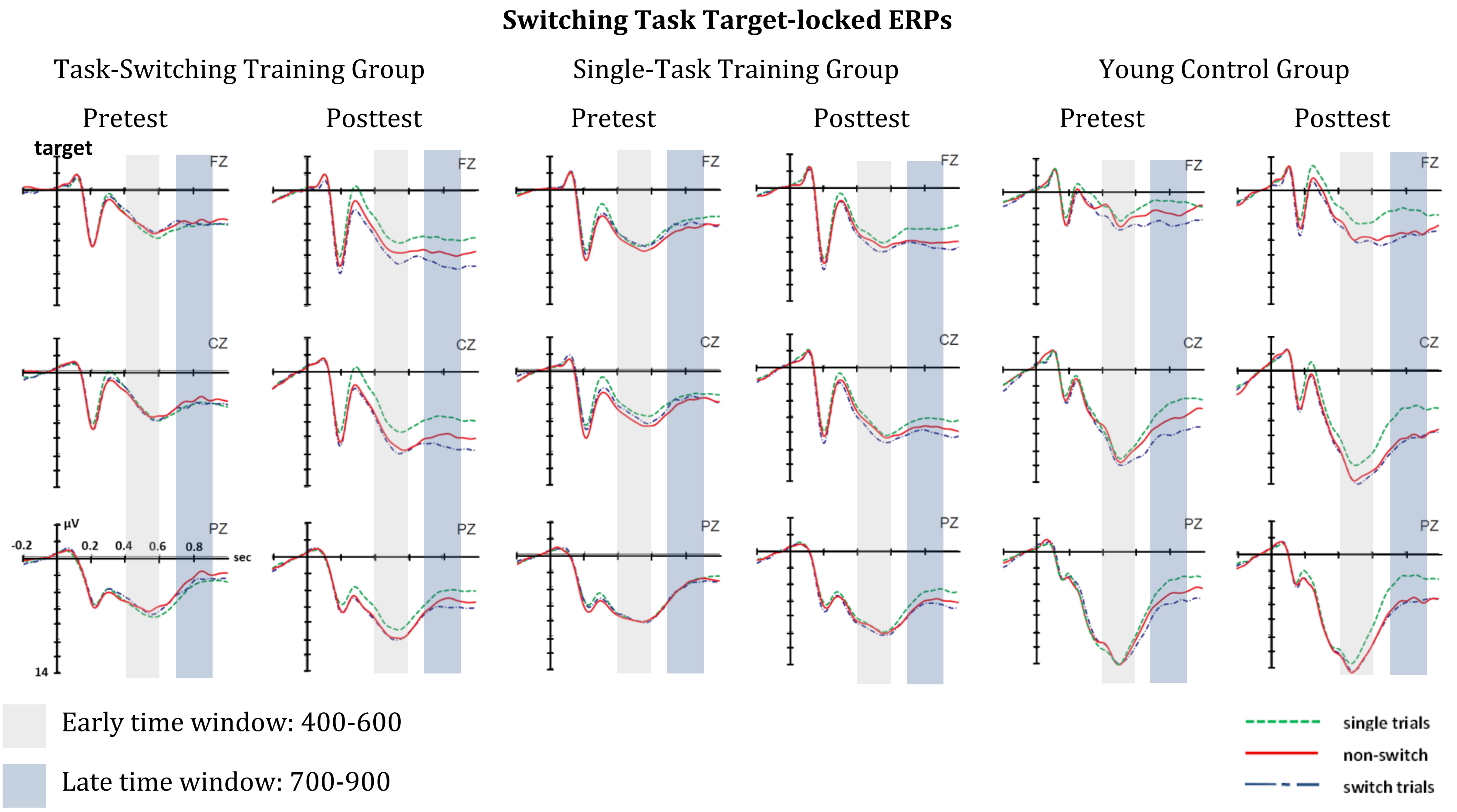


Figure 37. Target-locked grand average waveforms for single, non-switch, and switch trials at midline electrodes (Fz, Cz, Pz) in the task-switching training group, single-task training group, and young adults at pretest and posttest.

Table 9: Vector-normalized Target-locked P3 Amplitudes (μV) in the Switching Task in the Early Time Window (400-600 ms after target-onset) as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Single, Non-Switch, Switch) at the Electrodes Fz, Cz, and Pz.

Target-locked P3 mean amplitudes (μV) - Early Time Window (400-600 ms after target-onset)												
Electrode Fz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.246	.241	.206	.136	.228	.234	.238	.146	.215	.236	.305	.130
Single-Task	.263	.174	.201	.198	.295	.147	.227	.153	.243	.164	.238	.220
Young Control	.085	.145	.093	.144	.099	.170	.139	.151	.125	.170	.151	.169
Electrode Cz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.141	.289	.183	.224	.165	.204	.256	.213	.170	.199	.294	.192
Single-Task	.180	.241	.228	.211	.237	.216	.239	.201	.186	.235	.264	.217
Young Control	.314	.093	.316	.097	.321	.094	.361	.113	.348	.062	.369	.099
Electrode Pz												
Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.334	.200	.322	.170	.342	.154	.358	.135	.351	.144	.388	.115
Single-Task	.376	.138	.357	.156	.340	.148	.349	.133	.323	.166	.360	.136
Young Control	.417	.088	.372	.093	.415	.078	.404	.077	.425	.088	.401	.085

Table 10: Vector-normalized Target-locked P3 Amplitudes (µV) in the Switching Task in the Late Time Window (500-700 ms after target-onset) as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Single, Non-Switch, Switch) at the Electrodes Fz, Cz, and Pz.

Target-locked P3 mean amplitudes (µV) - Late Time Window (700-900 ms after target-onset)

Electrode Fz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.233	.263	.253	.171	.212	.258	.291	.156	.199	.264	.374	.108
Single-Task	.199	.252	.187	.249	.260	.299	.248	.188	.233	.229	.265	.241
Young Control	.002	.241	.076	.223	.122	.240	.220	.207	.176	.268	.249	.249

Electrode Cz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.153	.314	.226	.251	.090	.344	.273	.254	.130	.331	.358	.201
Single-Task	.179	.285	.224	.293	.228	.289	.253	.240	.200	.312	.275	.280
Young Control	.212	.178	.221	.181	.352	.164	.408	.137	.433	.123	.433	.156

Electrode Pz

Study Group	Single Trials				Non-switch Trials				Switch Trials			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.246	.197	.197	.184	.136	.280	.211	.161	.178	.236	.263	.151
Single-Task	.260	.180	.205	.207	.240	.201	.251	.187	.233	.208	.256	.184
Young Control	.198	.163	.135	.139	.310	.153	.287	.157	.365	.145	.314	.133

8.3 AX-CPT

Table 11: Means (M) and Standard Deviations (SD) for Mean RT, Error Rates, and Context Effects in the AX-CPT at Pretest as a Function of Age Group (Younger Adults, Older Adults) and Trial Type (Context-independent, Context-dependent; for Mean RT and Error Rates).

Mean RT (ms)						
	Trial Type				Context Effects	
Age Group	Context-independent		Context-dependent			
	M	*SD*	*M*	*SD*	*M*	*SD*
Young	478	66	572	124	94	77
Old	688	155	933	241	245	176

Error Rates (%)						
	Trial Type				Context Effects	
Age Group	Context-independent		Context-dependent			
	M	*SD*	*M*	*SD*	*M*	*SD*
Young	1.23	1.50	3.77	3.00	2.54	3.23
Old	3.27	8.88	13.53	12.59	10.26	12.59

Table 12: Mean RT (ms) and Error Rates (%) in the AX-CPT as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Context-independent, Context-dependent).

Mean RT (ms)

	Trialtype											
Study Group	Context-independent				Context-dependent				Context Effects			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	655	125	555	106	911	222	702	188	255	171	147	134
Single-Task	717	173	614	118	952	259	801	229	236	181	187	139
Young Control	478	66	429	66	572	124	498	144	94	76.8	69.26	104.3

Error Rates (%)

	Trialtype											
Study Group	Context-independent				Context-dependent				Context Effects			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	1.33	2.25	0.84	1.75	11.73	12.40	6.36	7.09	10.40	11.97	5.52	6.80
Single-Task	4.92	11.74	2.72	5.98	15.06	12.36	11.77	14.08	10.14	14.26	9.04	14.11
Young Control	1.23	1.50	0.76	1.23	3.77	3.00	3.64	2.25	2.54	3.23	2.89	2.36

Table 13: Vector-normalized Cue-locked P3 Amplitudes (μV) in the AX-CPT as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), Trialtype (Context-independent, Context-dependent) at the Electrodes Fz, Cz, and Pz.

Cue-locked P3 mean amplitudes (μV)

Electrode Fz

Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.363	.313	.286	.295	.311	.353	.354	.275
Single-Task	.378	.198	.356	.264	.427	.235	.352	.314
Young Control	-.205	.340	-.124	.365	-.151	.419	-.143	.423

Electrode Cz

Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.184	.326	.165	.327	.119	.400	.204	.400
Single-Task	.215	.280	.203	.401	.278	.321	.211	.335
Young Control	.060	.316	.136	.342	.196	.370	.187	.352

Electrode Pz

Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.136	.305	.133	.377	.157	.352	.136	.376
Single-Task	.168	.310	.165	.325	.247	.324	.179	.284
Young Control	.197	.280	.241	.309	.400	.334	.387	.278

AX-CPT Cue-locked ERPs

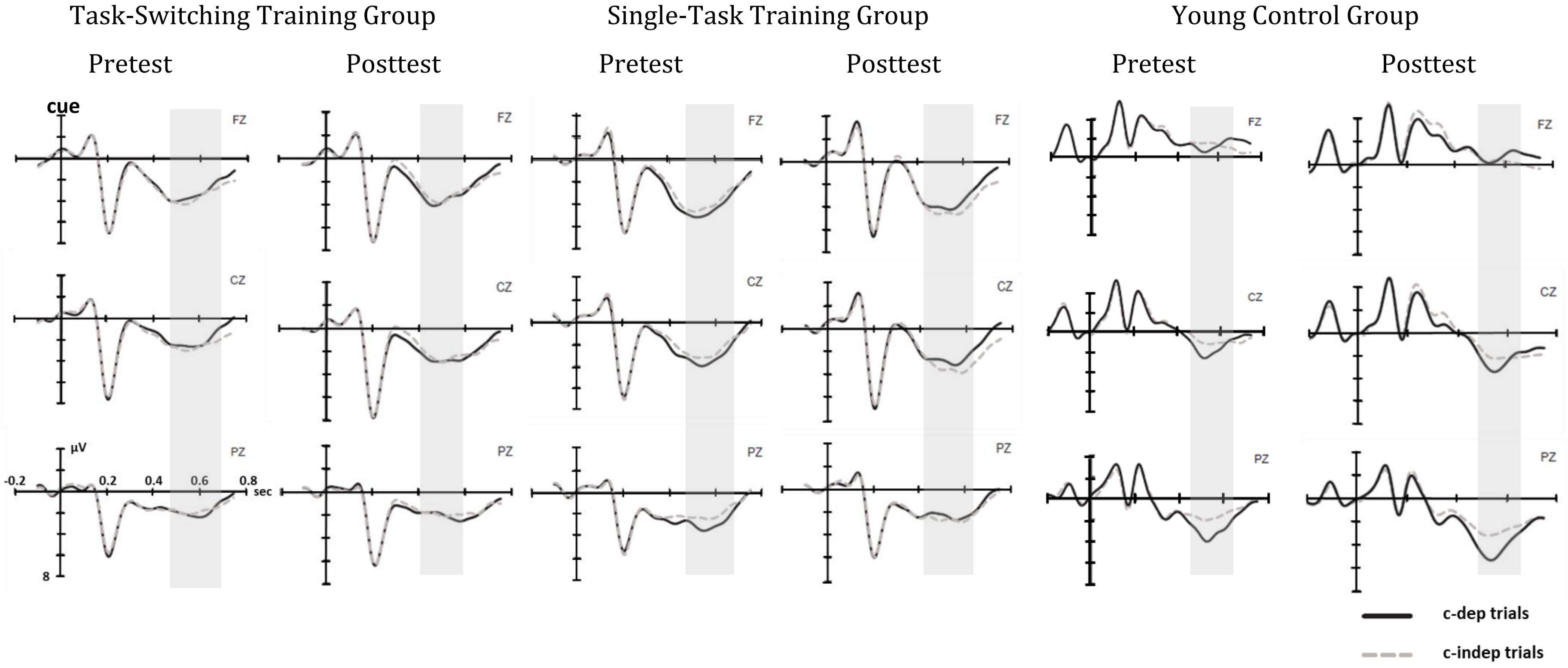
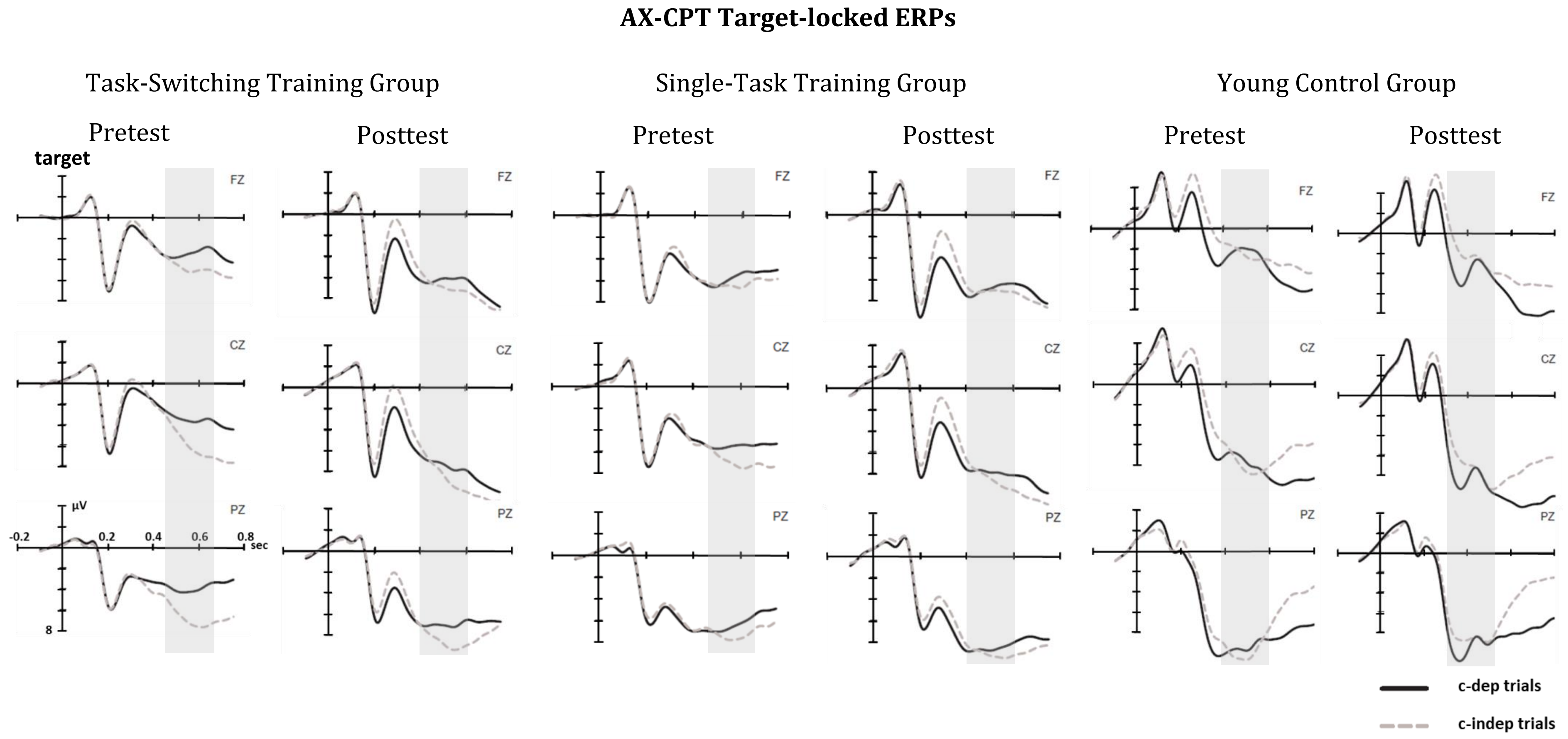


Figure 38. Cue-locked grand average waveforms for c-indep and c-dep trials at the midline electrodes (Fz, Cz, Pz) for all study groups at pretest and posttest in the AX-CPT.

Table 14: Vector-normalized Target-locked N450 Amplitudes (μV) in the AX-CPT as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trialtype (Context-independent, Context-dependent) at the Electrodes Fz, Cz, and Pz.

Target-locked N450 mean amplitudes (μV)								
				Electrode Fz				
Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.302	.228	.293	.208	.193	.270	.258	.338
Single-Task	.322	.292	.290	.244	.310	.144	.293	.192
Young Control	.075	.260	.052	.331	.117	.230	.132	.273
				Electrode Cz				
Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.307	.281	.334	.260	.101	.382	.252	.331
Single-Task	.348	.240	.328	.271	.253	.252	.323	.224
Young Control	.344	.185	.321	.243	.358	.175	.373	.224
				Electrode Pz				
Study Group	Context-independent				Context-dependent			
	Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.484	.257	.436	.184	.233	.283	.309	.183
Single-Task	.440	.203	.434	.174	.380	.145	.414	.127
Young Control	.514	.135	.410	.221	.509	.119	.439	.212



AX-CPT Target-locked ERPs

Task-Switching Training Group

Single-Task Training Group

Young Control Group

Pretest

Posttest

Figure 39. Target-locked grand average waveforms for c-indep and c-dep trials at the midline electrodes (Fz, Cz, Pz) for all study groups at pretest and posttest.

8.4 WMC Task

Table 15: Means (M) and Standard Deviations (SD) for Latencies and Error Rates in the WMC Task at Pretest as a Function of Age Group (Younger Adults, Older Adults) and Trial Type (Distractor, Interrupter, Passive View).

Mean RT (ms)						
	Trial Type					
Age Group	Distractor		Interrupter		Passive View	
	M	*SD*	*M*	*SD*	*M*	*SD*
Young	631	133	664	127	418	71.4
Old	804	133	854	130	597	98.6
Error Rates (%)						
	Trial Type					
Age Group	Distractor		Interrupter		Passive View	
	M	*SD*	*M*	*SD*	*M*	*SD*
Young	4.49	3.18	3.27	2.43	0.51	1.43
Old	7.61	7.81	10.30	7.38	0.22	0.62

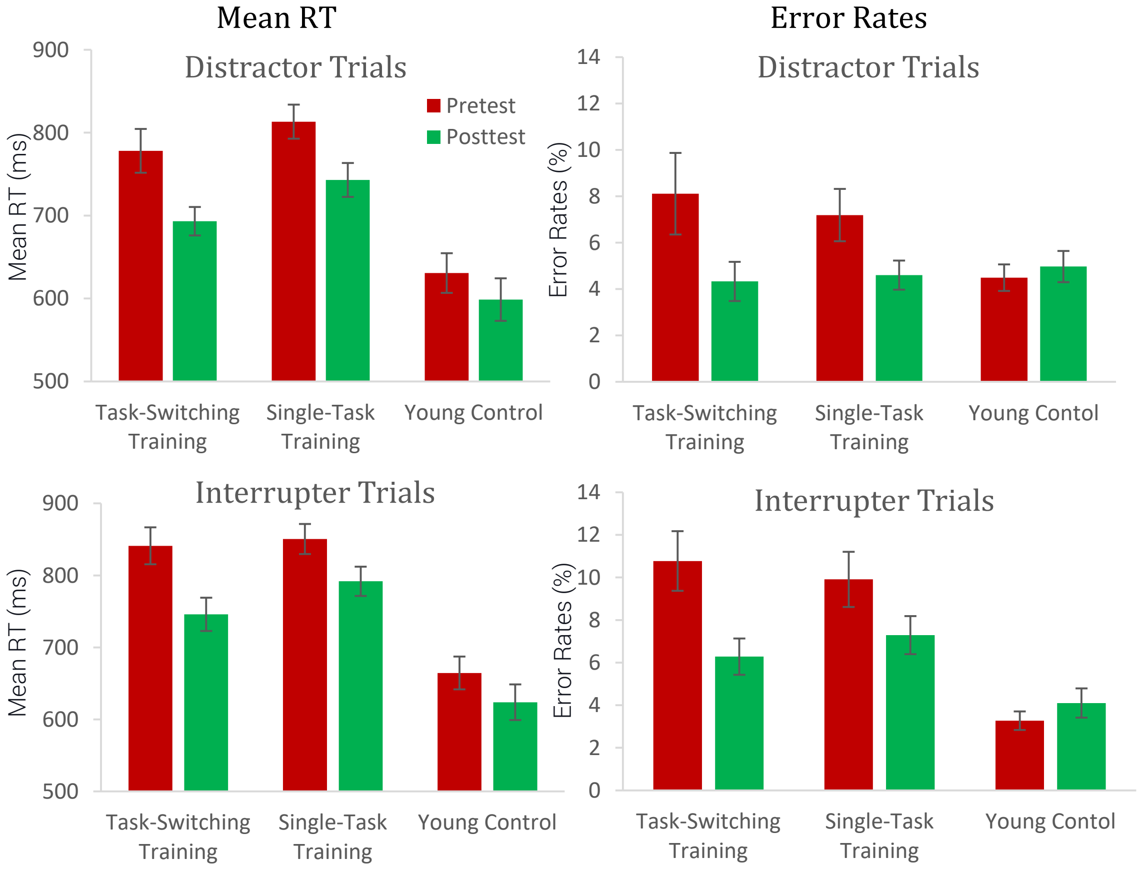


Figure 40. Mean RT (ms, left panels) and error rates (%, right panels) as a function of study group (task-switching training, single-task training, young control) and session (pretest, posttest) for distractor and interrupter trials. Error bars refer to standard errors of the mean.

Table 16: Mean RT (ms) and Error Rates (%) in the WMC Task as a Function of Study Group (Task-Switching Training, Single-Task Training, Young Control), Session (Pretest, Posttest), and Trial Type (Distractor, Interrupter, Passive View).

Mean RT (ms)

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	778	138	693	89.1	841	133	746	120	590	95.4	501	152
Single-Task	813	120	744	119	851	122	792	119	603	104	537	86.2
Young Control	631	133	599	143	664	127	624	138	418	71.4	390	73.9

Error Rates (%)

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	8.11	9.14	4.33	4.40	10.77	7.29	6.28	4.42	0.16	0.64	0.16	0.48
Single-Task	7.19	6.58	4.6	3.67	9.91	7.55	7.29	5.20	0.28	0.61	0.19	0.52
Young Control	4.49	3.18	4.97	3.74	3.27	2.43	4.10	3.83	0.51	1.43	0.35	0.88

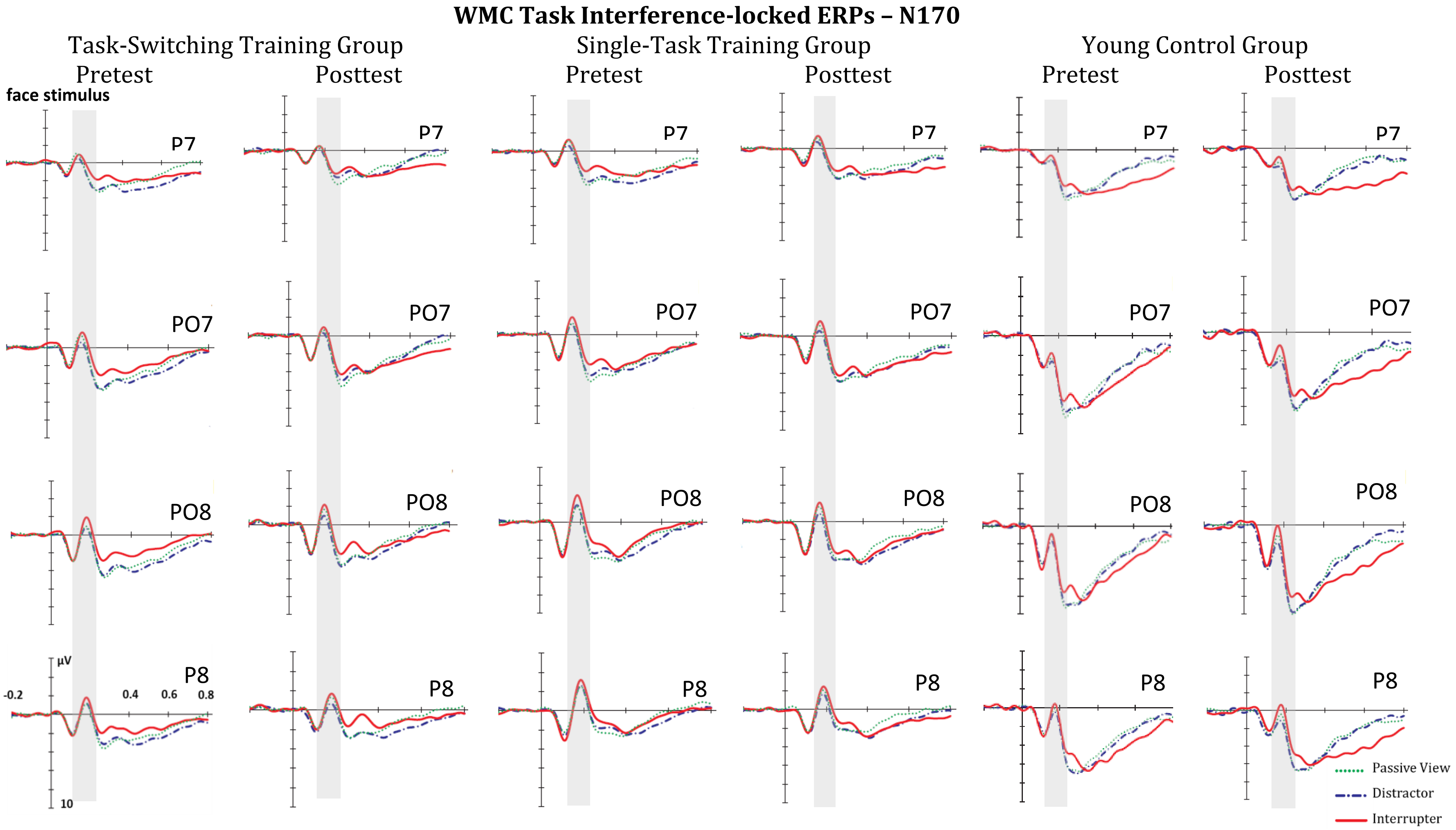


Figure 41. Interference-locked grand average waveforms for distractor trials, interrupter trials, and passive view at the parietal electrodes (P7, PO7, PO8, P8) for all study groups at pretest and posttest.

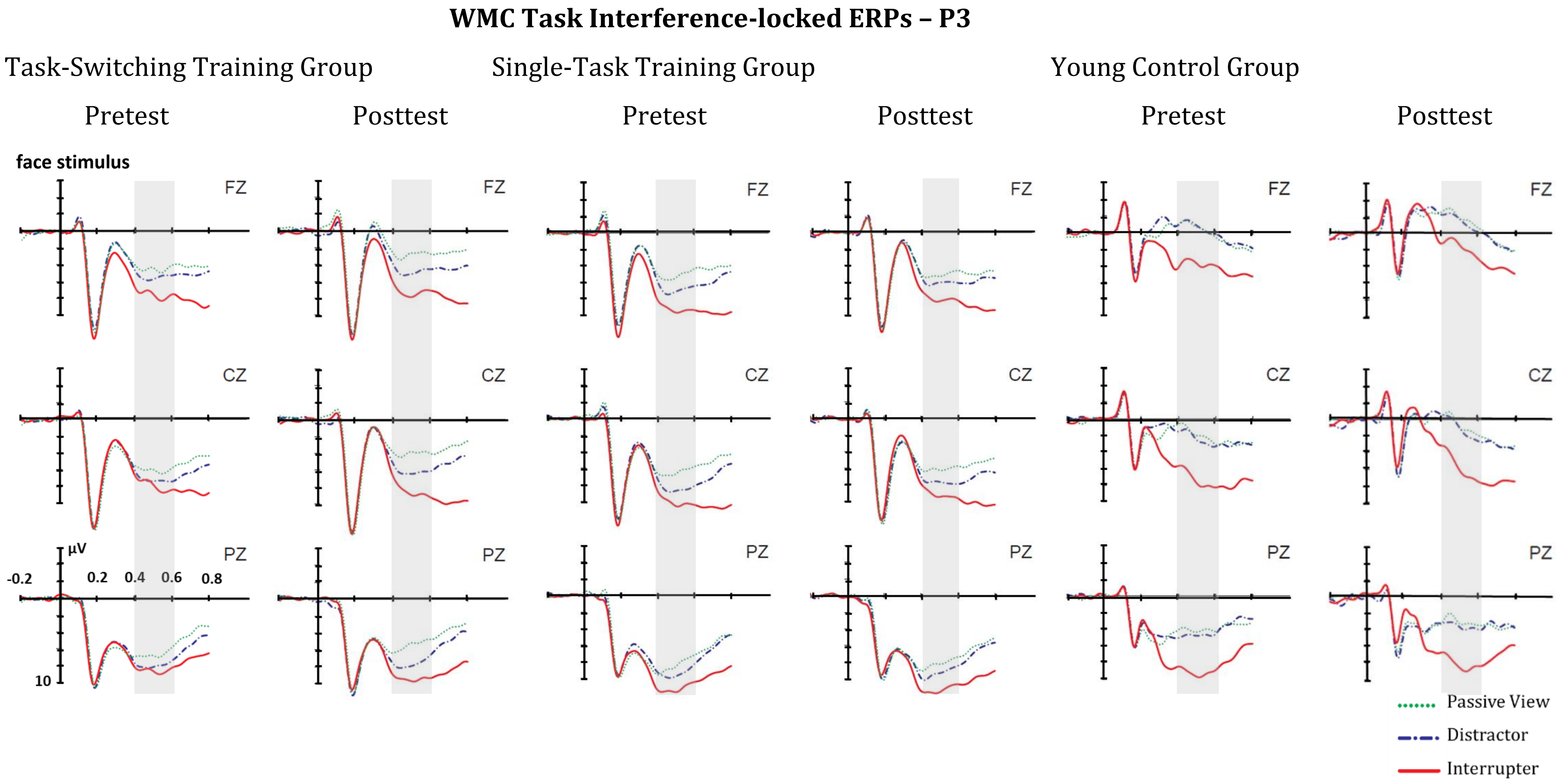


Figure 42. Interference-locked grand average waveforms for distractor trials, interrupter trials, and passive view at the parietal electrodes (Fz, Cz, Pz) for all study groups at pretest and posttest.

Table 17: Vector-normalized N170 and P3 Amplitudes (μV) in the WMC Task as a Function of Study Group (Task-Switching, Single-Task, Young Control), Session (Pretest, Posttest), Trial Type (Distractor, Interrupter, Passive View), and Electrode (for P3).

N170 mean amplitudes (μV)

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.079	.237	.106	.227	-.034	.222	-.023	.264	.055	.215	.215	.232
Single-Task	-.003	.234	.032	.182	-.080	.286	-.050	.225	-.031	.208	-.009	.228
Young Control	.212	.146	.248	.109	.146	.182	.139	.167	.206	.130	.227	.138

P3 mean amplitudes (μV) - Fz

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.248	.136	.207	.158	.308	.140	.316	.153	.181	.140	.100	.167
Single-Task	.246	.117	.228	.097	.325	.126	.280	.188	.177	.320	.182	.149
Young Control	-.044	.250	-.116	.190	.187	.250	.082	.285	-.031	.209	-.150	.243

P3 mean amplitudes (μV) - Cz

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.322	.115	.274	.167	.305	.202	.355	.243	.255	.121	.158	.165
Single-Task	.307	.100	.293	.103	.356	.140	.322	.239	.230	.141	.229	.167
Young Control	.124	.193	.057	.184	.379	.197	.370	.246	.103	.199	.039	.219

P3 mean amplitudes (μV) - Pz

Study Group	Distractor Trials				Interrupter Trials				Passive View			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Task-Switching	.382	.136	.370	.108	.370	.116	.437	.156	.310	.136	.253	.108
Single-Task	.349	.109	.366	.102	.419	.112	.423	.105	.320	.101	.312	.133
Young Control	.245	.227	.230	.241	.482	.253	.538	.191	.222	.259	.193	.198

9. Abbreviations

ACC	Anterior Cingulate Cortex
Ag	Argentum
ANOVA	Analysis of variance
AX-CPT	AX-Continuous Performance Task
c-dep	context-dependent
cf.	conferatur – compare
c-indep	context-independent
Cl	Chloride
DSST	Digit Symbol Substitution Test
EEG	Electroencephalography
e.g.	For Example
EKP	Ereigniskorreliertes Potenzial
EOG	Electrooculography
EOI	Electrode(s) of Interest
ERP	Event-Related Potential
fMRI	Functional Magnetic Resonance Imaging
Hz	Hertz
i.e.	That Is
ITI	Inter-trial interval
M	Mean
ms	Milliseconds
MWT-B	Mehrfachwahl-Wortschatz-Test ,Version B
PFC	Prefrontal Cortex
RT	Reaction Time
SD	Standard Deviation
SAS	Supervisory Attentional System
SR	Sampling Rate
WMC	Working-Memory Control

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„Die beste Bildung findet ein gescheiter Mensch auf Reisen."

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