Potential and Limits of Executive Control Training

Age Differences in the Near and Far Transfer of Task-Switching Training

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Zusammenfassung in deutscher Sprache

Theoretischer Hintergrund

„Kognitives Training“, „Denktraining“ und „Gehirnjogging“ – diese Begriffe beschreiben eine Vielzahl von Trainingsprogrammen, die auf verschiedenste Art und Weise dazu dienen sollen, unsere kognitive Leistungsfähigkeit zu steigern. Das Angebot und der Umsatz an kommerziellen Produkten dieser Art sind in den letzen Jahren stetig gestiegen. Allerdings kommt man bei der Vielfalt der Produkte nicht umhin, sich zu fragen: Wie effektiv ist kognitives Training? Und was genau macht eine bestimmt Art von Training wirkungsvoll? Welche kognitiven Fähigkeiten kann man durch Training verbessern? Und wer von uns profitiert am meisten von welcher Art des Trainings?

Im klinischen Kontext werden Trainingsprogramme häufig bei Patienten mit kognitiven Defiziten eingesetzt, die mit einer Fülle von Krankheitsbildern einhergehen, wie z.B. Aufmerksamkeitsdefizit und Hyperaktivitätsstörungen, Schizophrenie, Demenz oder zerebralem Insult. Mittlerweile haben zahlreiche Studien gezeigt, dass verschiedene Arten kognitiven Trainings deutliche Veränderungen auf behavioraler und neuronaler Ebene hervorrufen können (einen Überblick bieten Bissig & Lustig, 2007; Jones et al., 2006). Dabei bietet kognitives Training auch die Gelegenheit, Altersunterschiede hinsichtlich kognitiver Plastizität zu untersuchen, d.h. der Fähigkeit, die eigenen Leistungen durch Übung zu verbessern. Bisherige Befunde zeigen, dass die kognitive Plastizität über die Lebensspanne beträchtlich ist (z.B. Brehmer, Li, Müller, von Örtzen & Lindenberger, 2007; Cepeda, Kramer & Gonzales DeSather, 2001; Derwinger, Stigsdotter Neely & Persson, 2003; Kramer, Hahn & Gopher, 1999; Kray, Eber & Karbach, im Druck; Kray & Lindenberger, 2000; Minear, Shah &

Park, 2002; Schaie & Willis, 1986; Verhaeghen, Marcoen & Goossens, 1992; Überblicke bieten Bissig & Lustig, 2007; Jones et al., 2006; Kramer & Willis, 2002), aber im sehr hohen Alter eingeschränkt zu sein scheint (Singer, Lindenberger & Baltes, 2003). Ein Aspekt, dem in den letzten Jahren mehr und mehr Aufmerksamkeit zuteil wurde, ist die Frage, ob sich trainingsbedingte Leistungsverbesserungen auf neue, ungeübte Aufgabensituationen transferieren lassen. Dieser Aspekt ist besonders bedeutsam für die Anwendung von Trainingsprogrammen, z. B. im klinischen und pädagogischen Kontext. So ist es erstaunlich, dass trotz der langen Tradition der Transferforschung noch immer kein Konsens darüber herrscht, ob und in welchem Ausmaß der Transfer von trainingsbedingten Leistungsverbesserungen möglich ist (einen Überblick bieten Barnett & Ceci, 2002). Die bisherige Forschung verweist auf deutliche Grenzen der Transferierbarkeit kognitiven Trainings. Dabei war Transfer, d. h. Leistungsverbesserungen in neuen, untrainierten Kontexten, zumeist beschränkt auf strukturell ähnliche Aufgaben. Diese Befunde legen nahe, dass sich kognitives Training vorwiegend auf aufgabenspezifische Komponenten auswirkt, die nicht auf strukturell unähnliche Aufgaben übertragen werden können (z.B. Derwinger et al., 2003; Klauer, 1989a, 1989b; Roth-van der Werf, Resing & Slenders, 2002). Im Gegensatz dazu weisen jüngste Studien darauf hin, dass eine weitere Generalisierung von Trainingsgewinnen in verschiedenen Altersgruppen durchaus möglich ist (Bherer et al., 2005; Dowsett & Livesey, 2000; Klingberg et al., 2005; Klingberg, Forssberg & Westerberg, 2002b; Kramer, Larish & Strayer, 1995; Kramer, Larish, Weber & Bardell, 1999; Rueda, Rothbart, McCandliss, Saccomanno & Posner, 2005). Während die meisten Transferstudien aus den Bereichen Gedächtnis und induktives Denken stammen (einen Überblick bietet Klauer, 2001), haben sich in den letzten Jahren auch einige Arbeiten mit exekutiven Funktionen beschäftigt.

Der Begriff „exekutive Funktionen“ beschreibt eine Reihe von übergeordneten kognitiven Kontrollprozessen, die grundlegendere Prozesse regulieren, unser Verhalten steuern und es uns ermöglichen, uns optimal an die ständigen Veränderungen in unserer

Umwelt anzupassen (vgl. Baddeley, 2000; Duncan, 1995; Logan 2000; Norman & Shallice, 1986; Roberts & Pennington, 1996; Smith & Jonides, 1999). Zu den Prozessen, die unter den Begriff „exekutive Funktionen“ subsumiert werden, gehören beispielsweise die Inhibitionskontrolle, das Planen und Koordinieren von Aufgabensequenzen und das Kodieren von Arbeitsgedächtnisinhalten (vgl. Smith & Jonides, 1999). Während traditionelle Modelle ein einziges zentrales Kontrollsystem angenommen haben, wie z.B. die „zentrale Exekutive“ in Baddeley’s Modell (1986, 2000), oder das „überwachende Aufmerksamkeitssystem“ im Modell von Norman und Shallice (1986), geht man heute weitgehend davon aus, dass exekutive Kontrolle mehrere differenzierbare Kontrollkomponenten umfasst, darunter Wechselfähigkeit, Aufrechterhaltung und Inhibition (vgl. Fisk & Sharp, 2004; Huizinga, Dolan & Van der Molen, 2006; Kray & Lindenberger, 2000; Miyake et al., 2000). Darüber hinaus weisen empirische Befunde darauf hin, dass exekutive Funktionen eng mit intellektuellen Fähigkeiten zusammenhängen (Überblicke bieten Kray & Lindenberger, 2007; Lindenberger & Kray, 2005). Defizite in exekutiven Kontrollfunktionen gehen üblicherweise mit einer Vielzahl von neuropsychiatrischen Störungen einher, darunter Depression, Schizophrenie und Aufmerksamkeitsdefizit und Hyperaktivitätsstörungen (einen Überblick bietet Royall et al., 2002); allerdings finden sich ähnliche Einschränkungen auch bei Kindern und älteren Menschen (Bedard et al., 2002; Cepeda et al., 2001; Comalli, Wapner & Werner, 1962; Kray et al., im Druck; Kray, Eber & Lindenberger, 2004; Williams, Ponesse, Schachar, Logan & Tannock, 1999).

Zur experimentellen Erfassung von Altersunterschieden in verschiedenen exekutiven Kontrollkomponenten wurde bislang eine Fülle von Paradigmen eingesetzt, z.B. das Doppelaufgabenparadigma (z.B. Kramer et al., 1995; Kramer, Larish, et al., 1999) oder die Stroop-Aufgabe (Stroop, 1935; einen Überblick bietet McLeod, 1991). Eine der am weitesten verbreiteten Methoden ist das Aufgabenwechselparadigma, welches auch in der vorliegenden Studie verwendet wurde (vgl. Kray & Lindenberger, 2000; Rogers & Monsell, 1995; einen

Überblick bietet Monsell, 2003). In Aufgabenwechsel-Studien werden Probanden üblicherweise instruiert, zwei einfache Aufgaben A und B auszuführen. Diese Aufgaben werden entweder einzeln (AAA.... oder BBB...; aufgabenhomogene Blöcke) oder im Wechsel ausgeführt (AABBAABB...; aufgabenheterogene Blöcke). Um den Pobanden anzuzeigen, welche Aufgabe im folgenden Trial ausgeführt werden soll, kann entweder ein externer Hinweisreiz gegeben werden („task-cueing" Paradigma; z.B. Karbach & Kray, 2007; Mayr, 2001), oder in den aufgabenheterogenen Blöcken wird eine feste Aufgabenfolge gewählt (z.B., AABBAABB, „alternating-runs" Paradigma, z.B. Kray & Lindenberger, 2000; Rogers & Monsell, 1995). Das Wechseln zwischen zwei Aufgaben geht mit sogenannten Wechselkosten einher, die sowohl auf der Ebene der Reaktionszeiten, als auch auf Ebene der Antwortgenauigkeit nachweisbar sind. Die Aufteilung eines Experimentes in aufgabenhomogene und aufgabenheterogene Blöcke ermöglicht die Berechnung zweier Kostenmaße: *Generelle Wechselkosten* sind definiert als die Differenz der Leistung zwischen den homogenen und den heterogenen Blöcken, d.h. sie messen den zusätzlichen Aufwand, der damit verbunden ist, zwei Aufgaben aufrecht zu halten und die jeweils relevante auszuwählen. *Spezifische Wechselkosten* werden berechnet als die Differenz zwischen Wechseltrials (AB, BA) und Nichtwechseltrials (AA, BB) *innerhalb* der aufgabenheterogenen Blöcke und messen damit die Kosten für den eigentlichen Aufgabenwechsel. Aus entwicklungspsychologischer Perspektive besonders interessant ist der Befund, dass sich beide Komponenten offensichtlich multidirektional entwickeln, d.h. dass sie unterschiedliche Entwicklungsverläufe über die Lebensspanne hinweg aufweisen: Die Fähigkeit zur Aufgabenaufrechterhaltung und -selektion hat einen u-förmigen Verlauf über die Lebensspanne hinweg (Cepeda et al., 2001; Kray et al., im Druck; Kray et al., 2004; Reimers & Maylor, 2005; siehe auch Abbildung 2), d.h. man findet einen deutlichen Anstieg von der Kindheit bis ins junge Erwachsenenalter, gefolgt von einem konstanten Abbau im Alter (Bherer et al., 2005; Crone, Ridderinkhof, Worm, Somsen & Van Der Molen, 2004; De Jong, 2001;

Karbach & Kray, 2007; Kray, 2006; Kray & Lindenberger, 2000; Mayr, 2001; Meiran, Gotler & Perlman, 2001). Im Gegensatz dazu scheint die Fähigkeit zum Aufgabenwechsel weniger altersbedingten Veränderungen zu unterliegen (Crone et al., 2004; Karbach & Kray, 2007; Kray et al., im Druck; Kray et al., 2004; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; eine Metaanalyse findet sich bei Verhaeghen & Cerella, 2002). Auf konzeptueller Ebene sprechen diese differenzierten Entwicklungstrends wiederum dafür, dass exekutive Kontrolle tatsächlich mehrere unterschiedliche Kontrollkomponenten umfasst (vgl. Fisk & Sharp, 2004; Huizinga et al., 2006; Kray & Lindenberger, 2000; Miyake et al., 2000).

Von besonderer Bedeutung für die vorliegende Studie ist die Frage, ob Altersunterschiede in Aufgabenwechselfähigkeiten durch kognitives Training modulierbar sind. Zwei Arten der kognitiven Intervention sind im Kontext der vorliegenden Untersuchung von besonderer Bedeutung: Verbale Selbstinstruktionstechniken und intensives Aufgabentraining. Mittlerweile hat eine ganze Reihe von Studien gezeigt, dass verbale Prozesse (z.B. in Form „innerer Sprache"; vgl. Vygotsky, 1988) den Abruf und die Aktivierung von Aufgabenzielen unterstützen, ganz besonders dann, wenn keine externen Hinweisreize vorliegen und somit hohe Anforderungen an endogene Kontrollprozesse gestellt werden (Baddeley, Chincotta & Adlam, 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Gruber & Goschke, 2004; Kray et al., im Druck; Miyake, Emerson, Padilla & Ahn, 2004; Saeki & Saito, 2004; siehe auch Abbildung 3). Im Einklang damit zeigt eine aktuelle Studie, dass besonders Kinder und ältere Erwachsene verbale Selbstinstruktionen nutzen können, um altersbedingte Defizite bei der Aufrechterhaltung und Selektion von Aufgabenzielen zu kompensieren (Kray et al., im Druck; siehe auch Abbildung 4). Eine weitere Möglichkeit, Altersunterschiede in der Aufgabenwechselfähigkeit zu modulieren, ist intensives Training. Eine ganze Reihe von Aufgabenwechselstudien konnte zeigen, dass beide Arten von Wechselkosten durch Training reduziert werden können, aber auch nach intensivem Üben nicht ganz verschwinden (z.B. Cepeda et al., 2001; Kray et al., im Druck; Kray & Lindenberger, 2000; Kramer, Hahn, et al., 1999; Minear et al., 2002). Auf der Ebene der generellen Wechselkosten scheint der Trainingsgewinn für Kinder und ältere Erwachsene besonders ausgeprägt zu sein (Cepeda et al., 2001; Kramer, Hahn et al., 1999; Kray et al., im Druck; Kray & Lindenberger, 2000; Minear et al., 2002; siehe auch Abbildung 5), ein Befund, der ebenfalls für kompensatorische Effekte kognitiven Trainings spricht.

Für die Anwendung von Trainingsprogrammen sind allerdings nicht nur Trainingseffekte interessant, sondern auch deren Transferierbarkeit auf andere Situationen und Aufgabenbereiche. Bei der Untersuchung von Transfereffekten differenzieren die meisten Autoren zwischen verschiedenen Formen von Transfer (z.B. Butterfield & Nelson, 1991; Dettermann, 1993; Mayer & Wittrock, 1996; Salomon & Perkins, 1989; Novick, 1990). Für diese Studie besonders bedeutsam ist der Unterschied zwischen nahem und weitem Transfer: Naher Transfer bezieht sich auf strukturell ähnliche Aufgaben, die sich nur durch perzeptuelle Details unterscheiden, beispielsweise der Transfer vom Aufgabenwechseltraining zwischen den Aufgaben A und B zum Wechsel zwischen den Aufgaben C und D. Weiter Transfer dagegen bezieht sich auf strukturell unähnliche Aufgaben, wie z.B. Transfer vom Aufgabenwechseltraining zur Stroop-Aufgabe oder zu Arbeitsgedächtnismaßen. Transfer wird üblicherweise anhand eines Prätest – Training – Posttest Designs untersucht, und ist definiert als Leistungssteigerung im Posttest in Relation zur Ausgangsleistung im Prätest.

Mittlerweile gibt es mehrere theoretische Modelle, die Annahmen dazu machen, welche prozessualen Veränderungen während des Trainings ablaufen und im Anschluss daran transferiert werden. Anderson (1982, 1987), nimmt beispielsweise an, dass trainingsbedingte Leistungsverbesserungen in zwei Schritten entstehen: Zunächst wird die Ausführung spezifischer Operationen optimiert; im Anschluss daran können mehrere dieser spezifischen Operationen durch eine einzige übergeordnete Operation ersetzt werden, sodass die Leistung beim Ausführen komplexer Aufgaben verbessert werden kann. Lange Zeit ging man davon aus, dass Transfer umso wahrscheinlicher wird, je mehr Elemente die Trainings-und die Transfersituation gemeinsam haben (‘identical elements theory’; Thorndike, 1903; siehe auch Singley & Anderson, 1989). Betrachtet man aber neuere Befunde, so erscheint es wahrscheinlicher, dass Transfer dann auftreten kann, wenn die Transferaufgaben eine oder mehrere der während des Trainings eingeübten Fähigkeiten beanspruchen – unabhängig davon, wie ähnlich sich die Trainings- und Transferaufgaben sind (einen Überblick bieten Schmidt & Bjork, 1992).

Inzwischen sind Trainingsprogramme eine zunehmend beliebte Interventionsform für Patienten mit exekutiven Defiziten im Rahmen einer Vielzahl von Erkrankungen geworden (einen Überblick bieten Bissig & Lustig, 2007; Royall et al., 2002). Da die interindividuellen Unterschiede hinsichtlich der Trainingsgewinne allerdings oft sehr groß sind (siehe Bissig & Lustig, 2007), sind differentielle Aspekte der Trainings- und Transferleistung von großer Bedeutung, ganz besonders für die Anpassung von Trainingsprogrammen an Zielgruppen mit besonderen Bedürfnissen, wie beispielsweise Kinder, ältere Menschen oder bestimmte Patientengruppen. Leider ist die Befundlage bezüglich der Vorhersage von Trainingseffekten relativ uneindeutig: Während einige Studien zeigen konnten, dass ein schlechterer kognitiver Status vor dem Training mit geringen Trainingsgewinnen einhergeht (Verhaeghen et al. 1992; Yesavage, Sheikh, Friedman & Tanke, 1990), haben andere Untersuchungen gezeigt, dass in diesem Fall die größten Trainingsgewinne erzielt werden konnten (z.B. Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002).

Bisherige Forschungsarbeiten zur Transferierbarkeit exekutiven Kontrolltrainings zeigen, dass exekutives Kontrolltraining bei Kindern im Vorschul- und Grundschulalter sowohl auf strukturell ähnliche, als auch unähnliche Aufgaben übertragbar war (Dowsett & Livesey, 2000; Fisher & Happé, 2005; Kloo & Perner, 2003). Darüber hinaus wurde sogar weiter Transfer zu strukturell sehr unterschiedlichen fluiden Intelligenzaufgaben nachgewiesen (Klingberg et al., 2005; Klingberg et al., 2002b; Rueda et al., 2005). Befunde für die Transferierbarkeit exekutiven Kontrolltrainings im Alter findet man in der Literatur zur

Doppelaufgabentätigkeit, die zeigt, dass sowohl junge als auch ältere Erwachsene Trainingsgewinne auf neue, ungeübte Doppelaufgaben übertragen können (Kramer, Larish, et al., 1999; Kramer et al., 1995). Mittlerweile ist dieser Befund auch für das Aufgabenwechselparadigma repliziert, d.h. es konnte gezeigt werden, dass junge und ältere Erwachsene Trainingsgewinne auf der Ebene von generellen und spezifischen Wechselkosten auf neue, ungeübte Wechselaufgaben übertragen können (Bherer et al., 2005; Minear et al., 2002; siehe auch Abbildung 7).

Da diese Ergebnisse die Möglichkeit zumindest nahen Transfers in unterschiedlichen Altersgruppen zeigen, stellt sich nun die Frage, ob und wie der Umfang dieses Transfers moduliert werden kann. In der Literatur finden sich einige experimentelle Manipulationen, von denen man annimmt, dass sie die Transferleistung beeinflussen können (Übersichten bieten Rosenbaum, Carlson & Gilmore, 2001; Schmidt & Bjork, 1992). Von besonderer Bedeutung für die vorliegende Studie ist der Befund, dass eine Rückmeldung (Feedback) über die Nützlichkeit einer erlernten Strategie, wie z.B. verbale Selbstinstruktion, den Transfer dieser Strategie Kindern unterstützen kann (Kennedy & Miller, 1976; Ringel & Springer, 1980; einen Überblick bieten Bjorklund, Miller, Coyle & Slawinski, 1997). Darüber hinaus weiß man, dass Transfer bei Erwachsenen durch variables Training gefördert werden kann, d.h. durch Training anhand verschiedenartiger Trainingsaufgaben und -bedingungen (Kramer et al., 1995; Sanders, Gonzalez, Murphy, Pesta & Bucur, 2002; Überblicke bieten Rosenbaum et al., 2001; Schmidt & Bjork, 1992; Shapiro & Schmidt, 1982).

Basierend auf diesen Vorbefunden hinsichtlich der Entwicklung exekutiver Funktionen und der Transferierbarkeit kognitiven Trainings war das Ziel der vorliegenden Studie, Altersunterschiede im nahen und weiten Transfer von Aufgabenwechseltraining bei Kindern (8 – 10 Jahre), jüngeren Erwachsenen (19 – 27 Jahre) und älteren Erwachsenen (63 - 76 Jahre) zu untersuchen. Des Weiteren stand die Modulierbarkeit dieses Transfers durch verschiedene Arten von Training im Mittelpunkt.

Methode und Hypothesen

Die Stichprobe der vorliegenden Untersuchung bestand aus insgesamt 216 Probanden, von denen 210 Personen in die endgültige Auswertung aufgenommen werden konnten (70 Kinder, *mittleres Alter*: 9,3 Jahre; 70 jüngere Erwachsene, *mittleres Alter*: 22,4 Jahre; und 70 ältere Erwachsene, *mittleres Alter*: 68,7 Jahre; siehe Tabelle 1). Die jüngeren Erwachsenen wurden an der Universität des Saarlandes rekrutiert, die Kinder und älteren Erwachsenen stammen aus den Versuchspersonenpool der Arbeitseinheit Entwicklungspsychologie.

Zur Untersuchung von Transfereffekten wurde ein Prätest - Training - Posttest Paradigma gewählt, welches jeweils zwei Sitzungen für die Prätest und Posttest-Messung und vier Trainingssitzungen umfasste (insgesamt acht Sitzungen; siehe Tabelle 2). Im Prätest und im Posttest führten die Versuchsteilnehmer eine Wechselaufgabe (mit den Einzelaufgaben A und B) ähnlich der Trainingsaufgabe (mit den Einzelaufgaben C und D) aus. Anhand dieser Aufgabe konnte der nahe Transfer vom Aufgabenwechseltraining zu einer strukturell ähnlichen Trainingsaufgabe untersucht werden. Um die Rekrutierung interner verbaler Prozesse in der Phase der Aufgabenvorbereitung zu erhöhen, wurde in der gesamten Studie ein „alternating-runs“ Paradigma ohne externe Hinweisreize eingesetzt, sodass die Probanden die Aufgabensequenz der aufgabenheterogenen Blöcke (AABBAABB…) intern aufrechterhalten mussten. Zur Untersuchung von weitem Transfer des Aufgabenwechseltrainings absolvierten die Versuchsteilnehmer im Prätest und im Posttest außerdem eine kognitive Testbatterie (siehe Tabellen 3 und 4), die sowohl exekutive Kontrollaufgaben (die Stroop–Aufgabe, verbale und räumlich-visuelle Arbeitsgedächtnismaße), als auch Maße der fluiden Intelligenz umfasste. Um zu kontrollieren, dass das Aufgabenwechseltraining nicht zu Aufgaben transferiert, die nicht auf exekutiven Kontrollfähigkeiten beruhen, enthielt die Testbatterie darüber hinaus einige Kontrollaufgaben aus den Bereichen verbale Geschwindigkeit, perzeptuelle Verarbeitungsgeschwindigkeit und semantisches Wissen. Da die vorliegende Studie ebenfalls das Ziel hatte, die „optimale“ Art des Trainings für die verschiedenen Altersgruppen zu identifizieren, d.h. die Form des Trainings, die zu den größten Transfereffekten führt, wurden die Probanden während der vier Trainingssitzungen einer von fünf Trainingsgruppen zugeteilt (siehe S. 119). Die ersten beiden Trainingsbedingungen dienten dazu, den „reinen“ Transfer des Aufgabenwechseltrainings zu untersuchen. Daher wurde die *erste Trainingsgruppe*, welche als Kontrollgruppe diente, nur im Ausführen der Einzelaufgaben trainiert (d.h. nur aufgabenhomogene Blöcke mit den Aufgaben C und D), sodass die exekutiven Kontrollanforderungen während des Trainings gering sein sollten. Im Gegensatz dazu trainierte die *zweite Trainingsgruppe* nur den Aufgabenwechsel (d.h. nur aufgabenheterogene Blöcke mit den Aufgaben C und D), sodass die exekutiven Kontrollanforderungen in den Trainingssitzungen hoch waren (vgl. Minear, 2004; Minear et al., 2002). Besonders wichtig ist die Tatsache, dass beide Gruppen während des Trainings die gleiche Anzahl von Aufgaben und Trials ausführten. Ein Vergleich der Leistungen dieser beiden Gruppen ermöglicht eine Aussage darüber, ob naher Transfer des Aufgabenwechseltrainings stattgefunden hat (d.h. eine stärkere Reduktion der Wechselkosten vom Prätest zum Posttest in der Aufgabenwechsel-Gruppe als in der Einzelaufgaben-Gruppe). Die *dritte Trainingsgruppe* erhielt das gleiche Aufgabenwechseltraining wie die zweite Gruppe. Basierend auf dem Befund, dass besonders Kinder und ältere Menschen verbale Selbstinstruktionen nutzen können, um altersbedingte Defizite in Bereich der Aufgabenaufrechterhaltung und –selektion zu kompensieren (Kray et al., im Druck), sollte anhand der dritten Trainingsgruppe aber auch untersucht werden, ob sich die Leistungssteigerung aufgrund der verbalen Strategie auf andere Aufgabensituationen übertragen lässt. Deswegen wurden die Probanden in dieser dritten Gruppe instruiert, in dem Trainingssitzungen eine verbale Selbstinstruktionsstrategie zu benutzen, d.h. während des Aufgabenvorbereitungsintervalls das nächste Aufgabenziel laut zu benennen (vgl. Kray et al., im Druck). Allerdings haben frühere Studien gezeigt, dass vor allem Kinder Probleme mit dem Transfer verbaler Strategien haben und dass Feedback hinsichtlich der Nützlichkeit der verbalen Strategie deren Transfer unterstützen kann (z.B. Kennedy & Miller, 1976; Ringel & Springer, 1980; vgl. Dowsett & Livelsey, 2000). Aus diesem Grund wurde in der *vierten Trainingsgruppe* das gleiche Aufgabenwechsel- und Selbstinstruktionstraining durchgeführt wie in der dritten Gruppe, allerdings erhielten die Probanden zu bestimmten Zeitpunkten in den Trainingssitzungen (nach dem ersten und dem zweiten Drittel und am Ende) ein Feedback über ihre Trainingserfolge, welches den Nutzen der Verbalisierungsstrategie explizit betonte. Die Art des Trainings in der *fünften Trainingsgruppe* beruhte schließlich auf dem Befund, dass variable Trainingsbedingungen den Umfang des Transfers bei Erwachsenen steigern können (vgl. Kramer, Larish et al., 1999; Sanders et al., 2002; Überblicke bieten Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Zusätzlich zum Aufgabenwechsel- und Verbalisierungstraining erhielt die fünfte Gruppe deswegen ein variables Training in Form von unterschiedlichen Wechselaufgaben und Stimuli in jeder der vier Trainingssitzungen. Diese Aufgaben (E/F, G/H, I/J) waren strukturell identisch mit den Trainingsaufgaben C und D (siehe Tabelle 5).

Die Forschungshypothesen der vorliegenden Arbeit sind in drei Bereiche untergliedert: (1) Trainingsbedingte Leistungsgewinne innerhalb der vier Trainingssitzungen, (2) naher Transfer des Aufgabenwechseltrainings zu strukturell ähnlichen Aufgaben und (3) weiter Transfer des Aufgabenwechseltrainings zu strukturell unähnlichen exekutiven Aufgaben und anderen Aufgabenbereichen, sowie die Modulation der drei Bereiche durch die Art des Trainings. Obwohl der erste Aspekt nicht im Mittelpunkt der Untersuchung steht, ist die Analyse der Trainingsgewinne eine wichtige Voraussetzung für die Interpretation anschließender Transfereffekte und wird aus diesem Grund zuerst abgehandelt. Anhand des Untersuchungsdesigns wurden folgende Hypothesen geprüft:

(1) Es wurde erwartet, dass jüngere und ältere Erwachsene ihre spezifischen Wechselkosten vom Beginn bis zum Ende des Aufgabenwechseltrainings reduzieren können (vgl. Bherer et al., 2005; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). Obwohl es keine entsprechenden Befunde für Kinder gibt, wird in dieser Altersgruppe ein ähnliches Ergebnis erwartet. Da keine externen Hinweisreize verwendet wurden und somit die Anforderungen an endogene Kontrollprozesse sehr hoch waren, sollten in den Trainingsgruppen, die verbale Selbstinstruktionen ausführten, die spezifischen Wechselkosten geringer sein als in der Gruppe, die den Aufgabenwechsel ohne Verbalisierung trainierte. Hinsichtlich des Einflusses von verbaler Selbstinstruktion, Feedback und variablem Training auf den Umfang trainingsbedingter Leistungssteigerungen auf der Ebene spezifischer Wechselkosten gibt es bisher keine Vorbefunde. Da man weiß, dass variables Training in anderen Paradigmen zu einer Reduktion der Trainingszugewinne geführt hat (vgl. Rosenbaum et al., 2001; Schmidt & Bjork, 1992), könnte man allerdings vermuten, dass der Trainingsgewinn (die Reduktion der spezifischen Wechselkosten von der ersten bis zur letzten Trainingssitzung) in der Variabilitätsgruppe geringer ausfällt als in den übrigen Gruppen.

(2) Der zweite Teil der Hypothesen bezieht sich auf den nahen Transfer des Aufgabenwechseltrainings zu einer strukturell ähnlichen Wechselaufgabe und auf die Modulation dieses Transfers durch die Art des Trainings. Grundsätzlich wird erwartet, dass generelle Wechselkosten bei Kindern und älteren Erwachsenen größer sind als bei jüngeren Erwachsenen, während Altersunterschiede in spezifischen Wechselkosten geringer oder nicht vorhanden sein sollten (Cepeda et al., 2001; Crone et al., 2004; Kray, 2006; Kray et al., im Druck; Kray et al., 2004; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Mayr, 2001; Verhaeghen & Cerella, 2002). Hinsichtlich des Transfers wird ähnlich wie in vorherigen Studien erwartet, dass die Reduktion beider Kostenmaße vom Prätest zum Posttest nach dem Aufgabenwechseltraining größer ist als nach dem

Einzelaufgabentraining (vgl. Minear, 2004; Minear et al., 2002), und dass dieser nahe Transfer zumindest bezüglich der generellen Wechselkosten für ältere Erwachsene größer ist als für jüngere Erwachsene (vgl. Minear et al., 2002). Da es keine Vorbefunde für Kinder gibt, ist naher Transfer bezüglich beider Kostenmaße in dieser Altersgruppe eine offene Frage.

Hinsichtlich der Modulation des nahen Transfers durch die Verbalisierungsstrategie, das Feedback und die Variabilität wird folgendes erwartet: Da verbale Selbstinstruktionen die Aufgabenaufrechterhaltung und –selektion unterstützen können (Kray et al., im Druck), sollte der Transfer (d.h. die Reduktion der generellen Wechselkosten vom Prätest zum Posttest) in der Gruppe, die den Aufgabenwechsel und die Verbalisierung trainiert, größer sein als in der Gruppe, die nur den Aufgabenwechsel übt. Weil Kinder und ältere Menschen besonders von der verbalen Strategie profitieren (Kray et al., im Druck), sollte der Transfer in diesen Altersgruppen besonders hoch sein. Allerdings scheint der Einfluss verbaler Prozesse auf spezifische Wechselkosten beschränkt zu sein (Bryck & Mayr, 2005); deswegen wird in den Verbalisierungsgruppen keine Modulation des Transfers bezüglich dieses Kostenmaßes erwartet. Auch zu beachten ist, dass gerade Kinder Probleme mit dem Transfer verbaler Strategien haben (Flavell, Beach & Chinsky, 1966; Ringel & Springer, 1980; Salomon & Perkins, 1989; einen Überblick bieten Bjorklund et al. 1997). Man geht davon aus, dass der Transfer verbaler Techniken in dieser Altersgruppe durch explizites Feedback, welches den Nutzen der Strategie anzeigt, unterstützt werden kann (Kennedy & Miller, 1976; Ringel & Springer, 1980). Folglich wird in der vorliegenden Studie angenommen, dass zumindest Kinder eine Steigerung des Transfers nach Aufgabenwechsel- und Verbalisierungstraining nur dann zeigen, wenn sie zusätzliches Feedback erhalten, das den Nutzen der verbalen Strategie anzeigt. Schließlich ist aus früheren Untersuchungen bekannt, dass variables Training zwar die Aneignung einer bestimmten Fähigkeit während der Trainingsphase verlangsamen, aber dennoch nach dem Training zu einer höheren Transferleistung führen kann (siehe Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Obwohl es keine Vorbefunde aus Aufgabenwechselstudien gibt, weisen Ergebnisse aus Doppelaufgabenstudien mit jüngeren und älteren Erwachsene in dieselbe Richtung (Kramer, et al., 1995). In der vorliegenden Studie wurde somit erwartet, dass durch variables Training (mit anderen Aufgaben und Stimuli in jeder der vier Trainingssitzungen) bei Erwachsenen ein umfangreicherer Transfer (Reduktion der Wechselkosten vom Prätest zum Posttest) erreicht wird als durch Training mit den gleichen Aufgaben in allen vier Trainingssitzungen. Bei Kindern ist die Frage, wie sich das variable Training auf die Höhe des Transfers auswirkt, offen.

(3) Der letzte Hypothesenteil bezieht sich auf den weiten Transfer des Aufgabenwechseltrainings zu strukturell unterschiedlichen exekutiven Kontrollaufgaben (Stroop-Aufgabe, verbales und räumlich-visuelles Arbeitsgedächtnis) und zu einem anderen Aufgabenbereich (fluide Intelligenz). Da die Transferaufgaben ähnliche exekutive Fähigkeiten beanspruchen wie die Trainingsaufgaben, z.B. die Inhibition aufgabenirrelevanter Information oder die Aufrechterhaltung aufgabenrelevanter Information, sollte es zumindest theoretisch möglich sein, Transfereffekte zu finden (vgl. Schmidt & Bjork, 1992). Vorbefunde im Hinblick auf weiten Transfer exekutiven Kontrolltrainings sind allerdings beschränkt auf die Kindheit (Dowsett & Livesey, 2000; Fisher & Happé, 2005; Klingberg et al., 2005; Klingberg et al., 2002b; Kloo & Perner, 2003; Rueda et al., 2005), und es gibt weder Befunde aus Aufgabenwechselstudien, noch hinsichtlich der Modulation des Transfers durch die Art des Trainings. Geht man aber davon aus, dass das Aufgabenwechseltraining tatsächlich exekutive Kontrollprozesse einschließlich der Inhibitionskontrolle fördert, dann sollte weiter Transfer zur Stroop-Aufgabe (d.h. die Reduktion des Stroop-Interferenzeffektes vom Prätest zum Posttest) nach dem Aufgabenwechseltraining größer sein als nach dem Einzelaufgabentraining. Gleiches gilt für die Arbeitsgedächtnismaße: Verbessert das Aufgabenwechseltraining

auch Kontrollprozesse auf der Ebene der Aufgabenaufrechterhaltung, sollte der weite Transfer (d.h. eine Verbesserung der Leistung vom Prätest zum Posttest) nach dem Aufgabenwechseltraining größer sein als nach dem Einzelaufgabentraining.

Im Hinblick auf den weiten Transfer zu einem anderen Aufgabenbereich weiß man, dass es einen engen Zusammenhang zwischen exekutiven Funktionen und fluider Intelligenz gibt (Überblicke bieten Kray & Lindenberger, 2007; Lindenberger & Kray, 2005). Daher wird vermutet, dass weiter Transfer (d.h. eine Leistungsverbesserung vom Prätest zum Posttest) nach dem Aufgabenwechseltraining größer ist als nach dem Einzelaufgabentraining. Da Transfereffekte üblicherweise geringer ausfallen, je unähnlicher die Transferaufgabe der Trainingsaufgabe ist (vgl. Klauer, 2001), wird eine entsprechend geringere Modulation des Transfers durch die Art des Trainings beim weiten in Vergleich zum nahen Transfer erwartet.

Unter der Annahme, dass das Aufgabenwechseltraining primär exekutive Kontrollprozesse beansprucht, wird weiterhin angenommen, dass es keinen weiten Transfer zu den Kontrollmaßen geben sollte, die nicht auf exekutiver Kontrolle beruhen (verbale Geschwindigkeit, perzeptuelle Verarbeitungsgeschwindigkeit, semantisches Wissen), d.h. es sollte keinen Unterschied zwischen den Trainingsgruppen hinsichtlich der Prätest-Posttest Verbesserung in den Kontrollmaßen geben.

Ergebnisse und Diskussion

Die Ergebnisse der vorliegenden Studie erbrachten eine ganze Reihe wichtiger neuer Befunde, die in diesem Abschnitt entlang der Hypothesenstruktur erläutert und diskutiert werden. Die Analyse der Trainingsdaten zeigt, dass tatsächlich nicht nur jüngere und ältere Erwachsene ihre spezifischen Wechselkosten von der ersten zur letzten Trainingssitzung reduzieren konnten (vgl. Bherer et al., 2005; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear, et al., 2002), sondern dass dieser Befund auch auf Kinder erweitert werden konnte (siehe Abbildung 13). Spezifische Wechselkosten in allen Altersgruppen waren generell geringer in den Trainingsgruppen, die die verbale Selbstinstruktion ausführten, als in der Gruppe, die den Aufgabenwechsel ohne Verbalisierung ausführte. Dieser Befund zeigt, dass verbale Prozesse nicht nur die Aufgabenaufrechterhaltung und –selektion unterstützen können (Emerson & Miyake, 2003; Kray et al., im Druck; Miyake et al., 2004; Saeki & Saito, 2004), sondern auch die Fähigkeit zum flexiblen Aufgabenwechsel. Betrachtet man allerdings die Trainingsgewinne, also die Reduktion der spezifischen Kosten vom Prätest zum Posttest, findet man in keiner der Altersgruppen einen Einfluss der Verbalisierung und des Feedbacks, dafür aber einen Reduktion der Trainingsgewinne in der Variabilitäts-Gruppe. Dieses Ergebnis passt gut zu früheren Studien, die berichtet haben, dass variables Training das Erlernen einer Tätigkeit oder Fähigkeit verlangsamen kann (z.B., Sanders et al., 2002; Überblicke bieten Rosenbaum et al., 2001: Schmidt & Bjork, 1992).

Das Hauptziel der vorliegenden Arbeit war jedoch die Untersuchung von Transfereffekten. Tatsächlich zeigte die Analyse der Prätest und Posttest-Daten substantiellen nahen Transfer des Aufgabenwechseltrainings zu einer strukturell ähnlichen, ungeübten Wechselaufgabe in allen drei Altersgruppen; d.h. nach dem Aufgabenwechseltraining war die Reduktion der generellen und spezifischen Wechselkosten vom Prätest zum Posttest größer als nach dem Einzelaufgabentraining (siehe Abbildung 14). Hinsichtlich der Erwachsenen konnten somit frühere Befunde repliziert (Bherer et al., 2005; Minear, 2004; Minear et al., 2002), und darüber hinaus auch auf Kinder erweitert werden. Die stärkere Reduktion der Kosten nach dem Aufgabenwechseltraining in Vergleich zum Einzelaufgabentraining ist aus theoretischer Perspektive insofern bedeutsam, als sie darauf hinweist, dass die Trainierbarkeit und Transferierbarkeit von Aufgabenwechselfähigkeiten nicht alleine auf einer Automatisierung der Einzelaufgabenkomponenten beruht (vgl. Kramer, Larish, et al., 1999), sondern dass während des Aufgabenwechseltrainings generalisierbare exekutive Fähigkeiten erworben wurden.

Entwicklungspsychologisch besonders interessant ist, dass der Transfer auf Basis der generellen Kosten für Kinder und ältere Erwachsene besonders ausgeprägt war. D.h. die Altersgruppen, die üblicherweise die größten Defizite bezüglich der Aufgabenaufrechterhaltung und –selektion aufweisen (z.B. Cepeda et al., 2001; Kray et al., im Druck; Kray et al., 2004; Reimers & Maylor, 2005), zeigen auch die umfangreichsten Transfereffekte, was auf kompensatorische Effekte des Trainings hinweist und zweifellos wichtige Konsequenzen für die Anwendung von Trainingsprogrammen im klinischen und pädagogischen Kontext hat.

Darüber hinaus war es Ziel der vorliegenden Studie, Altersunterschiede in der Modulierbarkeit des nahen Transfers durch verbales Selbstinstruktionstraining, Feedback hinsichtlich der verbalen Strategie und durch Trainingsvariabilität zu untersuchen. Entgegen der ursprünglichen Erwartungen wurde die Höhe des nahen Transfers weder auf Ebene der generellen noch auf Ebene der spezifischen Wechselkosten durch das Verbalisierungstraining moduliert. Für dieses unerwartete Ergebnis gibt es mindestens zwei wahrscheinliche Erklärungsmöglichkeiten: Einerseits könnte man annehmen, dass die Trainingsgruppe, die den Aufgabenwechsel ohne die verbale Strategie trainiert hat, intern eine ähnliche verbale Strategie benutzte wie die Gruppe, die während des Trainings laut verbalisiert hat, sodass man in Posttest hinsichtlich der Transferleistung keinen Unterschied zwischen diesen Gruppen findet. Andererseits gibt es Befunde, die darauf hindeuten, dass die Ähnlichkeit zwischen Trainings- und Transfersituation eine wichtige Voraussetzung für die Transferierbarkeit trainierter Strategien ist (vgl. Klauer, 2001). Entsprechend könnte man vermuten, dass der Transfer der Leistungsverbesserung durch die Verbalisierung (d.h. eine stärkere Prätest-Posttest Reduktion der Wechselkosten in der Verbalisierungsgruppe im Vergleich zu der Gruppe, die nicht verbalisiert hat) eher stattfinden würde, wenn die

Probanden nicht nur während des Trainings verbalisieren würden, sondern auch im Posttest. In der Tat zeigt eine Nachfolgestudie (Karbach & Kray, in Vorbereitung), dass ältere Erwachsene, die sowohl im Aufgabenwechsel, als auch in der Nutzung der verbalen Selbstinstruktionsstrategie trainiert wurden, auf Basis beider Kostenmaße höheren Transfer zeigen, wenn sie die verbale Strategie auch im Posttest anwenden dürfen. Dieses Ergebnis ist konsistent mit Befunden von Healy, Wohldmann, Parker und Bourne (2005), die annehmen, dass die Trainingsaufgabe und die verbale Strategie während des Trainings in eine einzige, komplexere Aufgabe integriert werden und Transfer nur dann stattfindet, wenn die kognitiven Operationen, die während des Trainings erlernt wurden, in ähnlicher Weise im Posttest angewendet werden können.

Die vorliegende Studie enthielt allerdings noch eine weitere Manipulation, die dazu dienen sollte, vor allem bei Kindern den Transfer der verbalen Strategie zu fördern: In einer Trainingsgruppe erhielten die Probanden explizites Feedback, welches die Nützlichkeit der Verbalisierung betonen sollte (vgl. Kennedy & Miller, 1976; Ringel & Springer, 1980). Entgegen den Erwartungen hatte das Feedback aber keinen Einfluss auf das Ausmaß des Transfers, was vermutlich damit zusammenhängt, wie die Rückmeldung in der vorliegenden Studie operationalisiert wurde: Im Gegensatz zu anderen Untersuchungen, in denen oftmals sehr intensiv, visuell und kontinuierlich Rückmeldung gegeben wurde (z.B., Bherer et al., 2005; Kramer, Larish et al., 1999; Kramer et al., 1995), war das Feedback in der vorliegenden Studie auf gelegentliche verbale Informationen durch den Versuchsleiter beschränkt.

Differentielle Transfereffekte finden sich allerdings für die Gruppe, die variabel trainiert wurde. Die Notwendigkeit, sich in jeder Sitzung an neue Aufgabenanforderungen anzupassen, führte bei Kindern zu einer Reduktion, und bei Erwachsenen zu einer Steigerung der Transferleistung auf Ebene der generellen Wechselkosten (siehe Abbildung 14). Hinsichtlich der Erwachsenen ist dieser Befund konsistent mit Ergebnissen basierend auf anderen Paradigmen (vgl. Kramer et al., 1995) und deutet darauf hin, dass das variable Training die

Probanden optimal auf die veränderten Aufgabenanforderungen im Posttest vorbereitet (siehe Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Die Ergebnisse für die Kinder legen aber vielmehr nahe, dass die erhöhte kognitive Belastung in der variablen Trainingsbedingung dazu führte, dass nicht mehr genug Verarbeitungskapazität zu Verfügung stand, um die im Training eingeübten Fähigkeiten zu implementieren und eine kognitive Repräsentation der Aufgabenstruktur aufzubauen (vgl. van Merriënboer, Kester & Paas, 2006). Diese kognitive Belastungshypothese („cognitive load theory“) wurde in Bereich der pädagogischen Psychologie intensiv untersucht (Brünken, Plass & Leutner, 2003; Sweller, 1999; Sweller, van Merriënboer & Paas, 1998; Wallen, Plaas & Brünken, 2005). Dabei wird angenommen, dass die kognitive Kapazität eines Individuums bei zu hoher kognitiver Belastung überschritten werden kann, und sich dann die Lernleistung dieser Person entsprechend verschlechtert. Da Kinder im Vergleich zu Erwachsenen über eine eingeschränkte Arbeitsgedächtniskapazität verfügen (einen Überblick bietet Hitch, 2006), ist deren kognitive Kapazität schneller überschritten und somit die Transferleistung eher beeinträchtigt als bei Erwachsenen.

Zusammenfassend kann man also festhalten, dass die vorliegende Studie mehrere wichtige neue Befunde hinsichtlich der nahen Transferierbarkeit von Aufgabenwechseltraining und deren Modulation durch die Art des Trainings erbracht hat. Es konnte naher Transfer sowohl auf der Eben der generellen als auch der spezifischen Wechselkosten nachgewiesen werden, d.h. Probanden über einen weiten Altersbereich hinweg sind in der Lage, während des Aufgabenwechseltrainings sowohl eine generalisierbare Fähigkeit zur Aufgabenaufrechterhaltung und –selektion als auch zum flexiblen Wechseln zwischen zwei Aufgaben zu erwerben. Dabei hat das Training gewisse kompensatorische Effekte, da die Transfergewinne bezüglich der generellen Kosten für Kinder und ältere Erwachsene besonders hoch ausfallen. Außerdem scheint die „optimale“ Art des Trainings mit dem Alter zu variieren: Während Kinder die erlernten Fähigkeiten am besten generalisieren können, wenn sie die gleichen Aufgaben immer wieder intensiv üben, profitieren Erwachsene am meisten, wenn sie sich in jeder Sitzung an neue Aufgabenanforderungen anpassen müssen. Diese Ergebnisse haben ganz offensichtlich wichtige Auswirkungen auf die Anwendung von Trainingsprogrammen im klinischen und pädagogischen Kontext. Diese Implikationen werden im Anschluss an die Diskussion der weiten Transfereffekte kurz diskutiert.

Die vielleicht erstaunlichsten Effekte der vorliegenden Studie betreffen den weiten Transfer des Aufgabenwechseltrainings. Um Transfer zu anderen „exekutiven" Aufgaben zu untersuchen, enthielt die kognitive Testbatterie im Prätest und Posttest ebenfalls Maße der Inhibitionskontrolle (Stroop-Aufgabe) und des verbalen und räumlich visuellen Arbeitsgedächtnisses. In Übereinstimmung mit den Hypothesen zeigten die Ergebnisse für die Stroop-Aufgabe nach dem Aufgabenwechseltraining (aber nicht nach dem Einzelaufgabentraining) in allen Altersgruppen eine Reduktion der Interferenzeffekte vom Prätest zum Posttest, d.h. es gibt weiten Transfer vom Aufgabenwechseltraining zur Inhibitionskontrolle in der Stroop-Aufgabe (siehe Abbildung 17). Ähnliche Ergebnisse findet man für den weiten Transfer zum verbalen und räumlich-visuellen Arbeitsgedächtnis: Die Leistungssteigerung (Anzahl korrekter Antworten) vom Prätest zum Posttest war in allen Altersgruppen nach dem Aufgabenwechseltraining stärker ausgeprägt als nach dem Einzelaufgabentraining, d.h. es konnte auch weiter Transfer des Aufgabenwechseltrainings zu beiden Bereichen des Arbeitsgedächtnisses nachgewiesen werden (siehe Abbildungen 18 und 19).

Schließlich wurde weiter Transfer zu einem anderen Aufgabenbereich untersucht, nämlich zu fluider Intelligenz. Im Einklang mit den übrigen Indikatoren für weiten Transfer zeigen die Ergebnisse auch für die fluiden Intelligenzaufgaben nach dem Aufgabenwechseltraining in allen Altersgruppen eine stärkere Leistungsverbesserung vom Prätest zum Posttest als die Ergebnisse nach dem Einzelaufgabentraining (siehe Abbildung 20). Obwohl es für Kinder ähnliche Befunde nach anderen Formen des exekutiven Kontrolltrainings gibt (Klingberg et al., 2005; Klingberg et al., 2002b; Rueda et al, 2005), scheint dieser Befund der erstaunlichste zu sein, besonders unter dem Aspekt, dass Intelligenz als sehr stabiles Maß angesehen wird (z.B. Arbuckle, Maag, Puskar & Chaikelson, 1998; Deary, Whiteman, Starr, Whalley & Fox, 2004). Kann Aufgabenwechseltraining uns also intelligenter machen? Um diese Frage sinnvoll beantworten zu können, sollte man sich noch einmal klarmachen, welche Fähigkeiten in der vorliegenden Studie trainiert und transferiert wurden. Die bisher berichteten Ergebnisse sprechen klar dafür, dass verschiedene Komponenten exekutiver Kontrolle, z.B. die Selektion relevanter Aufgabenziele, die Aufrechterhaltung aufgabenrelevanter Information und die Inhibition aufgabenirrelevanter Information durch das Aufgabenwechseltraining verbessert wurden. In der Literatur findet man aber zahlreiche Hinweise darauf, dass diese exekutiven Fähigkeiten in enger Beziehung zu intellektuellen Fähigkeiten stehen (z.B. Duncan, 1993, 1995; siehe auch Duncan et al., 2000). So haben frühere Studien gezeigt, dass Arbeitsgedächtnis und fluide Intelligenz zusammenhängen (Engle, Tuholski, Laughlin & Conway, 1999) und dass räumlich-visuelle Arbeitsgedächtnisleistungen hoch mit der Leistung in einem prototypischen fluiden Intelligenzmaß, dem Raven Test, korrelieren (Fry & Hale, 1996); beide Befunde wurden in der vorliegenden Studie repliziert (siehe Tabelle 19). Dieser Zusammenhang ist auch auf der neuroanatomischen Ebene nachweisbar, da man z.B. bei der Ausführung von Arbeitsgedächtnisaufgaben und fluiden Intelligenzaufgaben überlappende neuronale Aktivität im präfrontalen Cortex und im Parietallappen findet (Gray, Chabris & Braver, 2003). Darüber hinaus sind identische Areale im superioren präfrontalen und parietalen Kortex mit der Entwicklung räumlich-visueller Arbeitsgedächtnisfähigkeiten und der Leistung in der Stroop-Aufgabe assoziiert (Adleman, Menon & Blasey, 2002; Klingberg, Forssberg & Westerberg, 2002a). Insgesamt ist es wahrscheinlich, dass diese Gemeinsamkeiten auf behavioraler und neuronaler Ebene erklären, warum ein Training, welches zur Stroop-Aufgabe und zum Arbeitsgedächtnis transferiert, auch zu fluider Intelligenz transferiert.

Bemerkenswert ist schließlich, dass für den weiten Transfer keinerlei Unterschiede zwischen den Altersgruppen und den verschiedenen Arten des Aufgabenwechseltrainings gefunden wurden. Dieses Befundmuster mag damit zusammenhängen, dass die Effektstärken für den weiten Transfer zwar hoch, aber generell geringer als für den nahen Transfer waren (vgl. Klauer, 2001; Salomon & Perkins, 1989). Je kleiner ein Effekt, desto schwerer ist er in kleinen Stichproben nachweisbar (für eine Metaanalyse, siehe Lipsey & Wilson, 1993). Ungekehrt bedeutet dies, dass mögliche Alters- oder Gruppenunterschiede in der vorliegenden Studie größer sein müssten, um Signifikanz zu erreichen, oder dass die Stichprobe wesentlich größer sein müsste um solche Effekte nachweisen zu können.

Zusammenfassend kann festgehalten werden, dass das Aufgabenwechseltraining im Gegensatz zum Einzelaufgabentraining zu substantiellen weiten Transfereffekten hinsichtlich inhibitorischer Fähigkeiten, verbaler und räumlich-visueller Arbeitsgedächtnisleistung sowie fluider Intelligenz führte. Während viele Trainingsprogramme in früheren Studien zwar zu deutlichen Leistungssteigerungen in der Trainingsaufgabe führten, war der Transfer zu anderen Aufgaben oft sehr eingeschränkt, was darauf hinweist, dass die trainierten Prozesse sehr aufgaben- und domänenspezifisch waren (z.B. Ball et al., 2002; Jennings, Webster, Kleykamp & Dagenbach, 2005). Im Gegensatz dazu zeigt die vorliegende Studie, dass relativ weiter Transfer über einen weiten Altersbereich hinweg erreicht werden kann, und zwar sogar zu Aufgaben, die der Trainingsaufgabe strukturell sehr unähnlich sind.

Obwohl viele Trainingsstudien die Leistung der Probanden auf Gruppenebene verbessern konnten, sind die individuellen Unterschiede oft sehr groß (siehe Bissig & Lustig, 2007). Aus diesem Grund wurde in dieser Studie auch der Frage nachgegangen, ob sich individuelle Trainings- und Transfergewinne vorhersagen lassen. Die Ergebnisse zeigen deutlich, dass unabhängig von ihrem Alter oder der Art des Aufgabenwechseltrainings jene Probanden die umfangreichsten Trainings- und Transfergewinne zeigten, die vor dem Training die schlechtesten Leistungen aufwiesen. Diese Ergebnisse sprechen klar für kompensatorische Effekte des Trainings und bilden damit einen Gegensatz zu Studien, die geringeren Trainingsgewinne für die leistungsmäßig schwächsten Individuen berichten (z.B. P. B. Baltes & Kliegl, 1992; Verhaeghen et al., 1992; Yesavage et al., 1990; siehe aber z.B. Cepeda et al., 2001; Edwards et al., 2005; Kray et al., im Druck; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002).

Die nahen und weiten Transfereffekte der vorliegenden Studie sind zweifellos besonders relevant für die Anwendung von Trainingsprogrammen in den verschiedensten Kontexten, z.B. für die Therapie von Kindern mit Aufmerksamkeitsdefizit und Hyperaktivitätssyndrom, die üblicherweise an deutlichen Schwächen im Bereich der Inhibitionskontrolle und Arbeitsgedächtniskapazität leiden. Für andere Patientengruppen mit exekutiven Störungen, z.B. nach Hirnverletzungen oder zerebralem Insult, wäre es darüber hinaus besonders wichtig zu untersuchen, ob der weite Transfer sich auch auf Tätigkeiten des alltäglichen Lebens erstreckt.

Insgesamt ist die vorliegende Studie die erste Untersuchung, die sowohl nahen Transfer des Aufgabenwechseltrainings zu einer strukturell ähnlichen Aufgabe, als auch weiten Transfer zu strukturell unähnlichen exekutiven Aufgaben und einem anderen Aufgabenbereich über eine weite Altersspanne hinweg zeigen konnte. Ihre Ergebnisse stehen damit im Gegensatz zu der Annahme, dass die Transferierbarkeit kognitiven Trainings generell eingeschränkt ist (z.B. Detterman, 1993; Derwinger et al., 2003; Roth-van der Werf et al., 2002; eine Überblick bieten Barnett & Ceci, 2002) und erweitern frühere Befunde, die zeigen konnten, dass sowohl naher als auch weiter Transfer exekutiven Kontrolltrainings in verschiedenen Altersgruppen möglich sind (vlg. Bherer et al., 2005; Dowsett & Livesey, 2000; Fisher & Happé, 2005; Klingberg et al., 2005; Klingberg et al., 2002b; Kramer et al., 1995; Kramer, Larish, et al., 1999; Minear, 2004; Minear et al., 2002; Rueda et al., 2005). Des Weiteren weisen die Ergebnisse dieser Studie auf beträchtliche kognitive Plastizität auch und besonders bei Kindern und älteren Menschen hin (vgl. Jones et al., 2006; Kramer & Willis,

2002) und sprechen somit gegen frühere Studien, die eingeschränkte Plastizität bei älteren im Vergleich zu jüngeren Erwachsenen berichten (z.B. P. B. Baltes & Kliegl, 1992; Lindenberger & P. B. Baltes, 1995).

Die Tatsache, dass Transfer nach dem Aufgabenwechseltraining, aber nicht nach dem Einzelaufgabentraining gefunden wurde, spricht dafür, dass während des Trainings eine generalisierbare exekutive Kontrollfähigkeit erworben wurde (vgl. Kramer, Larish et al., 1999). Diese Schlussfolgerung erscheint durchaus plausibel, wenn man bedenkt, dass das Aufgabenwechsel-Paradigma in dieser Untersuchung mehrere exekutive Kontrollprozesse beansprucht hat: Da keine externen Hinweisreize zu Verfügung standen, waren die Anforderungen zur Aufrechterhaltung des Aufgabenziels hoch; die Verwendung ambiger Stimuli (d.h. Stimuli, deren Merkmale für beide Aufgaben relevant waren) erforderte ständige Interferenzkontrolle; und das Wechseln zwischen zwei Aufgaben stellte hohe Ansprüche an die Fähigkeit zur Aufgabenselektion. Vor diesem Hintergrund scheint es weniger überraschend, dass das Aufgabenwechseltraining zu einem relativ breiten Transfer zu anderen exekutiven Aufgaben und anderen Aufgabenbereichen geführt hat, und somit geeignet zu sein scheint, gleich mehrere exekutive Fähigkeiten zu fördern. Zusammen mit dem Befund, dass das kompensatorische Effekte hinsichtlich exekutiver Kontrolldefizite hatte, liegt das Potential für die Anwendung im klinischen und pädagogischen Kontext auf der Hand.

Anhand der Befunde dieser Untersuchung können die Fragen, die in der Einleitung gestellt wurden, größtenteils beantwortet werden: Wie effektiv ist kognitives Training? Und was genau macht eine bestimmt Art von Training wirkungsvoll? Die vorliegende Studie hat eindrucksvoll gezeigt, dass kognitives Training in der Tat sehr wirkungsvoll sein kann, zumindest dann, wenn relevante Fähigkeiten trainiert werden. Das beste Beispiel ist der Vergleich des Aufgabenwechseltrainings, das hohe Anforderungen an exekutive Kontrolle gestellt hat, mit dem Einzelaufgabentraining, das nur geringe exekutive Kontrollanforderungen hatte: Obwohl beide Arten des Trainings sich hinsichtlich der Dauer und Intensität nicht unterschieden haben, gab es bedeutende Unterschiede hinsichtlich der Effektivität.

Welche kognitiven Fähigkeiten kann man durch Training verbessern? Diese Untersuchung zeigt, dass zumindest mit dieser Art des Aufgabenwechseltrainings in verschiedenen Altersgruppen eine weite Spanne von kognitiven Prozessen verbessert werden kann, z.B. die Inhibitionskontrolle, die Arbeitsgedächtniskapazität und die Leistung in fluiden Intelligenzaufgaben. Da viele vorherige Studien aber keinen weiten Transfer nachweisen konnten, scheint die Art des Trainings auch hier entscheidend zu sein. Bezüglich exekutiver Kontrolle deuten die vorliegenden Befunde an, dass ein Training dann besonders effektiv ist, wenn es möglichst viele exekutive Fähigkeiten fordert.

Wer von uns profitiert am meisten von welcher Art des Trainings? Die vorliegenden Daten zeigen eindeutig, dass die größten Trainings- und Transfergewinne bei jenen Probanden auftraten, die vor dem Training relativ schlecht abschnitten. D.h., genau diejenigen Individuen, die den höchsten Trainingsbedarf hatten, profitierten auch am meisten. Dieses Ergebnis zeigt deutlich, dass exekutives Kontrolltraining ein effektives Mittel zur Kompensation von exekutiven Defiziten sein kann.

I Theoretical Part

1. Introduction

"Cognitive training", "mental exercising", and "brain jogging" – these and other labels refer to a variety of training concepts supposed to somehow improve one's cognitive performance. The trainings are usually available on the Internet, as a computer program or as a paper-pencil version. Some institutions, such as the adult education center, even offer group trainings. Over the last years, the variety of theoretical concepts and commercial products along with their sales volumes have been constantly increasing. However, considering the large variety of training concepts, one cannot help but wonder: How effective is cognitive training? What exactly makes a given training useful? Which cognitive abilities can be improved? And which individuals benefit most from which type of training?

In the clinical context, training programs have become a frequently applied type of intervention in populations with cognitive deficits associated with a wide range of conditions, such as attention-deficit and hyperactivity disorder (ADHD), schizophrenia, head trauma, or dementia. It has been shown that training can lead to significant changes in behavior and brain function in different age groups (for reviews, see Bissig & Lustig, 2007; Jones et al., 2006). Thus, cognitive training provides the opportunity to study age differences in cognitive plasticity, that is, one's ability to improve performance after training. Prior evidence suggests that cognitive plasticity is considerable across the lifespan (e.g., Brehmer, Li, Müller, von Örtzen, & Lindenberger, 2007; Cepeda, Kramer, & Gonzales De Sather, 2001; Derwinger, Stigsdotter Neely, & Persson, 2003; Kramer, Larish, & Strayer, 1995; Kray, Eber, & Karbach, in press; Kray & Lindenberger, 2000; Minear, Shah, & Park, 2002; Schaie & Willis, 1986; Verhaeghen, Marcoen, & Goossens, 1992; for reviews, see Bissig & Lustig, 2007; Jones et al., 2006; Kramer & Willis, 2002), but seems to be limited in very old age (Singer, Lindenberger, & P.B. Baltes, 2003). One aspect receiving more and more attention over the last years is the transferability of training-related benefits to new, unfamiliar situations. This issue seems to be of particular importance for the application of training programs in the clinical and educational context. However, despite the long tradition of training and transfer research, there is still no consensus whether and to which extent transfer can be achieved (for a review, see Barnett & Ceci, 2002). Previous research indicated that the transferability of cognitive training seemed to be limited. Positive transfer was most often confined to near transfer, that is, performance in new, non-trained tasks only improved when these tasks were structurally similar to the training tasks (near transfer), but not if they are structurally dissimilar (far transfer). This suggests that the training primarily tapped task-specific components that could not be transferred to new, structurally dissimilar tasks (e.g. Derwinger et al., 2003; Klauer, 1989a, 1989b; Roth-van der Werf, Resing, & Slenders, 2002). However, a number of recent studies suggest that a larger generalization of training-related benefits can be achieved in different age groups (e.g., Bherer et al., 2005; Dowsett & Livesey, 2000; Klingberg, Forssberg, & Westerberg, 2002b; Klingberg et al., 2005; Kramer et al., 1995; Kramer, Larish, Weber, & Bardell, 1999; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005).

Most of the previous work regarding the transfer of training has focused on memory and inductive reasoning (for a review, see Klauer, 2001), but lately a number of studies also has investigated executive functions (e.g., Bherer et al., 2005; Dowsett & Livesey, 2000; Kramer et al. 1995; Kramer, Larish, et al., 1999; Minear, 2004; Minear et al., 2002; Rueda et al., 2005). Executive functions are assumed to be higher-level control processes necessary for the behavioral adaptation to environmental changes and relevant task demands, including action selection and action control. They refer to abilities such as the preparation and maintenance of upcoming tasks, the ability to flexibly switch between them, and the ability to resist to interference (e.g., Duncan, 1995; Kluwe, 1997; Norman & Shallice, 1986; Roberts &

Pennington, 1996; Smith & Jonides, 1999). Impairments in different executive control components are associated with a number of neuropsychiatric disorders, including depression, schizophrenia, or attention-deficit and hyperactivity disorder (for a review, see Royall et al., 2002), but similar impairments are also found in children and older adults (e.g., Bedard et al., 2002; Cepeda et al., 2001; Comalli, Wapner, & Werner, 1962; Kray et al., in press; Kray, Eber, & Lindenberger, 2004; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). For instance, it has been shown that the cost of switching between two tasks is smaller in younger adults than in children (e.g., Kray et al., 2004; Crone, Ridderinkhof, Worm, Somsen, & Van Der Molen, 2004) and older adults (e.g., Mayr, 2001; Meiran, Gotler, & Perlman, 2001). Although previous research indicated that the executive control deficits in these age groups can be reduced by training (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000), little is known about the extent to which these training-related benefits can be transferred to new task situations. Therefore, the aim of the present study was to investigate age differences in the near and far transfer of executive control training as well as the modulation of transfer by the type of training. In order to investigate transfer, a pretest - training - posttest design including four session of intensive task-switching training was applied to children (8 - 9 years of age), younger adults (18 – 27 years of age) and older adults (62 – 76 years of age). The influence of the training type was examined by means of five different training conditions.

This thesis is divided into a theoretical and an empirical part. The theoretical part first introduces the concept of executive functions and provides an overview of the most important theoretical concepts, the task-switching paradigm applied in this study, and empirical findings regarding lifespan changes in task-switching abilities. Afterwards, theoretical assumptions and empirical evidence with respect to cognitive training are reviewed, followed by a chapter dedicated to the transferability of training benefits across a wide range of ages. Based on this review of the relevant literature, the research hypotheses are developed. The empirical part starts with the introduction of the design and the measures applied in this study, followed by the comprehensive presentation of the results, structured along the research hypotheses, and closes with the extensive discussion of these findings in the light of the relevant literature.

2. Review of the Literature

The review of the literature is divided into three major parts. In the first part, the concept of executive functions is introduced and important theoretical aspects and empirical findings are illustrated, including age differences in executive control. The second part is dedicated to the modulation of these age differences by means of cognitive training. This section includes theoretical assumptions and empirical evidence with respect to the effects of cognitive interventions on age differences in executive control functioning. Finally, the third part presents theoretical and empirical aspects regarding the transferability of these training-induced improvements to new, unfamiliar task-situations. In addition, it is discussed how transfer can be promoted in different age groups. The theoretical part closes with an extensive summary of the findings most important for the present study and the presentation of the research predictions arising from these previous findings.

Executive Control

The first chapter of the theoretical part, focusing on executive functions, is subdivided into two sections. The first one introduces important theoretical models and frameworks, while the second one addresses the measurement of executive control, including the task-switching paradigm applied in the present study, and reviews empirical evidence for lifespan changes in executive control with emphasis on the task-switching literature.

Theoretical Concepts of Executive Functions

Definition of Executive Functions

In everyday live, we often are in situations requiring the selection of one action out of many possible action alternatives. Just imagine, you are driving a car while talking to a fellow passenger and keeping an eye on the navigation system. In scenarios like these, interference needs to be controlled and goal-directed actions have to be maintained, coordinated, and selected appropriately in order to prevent an accident. The cognitive processes responsible for controlling these functions are referred to as “executive control functions”.

Even though a lot of research has focused on executive functions, a generally accepted definition does not exist. However, most investigators agree when it comes to the main characteristics of executive functions: They refer to higher-level processes organizing lower-level processes in order to regulate behavioral activity. Thus, executive functioning is effective when it permits individuals to optimally adapt to continuous changes in the environment (see Baddeley, 1986, 2000; Duncan, 1995; Kluwe, 1997; Logan, 2000; Monsell, 2003; Norman & Shallice, 1986; Roberts & Pennington, 1996; Smith & Jonides, 1999). In line with this concept, Duncan (1995) defined executive control as the ability of the cognitive system to effectively organize its own processing. In addition, he suggested that executive functions are closely linked to intellectual abilities (in the sense of Spearman’s “g”; Spearman, 1927). This latter aspect will be extensively discussed below (see p. 34).

In order to provide a taxonomy of executive functions, a summary of processes associated with this concept has been put forward by Smith and Jonides (1999), including (1) attention and inhibition, (2) task management, (3) planning of task sequences, (4) task monitoring, and (5) coding of working memory representations. According to the authors, attention and inhibition as well as task management appear to be the most elementary and most interrelated processes. However, it is still an open question how executive control is organized in the cognitive system. Therefore, the most important theoretical views regarding the architecture of executive control are briefly reviewed in the next paragraph.

Models of Executive Functions

Mostly within the 1980ies and 1990ies, various researchers have proposed theoretical models of executive control. The majority of these traditional models suggested a unitary control system, such as the “central executive” in Baddeley’s (1986, 2000) working memory model or the “supervisory attentional system” in the model proposed by Norman and Shallice (1986). The latter model, for instance, assumes four components: (1) information processing systems, (2) action and thought schemata, (3) a language system, and (4) a superior control system, the “supervisory attentional system” (SAS). The schemata are supposed to be fixed sequences for motor and mental actions required for daily life activities, coordinated by lower level “contention scheduling” processes. On a higher level, the SAS indirectly controls lower level processes by modulating the activation and inhibition of schemata, while coordinating actions and currently relevant task demands at the same time. Thus, the SAS is particularly engaged in activity if confronted with new information, errors, or new action sequences. Therefore, the Norman and Shallice (1986) model accounts for consciously controlled as well as for automated behavior.

The fact that control failures, such as “utilization behavior”[1] (Lhermitte, 1983; for a review, see Archibald, Mateer, & Kerns, 2001) or “goal neglect”[2] (Duncan, 1993, 1995; Duncan et al., 1996), are typically associated with neurobehavioral disorders in frontal lobe

[1] Patients with this disorder are characterized by deficits in inhibitory control, that is, they reach out for objects in the environment and use them in an automatic manner. For instance, the sight of sewing materials will induce sewing, or a plate of food will induce eating.
[2] “In goal neglect, participants can say exactly what it is they should do, yet show no apparent attempt to do it. […] For example, the patient might be asked to watch for a light and to raise one hand when it appears. When the light is switched on, the patient might say “I should lift up my hand”, yet make no attempt to do so” (Duncan, Emslie, Williams, Johnson, & Freer, 1996, p. 131).

patients, has been considered evidence for the assumption of one central executive control mechanism for quite some time. However, despite these findings, the concept of a central control system is seriously doubted these days. Instead, it is widely accepted that executive control is not a unitary construct, but consists of separate control components. Evidence for this view comes from different psychometric studies investigating the organization of executive control in healthy participants (Fisk & Sharp, 2004; Huizinga, Dolan, & Van der Molen, 2006; Miyake et al., 2000). Miyake and colleagues (2000), for instance, used a latent variable approach to examine the unity or diversity of executive functions in a sample of young adults. They included three measures for each of three executive control functions (shifting, updating, and inhibition) in their analysis to examine whether these control functions are indeed separable. Confirmatory factor analysis (CFA) showed that a three-factor model in which the three factors were moderately correlated fitted the data best, supporting both the unity and diversity of executive functioning. In contrast, a three-factor model that did not allow the three latent factors to be correlated (i.e., testing the assumption of three fully independent executive control functions) resulted in a significantly worse fit than the full three-factor model, and so did a one-factor model (i.e., testing the assumption of the unity of executive control). Subsequent studies aimed at the extension of these findings to childhood and older age showed that a two-factor model (updating and shifting) fitted best between the ages of 7 and 21 years (Huizinga et al., 2006), and that a four-factor model (updating, shifting, inhibition, and long-term memory) was most adequate for older adults (up to 81 years of age) (Fisk & Sharp, 2004). All together, these studies argue against the existence of one central executive control mechanism.

These results are consistent with data from neuropsychological and neuroimaging research, showing different executive control processes, such as task maintenance, task switching or interference control, to be separable (e.g., Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Crone, Wendelken, Donohue, & Bunge, 2006; Koechlin, Ody, & Kouneiher, 2003; Shallice & Burgess, 1993). Furthermore, experimental data show different components of executive control to be susceptible to experimental manipulations (e.g., Bedard et al., 2002; Meiran, 2000) as well as individual differences in several aspects of executive control to be highly intercorrelated, but not unitary (Kray & Lindenberger, 2000; Miyake & Shah, 1999). This latter aspect is discussed in detail when age-related differences in task-switching abilities are reviewed below (see p. 45). First, the development of executive control is illustrated within the next section.

The Development of Executive Functions and Their Relationship to Intellectual Abilities

Over the last years, an increasing amount of research has focused on the development of executive control across the lifespan. This work is particularly important because executive functions are closely related to other cognitive functions, such as intellectual abilities (e.g., Duncan, 1993, 1995). Within this section, the relationship between executive and intellectual abilities is illustrated with reference to their lifespan development. One well-established model with respect to intellectual development is the "two-component model of lifespan intellectual development" (P. B. Baltes, 1990, 1993). This model is presented in the following section, along with theoretical accounts proposed to explain age differences in intellectual abilities, namely resource-oriented and process-oriented theories. Both are suggesting that one construct of particular importance for the explanation of age differences in intellectual abilities seems to be executive control.

The Two-Component Model of Lifespan Intellectual Development. This model proposed by P. B. Baltes (e.g., P. B. Baltes 1990, 1993; see also P. B. Baltes, Lindenberger, & Staudinger, 1998; P. B. Baltes, Staudinger, & Lindenberger, 1999; Lindenberger, 2000) allows the prediction of age-related changes with respect to different domains of intellectual abilities. Based on the model of fluid and crystallized intelligence (Cattell, 1971; Horn, 1970), the authors generally assume two components of intellectual development across the lifespan:

The mechanics and the pragmatics of cognition. The mechanics of cognition refer to basic components of the cognitive system, such as the speed, accuracy, and coordination as well as the classification of elementary processes (cf. P. B. Baltes, 1993). It is assumed that they are influenced by biological factors and invested into the development of the pragmatics of cognition. While the mechanics of cognition strongly increase during childhood and adolescence, they already start declining in middle adulthood, leading to a definite decrement of mechanic abilities in old age (see Figure 1).

The pragmatics of cognition, in contrast, refer to knowledge mediated through culture-based socialization across the lifespan, such as verbal knowledge and wisdom-related knowledge. P. B. Baltes (1990) characterized the pragmatics of cognition as context- and knowledge-related applications of the mechanics of cognition. In line with this concept, stability or even growth is found for the development of pragmatics across the lifespan (see Figure 1).

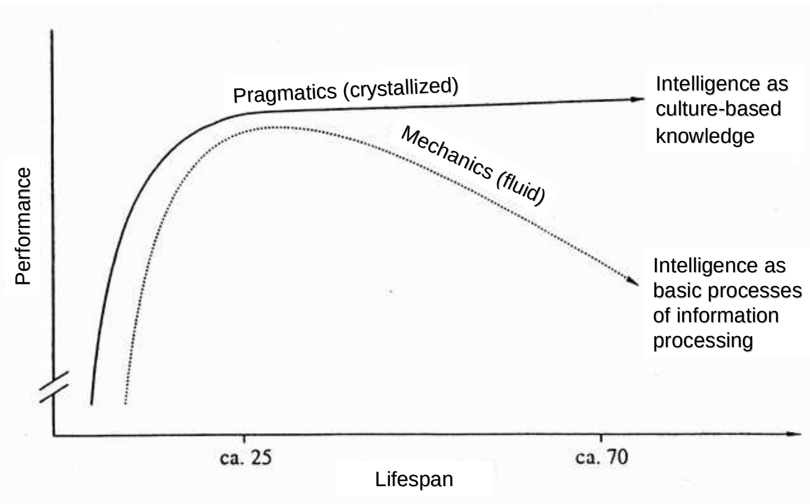

Figure 1: The two-component model of intellectual development. Adapted from P. B. Baltes, Staudinger, & Lindenberger (1999).

Empirical evidence indicates that age-related changes in executive functioning are closely linked to the increase in intellectual functioning during childhood and to its decline in old age (for reviews, see Kray & Lindenberger, 2007; Lindenberger & Kray, 2005). In fact, it has been shown that some measures of executive functions are highly correlated with measures of the mechanics of cognition, such as reasoning or perceptual speed (Kray & Lindenberger, 2000). Consistent with this finding, Duncan (1995) reported the phenomenon of “goal neglect” in frontal-lobe patients as well as in individuals with lower intelligence (e.g., older compared to younger adults), and Schonfield (1982) claimed that internal attention switches are associated with higher cognitive processes, particularly with fluid intelligence. However, the relationship between intellectual abilities and executive functions becomes more evident when theories with respect to the determinants of age differences in intellectual abilities are introduced in the next section.

Determinants of Age Differences in Intellectual Abilities. When it comes to the mechanisms underlying age-related changes in intellectual abilities, two major frameworks have been proposed: Resource-oriented concepts assume a small number of factors underlying age differences across the lifespan, while process-oriented concepts claim that multiple processes are involved.

Within the resource oriented account, three ideas have been put forward in order to explain age-related deficits in executive functioning: (1) The slowing of processing speed, (2) reduced inhibitory control, and (3) impaired working memory resources (for reviews, see Kray & Lindenberger, 2007; Lindenberger & Kray, 2005; Lindenberger, 2000). Salthouse’s (1996) “Processing Speed Hypothesis” assumes that a general slowing factor affecting all mental operations causes age differences in various cognitive abilities. According to this model, performance on cognitive tasks (regardless of their type and content) is slowed down by a constant factor in older adults compared to younger adults. Brinley (1965) showed that this factor typically ranges between 1.5 and 2.0, referred to as “general slowing” (Verhaeghen & Cerella, 2002). However, more recent studies show that general slowing is not adequate as the sole explanation for age differences in cognitive tasks (e.g., Mayr & Kliegl, 1993; for a meta-analysis, see Verhaeghen & Cerella, 2002).

Over the last years, the focus has mainly been on the second and the third approach. Specifically, it is assumed that inhibitory processes play an important role for the explanation of age differences in intellectual abilities. These processes include the ability to control irrelevant information and to focus attention to goal-directed information, that is, key aspects of executive control functioning. Given that inhibitory control increases through childhood and adolescence and declines again in older age (e.g., Comalli et al., 1962; Dempster, 1992; Diamond & Taylor, 1996; Hasher & Zacks, 1988; Lustig, Hasher, & Tonev, 2001), this approach has been used to explain age differences in the performance of various intellectual tasks.

Finally, there are theories attributing developmental changes in intellectual abilities to age-related differences in working memory resources (Band, Ridderinkhof, & Segalowitz, 2002; Roberts & Pennington, 1996). Accordingly, a number of studies showed that working memory is a critical factor in accounting for age differences on a broad range of cognitive tasks (e.g., Cherry & Park, 1993; Morell & Park, 1993; Raz, 2000). However, “…it is certainly possible that no single mechanism will be able to account for all age-related variance on cognitive tasks and that the best estimate of cognitive resource may be a combined measure of sensory function, speed of processing, and working memory” (Park & Payer, 2006, p.134). Consistently, structural equation modeling showed that both speed and working memory are important determinants of higher-order cognition (Park et al., 1996; see also Salthouse, 1991).

In contrast, process-oriented theories focus on neuroscientific and biological explanations for age differences in intellectual abilities, such as developmental changes in the frontal brain areas, which have also been linked to executive control. Specifically, we know that the prefrontal cortex (PFC) is of particular importance for executive functions (for reviews, see Casey, Tottenham, Liston, & Durston, 2005; Hedden & Gabrieli, 2004; West, 1996). The PFC develops slower than other brain areas, reaching maturation not until late adolescence, that is, the frontal lobe is among the last brain regions maturing during childhood and adolescence, and also one of the first deteriorating in old age (e.g., Dempster, 1992; Gogtay et al., 2004; Moscovitch & Winocur, 1995; Sowell et al., 2004). Therefore, age-related changes in the frontal lobe have often been linked to age-related differences in executive control abilities, that is, the immature PFC during childhood and a deteriorated frontal lobe in older age are associated with age deficits in executive and intellectual abilities (e.g., Bunge et al., 2002; Dempster, 1992; Diamond & Taylor, 1996; Duncan, 1995; Durston et al., 2002; Goldman-Rakić, 1987; Prull, Gabrieli, & Bunge, 2000; for reviews, see Casey et al., 2005; Hedden & Gabrieli, 2004; West, 1996). Evidence for this view comes from patients with frontal lobe lesions, typically showing performance deficits in a wide range of interference–sensitive as well as selective attention tasks, such as the Wisconsin Card Sorting Test and the Stroop Test (e.g., Baddeley, 1996; Diamond & Taylor, 1996; Duncan, 1995; Shallice & Burgess, 1993; Smith & Jonides, 1999). On the neurochemical level, changes in the dopamine metabolism have been linked to age differences in executive and intellectual functioning (e.g., Bäckman et al., 2000; Volkrow et al., 2000); however, these changes also seem to be closely related to PFC development (Raz, 2000).

Thus, both resource-oriented and process-oriented accounts suggest a close link between executive control and intellectual abilities, either because one determines the development of the other, or because they rely on similar neuronal structures. It is therefore not surprising that some executive control components and the mechanic component of intellectual abilities seem to have similar developmental trajectories, that is, a marked development from early childhood to adolescence, followed by a continuous decline in older age (e.g., Dempster, 1992; Li et al., 2004; Zelazo, Craik, & Booth, 2004; for a review, see

Craik & Bialystok, 2006). For instance, this u-shaped developmental pattern has been shown for executive control components such as task maintenance and selection (Cepeda et al., 2001; Kray et al., in press; Kray et al., 2004), as well as interference control (Comalli et al., 1962; Dempster, 1992; but see Karbach & Kray, sub.). However, we also know that other components of executive functions, such as the ability to flexibly switch between tasks (e.g., Cepeda et al., 2001; Crone et al., 2004; DeLuca et al., 2003; Karbach & Kray, 2007; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000) or the ability to stop initiated actions (Bedard et al., 2002; Kray, Kipp, & Karbach, sub.; Williams et al., 1999) are less affected by age. This finding, pointing to the multidirectional development of executive control functions, is illustrated in detail on the basis of control processes involved in task switching within the next section (see p. 45).

In sum, age differences in intellectual and executive control abilities are most likely based on general (resources) as well as specific (processes) components. Thus, it seems useful to integrate both aspects (cf. Kliegl, Mayr, & Krampe, 1994) and to consider neuroscientific models and theories (Lindenberger, Li, & Bäckman, 2006).

Measurement of Executive Functions

A variety of paradigms have been used to assess different aspects of executive functions, among them neuropsychological tests, cognitive tasks, and experimental paradigms. Among the frequently used experimental tasks are, for instance, the dual-task paradigm, the psychological refractory paradigm, and the Stroop task. Given that these paradigms are relevant within the context of the present study, they will briefly be introduced.

In dual-task studies, subjects are instructed to perform two simple tasks. Within each trial in a dual-task block, one stimulus for each of these tasks is presented and participants have to respond to both stimuli as fast as possible. These dual-task blocks can be compared to single-task blocks, in which only one of the tasks has to be performed. Performance is typically slower and more error-prone in dual-task blocks than in single-task blocks. The resulting difference in performance is referred to as dual-task cost, representing the ability to maintain and coordinate multiple tasks (e.g., Kramer et al., 1995; Kramer, Larish, et al., 1999).

Dual-task processing has also been investigated by means of the psychological refractory period paradigm (PRP). In this paradigm, two simple tasks are also performed on the same trial. However, the stimulus for task 1 is presented first and followed by the stimulus for task 2 after a variable amount of time. The onset between the stimuli of the two tasks, termed stimulus onset asynchrony (SOA), varies between very short and relatively long intervals. It should be noted that participants are usually instructed to first respond to the stimulus for task 1 and afterwards to the one for task 2. A prototypical finding is that performance in task 2 is impaired when the SOA between the two stimuli is decreased, a finding called the PRP effect (e.g., Maquestiaux, Hartley, & Bertsch, 2004; for a review, see Lien & Proctor, 2002).

The Stroop task (Stroop, 1935), in contrast, is designed to measure inhibitory control. Participants are instructed to read color words, which are either presented in the congruent font color (e.g., “red” in red font), or in an incongruent font color (e.g., “red” in green font). The typical finding is that participants need more time and make more errors when they have to read the incongruent words than when they have to read congruent words (or words that are not semantically related to colors); this effect is referred to as the Stroop interference effect (for an extensive review, see MacLeod, 1991).

Another well-established method to investigate executive control is the task-switching paradigm (for a review, see Monsell, 2003). Given that it was extensively applied in the present study, this paradigm is introduced in detail in the following section, along with the switch cost measures serving as indicators for executive control processes, and theoretical models explaining the origin of these task-switching costs.

The Task-Switching Paradigm and the Operationalization of Task-Switching Costs

About eighty years ago, Jersild (1927) introduced the experimental paradigm that we today refer to as task-switching paradigm. Jersild's idea was to compare the time needed to complete a sequence of trials in which people did or did not have to switch between different tasks on successive trials. In the early the 1990ies, Jersild's paradigm was rediscovered and has been applied and modified extensively (for a review, see Monsell, 2003).

In task-switching experiments, participants usually see successive stimuli on the computer screen, and they are instructed to perform two simple tasks A and B. A typical example for such a two-choice task is to present round and angular stimuli, either being red or green, and to instruct participants to classify the stimuli by shape (task A) and by color (task B). In order to increase executive control demands, stimuli are often ambiguous, that is, they represent features relevant for both tasks (e.g., a red circle).

In order to properly operationalize the task switch, a clear definition of "task" is needed. Using the more specific term "task set", Rogers and Monsell (1995) provided the following specification: "To form an effective intention to perform a particular task, regardless of which of the range of task-relevant stimuli will occur, is to adopt a task set. Familiar task sets, such as naming, can be called up from memory. Novel ones can be specified by instructions or other form of training" (Rogers & Monsell, 1995, p. 207). In experimental designs, task sets are usually induced by instructions according to the tasks at hand (e.g., classifying stimuli by shape or color).

A number of task-switching studies have adopted blocked designs, that is, the experiment consisted of two types of blocks: (1) Sections in which only one task has to be performed separately (A *or* B), referred to as single-task or task-homogenous blocks, and (2) sections requiring participants to switch between both tasks (A *and* B), referred to as mixed-task or task-heterogeneous blocks. In order to indicate which task had to be performed in the next trial during mixed-task blocks, either an external task cue was given ("cue-based switching paradigm"; e.g., Karbach & Kray, 2007; Mayr, 2001; Meiran, 1996) or an alternating task sequence, such as AABBAABB, was applied in mixed-task blocks ("alternating-runs paradigm"; e.g., Kray & Lindenberger, 2000; Rogers & Monsell, 1995). Traditionally, switch costs were calculated as the difference in performance between single-task and mixed-task blocks (e.g., Allport, Styles, & Hsieh, 1994; Jersild, 1927; Kluwe, 1997). In contrast, Rogers and Monsell (1995) assessed switch costs as the difference in performance between switch trials (AB, BA) and nonswitch trials (AA, BB) only *within* mixed-task blocks. This approach has the following advantage: The task demands for nonswitch and switch trials are the same within mixed blocks, so that switch costs are not confounded with working-memory demands (due to the maintenance of the instruction for both tasks A and B in mixed task blocks), thereby allowing a better identification of the cost associated with the task-shift per se. Kray and Lindenberger (2000) complemented the paradigm proposed by Rogers and Monsell (1995) with a nonswitch baseline (i.e., single-task blocks): "The goal was to assess executive control components that were specifically related to the switch situation and control components related to the dual-task situation in general" (Kray & Lindenberger, 2000, p. 127). This type of paradigm allows the definition of two types of switching costs: (1) General switch costs, calculated as the difference in performance between single-task and mixed-task blocks, thus measuring the ability to maintain two or more task sets and to select the appropriate one, and (2) specific switch costs, calculated as the difference in performance between switch and nonswitch trials within mixed-task blocks, thereby referring to the mere process of switching between the two tasks. Note that other researchers have adopted the same measures of switch costs under different labels[3].

[3] The difference in performance between single-task and mixed-task trials has been referred to as general switch costs (e.g., Kray & Lindenberger, 2000; Kray, Li, & Lindenberger, 2002), global switch costs (e.g., Mayr, 2001), set-selection costs (e.g., Kray et al., 2004), and mixing costs (Crone, Bunge, Van der Molen, & Ridderinkhof, 2006; Kray et al., in press; Meiran et al., 2001). Accordingly, the difference in performance between switch and nonswitch trials within mixed-task blocks has been labeled specific switch costs (e.g., Kray & Lindenberger, 2000; Kray et al., 2002), local switch costs (e.g., Mayr, 2001) and switch costs (Crone, Bunge, et al., 2006; Kray et al., 2004; Meiran et al., 2001), respectively.

General as well as specific switch costs have been reliably replicated (e.g., Bryck & Mayr, 2005; Cepeda et al., 2001; Crone et al., 2004; Crone, Bunge, et al., 2006; Karbach & Kray, 2007; Kray et al., in press; Kray et al., 2004; Kray et al., 2002; Kray & Lindenberger, 2000; Mayr, 2001; Meiran, 1996, 2000). Importantly, both types of costs are related, but separable psychometric factors. Kray and Lindenberger (2000), for instance, showed by means of CFA that a model with two intercorrelated latent factors (i.e., general and specific switching abilities) provided a significantly better fit than a one-factor model. The authors concluded that "… general and specific switch costs can be reliably identified as distinct and domain-general aspects of cognitive control" (Kray & Lindenberger, 2000, p.140; cf. Oberauer, Süß, Wilhelm, & Wittmann, 2003). This dissociation is consistent with other studies using a latent variable approach to investigate the structure of executive functions, showing that shifting and maintenance are indeed separable components of executive control (Fisk & Sharp, 2004; Huizinga et al., 2006; Miyake et al., 2000; see also p. 32). Meanwhile, these behavioral results are also supported by neuroimaging data. Crone, Wendelken and colleagues (2006) showed in a functional magnetic resonance imaging (fMRI) study that task representation and reconfiguration (i.e., task maintenance and task switching) are associated with dissociable neural activation in the lateral and the medial prefrontal cortex, respectively.

In the present study, an alternating-runs task-switching paradigm (i.e., a fixed sequence of tasks in mixed-task blocks) and a blocked design (single-task and mixed-task blocks) were applied. In line with Kray and Lindenberger (2000), two measures of task-switching costs were assessed, referred to as general and specific switch costs (see also Bryck & Mayr, 2005; Cepeda et al., 2001; Karbach & Kray, 2007; Kray et al., in press; Kray et al., 2004; Kray et al., 2002; Mayr, 2001; Meiran, 1996, 2000).

The Origin of the Task-Switching Costs

In search of an explanation for the occurrence of task-switching costs, at least two prominent theories have been widely discussed. One of these approaches emphasizes the role of interference, the other one that of preparation processes. Proponents of the first theory assume that whenever a task switch is performed, the previous task set along with the corresponding stimulus-response mapping is still active (“task set inertia”). This proactive interference impairs the execution of the following new task, so that a complete disengagement from the preceding task is not possible until “after the next imperative stimulus has arrived” (Allport et al., 1994, p. 437). According to Allport, this theory explains the fact that even after long preparation intervals, residual switch costs are found. Along this line, it has recently been proposed that switch costs arise in response to strong item specific stimulus-response bindings occurring when participants associate a particular stimulus with a response that must be inhibited when this particular stimulus appears in the context of another task (Waszak, Hommel, & Allport, 2003; see also Kray & Eppinger, 2006). Thus, switch costs in this framework are predominantly the result of bottom-up processes rather than the time taken by top-down control processes necessary to reconfigure a task set.

In contrast, Rogers and Monsell (1995) proposed two components of task control being active during task switches: Consciously controlled endogenous control processes support the preparation of the relevant and the inhibition of the irrelevant task set. Thus, switch costs include a measurement of this endogenous reconfiguration process. Exogenous processes that cannot be initiated until after the stimulus has been presented explain the residual switch costs found even after long preparation intervals. The exogenous processes are necessary for completing the reconfiguration process. Thus, the endogenous part can explain why reduced switch costs are see when participants are given more to prepare for a switch while the exogenous process explain why even with a longer preparatory interval, residual switch costs are still observed.

However, after extensively testing both theories, Meiran (1996) showed that none of them could completely explain the occurrence of switch costs, but that reconfiguration processes for the preparation of the new task as well as gradually decreasing interference from the preceding task both play important roles (cf. Cepeda et al., 2001).

In sum, the aim of the interference as well as the preparation theories (e.g., Allport et al., 1994; Rogers & Monsell, 1995) was to explain switch costs by one type of control mechanism. However, even though the quantification is still controversial, most investigators today agree that more than one factor contributes to the occurrence of switch costs (see Monsell, 2003).

Age Differences in Task-Switching Abilities

Most task-switching studies have investigated young adults between 20 and 25 years of age, that is, at the "peak level" of optimal executive functioning. However, given that this study focused on age differences in task-switching abilities, it was most interesting how general and specific switching abilities change across the lifespan.

Lifespan Studies. Lifespan studies investigating the development of task-switching abilities are scarce. Nonetheless, their results are very consistent with respect to general switch costs, typically showing a u-shaped developmental function for this type of costs. That is, general switch costs are larger in children and older adults than in younger adults (Cepeda et al., 2001; Kray et al., in press; Kray et al., 2004; Reimers & Maylor, 2005).

When it comes to specific switch costs, results are less clear. Most studies found that age differences in this type of costs are small or not existent, at least when age differences in baseline performance are accounted for (for instance, by means of log-transformed RT; details are provided on p. 124, Method) (Kray et al., in press; Kray et al., 2004; Reimers & Maylor, 2005). Thus, compared to younger adults, children and older adults are characterized by deficits in the ability to maintain and select two task-sets (i.e., general switch costs), but less in switching per se (i.e., specific switch costs). As an example, the typical pattern of age-related differences in general and specific switch costs is illustrated in Figure 2, based on findings from Kray et al. (2004) and Reimers and Maylor (2005). Both graphs show the u-shaped developmental function for general switch costs, but no age differences in specific switch costs.

Although lifespan studies are rare, many studies either focusing on childhood development or on cognitive aging have confirmed this differential age-related pattern with respect to general and specific switch costs. The most important findings are reported below.

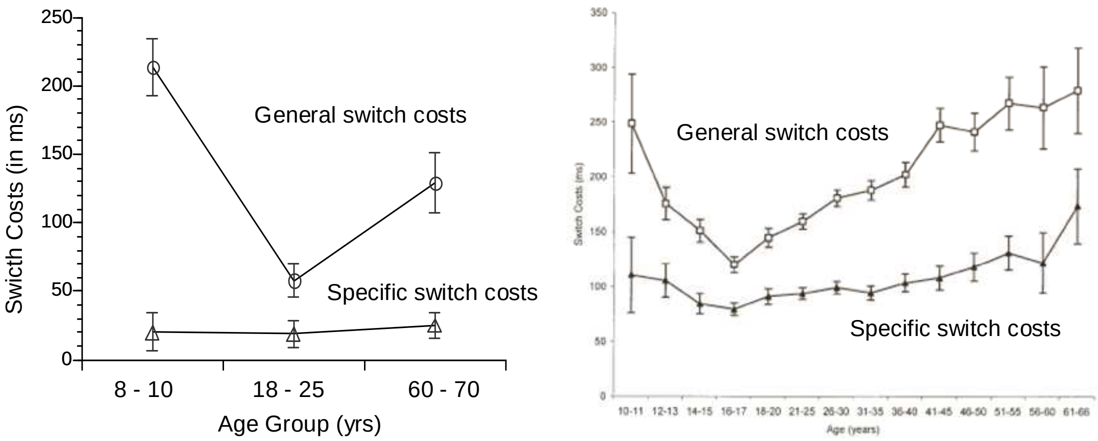

Figure 2: Prototypical findings for age differences in general and specific switch costs. Figures adapted from Kray, Eber, and Lindenberger (2004) (left panel), and from Reimers & Maylor (2005) (right panel).

Childhood and Adolescence. Studies focusing on switching abilities in children younger than 5 years of age usually apply modified versions of the task-switching paradigm, such as the day-night task (e.g., Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994) or the dimensional change card sort (DCCS; e.g., Kirkham, Cruess, & Diamond, 2003; Zelazo, Frye, & Rapus, 1996). These studies indicated that children's rule switching ability markedly increases between the ages of 3 and 6 (for reviews, see Garon, Bryson, & Smith, 2008; Zelazo, 1999, 2000; Zelazo & Jacques, 1996). However, given that the card sorting tasks applied to preschool children are not computerized and reaction time is not measured, the analysis is mostly restricted to accuracy measures, and in most experiments no measures comparable to switch costs are calculated.

There is one study investigating task-switching abilities in 5-year-old and 9-year old children by means of a cue-based switching paradigm (Karbach & Kray, 2007). Results showed substantially larger general switch costs in 5-year-olds than in 9-year-olds, but no age differences in specific switch costs, suggesting that both capabilities reflect separate developmental trajectories rather than a unitary trend. This result joins others in demonstrating that age functions for general and specific switching abilities are not unitary across childhood (Cepeda et al., 2001; Crone, Bunge, et al., 2006; Crone et al., 2004; Kray et al., 2004). Although 5-years-olds are able to represent a higher order rule allowing them to select between two tasks (Zelazo, 1999; Zelazo & Frye, 1998), task-set selection is still associated with substantial costs in this age group. With increasing age, these costs are substantially reduced, that is, children's ability to maintain and select task-sets improves (cf. Diamond & Taylor, 1996; Gerstadt et al., 1994). This view is supported by findings from Chelune and Baer (1986), reporting a linear increase in set maintenance between the ages of 6 and 10 in the Wisconsin Card Sorting Test (WCST; see also DeLuca et al., 2003; Welsh, Pennington, & Groisser, 1991). Consistently, Huizinga and Van der Molen (2007) reported that children's ability for set switching in the WCST reached adults levels at the age of 11, while the ability for set maintenance reached this level at the age of 15. A task-switching study from Crone and colleagues (2004) consistently revealed that the increase in the ability to maintain task sets was most pronounced between the ages of 11-12 and 13-15 years of age (in cued tasks)[4]. In sum, these findings point to an earlier maturation of task-set switching than task-set maintenance, possibly associated with maturation of different sub-regions of the PFC (cf. Crone et al., 2004; Stuss, 1992; Van der Molen, 2001; for a review, see Casey et al., 2005).

Cognitive Aging. Evidence for adult age differences in task-switching abilities is considerable these days (for a review, see Kramer & Kray, 2006). Kray and Lindenberger (2000), for instance, used an alternating-runs paradigm in order to investigate adult age differences (20 to 80 years) in both general and specific switch costs. They found larger age differences in general switch costs than in specific switch costs (see also Kray, 2006; Kray et al., in press; Kray et al. 2004), and this effect was resistant to practice and increased preparation time. Based on this finding, the authors concluded that age-related deficits particularly concern task-set maintenance and selection, at least in situations where no external task cue is given and hence high demands on executive control are imposed (Kray & Lindenberger, 2000).

Mayr (2001) replicated the finding of larger age differences in general compared to specific switch costs with a cued version of the task-switching paradigm, that is, under reduced working-memory demands (but see Kray et al., 2002). Moreover, he found that the amount of interference at the stimulus and response level (stimulus ambiguity and response-set overlap[5]) modulated age differences in general switch costs. Interestingly, age differences

[4] Crone, Bunge, and colleagues (2006), however, reported conflicting results: They found no age differences in general switch costs between younger children (7-8 years), older children (10-12 years), and young adults (20-25 years). However, it should be noted that in their study general switch costs were defined as the difference between single-task trials and nonswitch trials (instead of singe-task blocks vs. mixed-task blocks).

[5] Stimulus ambiguity refers to the fact that stimuli represent attributes of both tasks involved in task switching. Participants in the Mayr (2001) study, for instance, were instructed to classify pictures by shape (circle or square?) and by color (red or green?). The ambiguous stimuli featured attributes relevant for both tasks, such as red squares or green circles. Response set overlap refers to the fact that two response alternatives were mapped onto the same response button, that is, one button for the response alternatives ‘circle’ (for the shape classification) and ‘green’ (for the color classification), and

in general switch costs disappeared when there was no overlap at the stimulus and response level, suggesting that older adults particularly have problems to separate overlapping task-set representations. Mayr (2001) further assumed that this pattern of age differences may be due to an updating process performed by older participants to internally re-ensure task sets in nonswitch as well as in switch trials within mixed-task blocks. This strategy results in relatively large general and small specific switch costs. Younger adults, in contrast, are supposed to rely on this updating strategy in switch trials only. This interpretation is supported by neuroscientific evidence, revealing neural activation in the dorsal and medial prefrontal cortex while performing nonswitch as well as switch trials in older adults, while younger adults only show this activation in switch trials (DiGirolamo et al., 2001).

De Jong (2001), in contrast, applied an alternating runs paradigm and found larger general as well as specific switch costs in older adults compared to younger adults (cf. Bherer et al., 2005; Meiran et al., 2001). This finding is consistent with previous results based on cued switching paradigms, indicating that older adults showed larger specific switch costs than younger adults (Kramer, Hahn, & Gopher, 1999; Salthouse, Fristoe, McGuthry, & Hambrick, 1998). De Jong (2001) found that under time pressure induced by reducing the response time interval, age differences in specific switch costs were unaffected, while those in general switch costs disappeared. Based on this finding, he concluded that age differences in general switch costs are caused by a more conservative response bias in old adults during mixed-task blocks, resulting in larger general switch costs in old adults compared to younger adults in situations without time pressure.

However, despite of some conflicting findings (for a review, see Kramer & Kray, 2006), most studies comparing the performance of younger and older adults found substantial age differences in general switch costs beyond “general slowing”, while specific switch costs were

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the other response button for the response alternatives ‘square’ and ‘red’. Designs with ambiguous stimuli and response set overlap induce high interference at the stimulus and the response level.

relatively stable across the adult lifespan (for a meta-analysis, see Verhaeghen & Cerella, 2002). These findings point to an earlier decline of task-set maintenance and selection than task-set switching probably associated with the age-related development of different sub-regions of the PFC assumed to be extensively involved in multitask-processing and task coordination (cf. Braver et al., 2001; for reviews, see Hedden & Gabrieli, 2004; West, 1996).

In sum, children and older adults show marked deficits in the ability to maintain and select two task sets, but less in the ability to switch between tasks (e.g., Crone et al., 2004; Karbach & Kray, 2007; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; cf. Verheagehn & Cerella, 2002). The relative amount of age differences in both types of switching costs depends on a number of factors, among them the cueing type (e.g., van Asselen & Ridderinkhof, 2000), preparation time (e.g., De Jong, 2001; Meiran et al., 2001), task ambiguity (Rubin & Meiran, 2005), and the amount of interference (e.g., Mayr, 2001). Given that these manipulations were not the focus of the present study, they are not discussed in more detail. Instead, the next section is dedicated to an aspect highly relevant for the present study, namely the question whether age-differences in task-switching abilities can be influenced by means of cognitive interventions, including intensive training and the application of verbal strategies.

Cognitive Training

Cognitive interventions (Kramer & Willis, 2002) provide the opportunity to study age differences in cognitive plasticity, that is, the ability to improve one's performance through instruction and training[6] (cf. Singer & Lindenberger, 2000). The plasticity of cognitive abilities across the lifespan varies within the age-related limits of mechanic abilities (cf. Kray & Lindenberger, 2007). Participants across a wide age range usually show performance improvements after cognitive interventions (for reviews, see Jones et al., 2006; Kramer & Willis, 2002). However, given that the development of fluid intelligence as well as several executive control abilities is characterized by a u-shaped lifespan pattern (see p. 34), the question is whether cognitive plasticity is already present in childhood and maintained in older age.

Most evidence for developmental differences in cognitive plasticity comes from the domain of memory. In one study, for instance, participants (age range: 9 – 78 years of age) learned and practiced an imagery-based mnemonic technique to encode and retrieve words by location cues (Brehmer et al., 2007). While subjects in all age groups were able to optimize the use of the technique, children benefited more from training and reached higher performance levels than older adults. However, other studies indicated that older adults nevertheless show considerable cognitive plasticity, not only in the area of fluid intelligence (e.g., Schaie & Willis, 1986), but also with respect to memory (e.g., Derwinger et al., 2003; Verhaeghen et al., 1992) and executive control (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kramer et al., 1995; Kramer, Larish et al., 1999; Kray et al., in press; Kray &

[6] It should be noted that the terms “training” and “practice” have been used with different connotations in the literature. Some authors refer to “practice” as repeatedly performing a certain task, while “training” is characterized by the additional use of some strategy, such as performing a mnemonic strategy during memory training (e.g., Derwinger et al., 2003). However, in numerous publications the terms are not clearly defined and used interchangeable. Given that the cognitive intervention applied in the present study (for details, see Method) partly qualifies as practice and partly as training intervention, the terms will also be used interchangeable within the context of the present study.

Lindenberger, 2000; Minear et al., 2002; see also p. 57). The Seattle Longitudinal Study (Schaie, 1996), for instance, showed that the degree of training-related benefits in fluid intelligence corresponded to the degree of longitudinally assessed decline over the previous 15 to 20 years (Schaie, 1996; Schaie & Willis, 1986). Still, this cognitive plasticity seems to be limited in very old age (Singer et al., 2003) and in patients suffering from dementia, so that the reduction of cognitive plasticity has been used for the early diagnosis of dementia (Bäckman, 1992; M. Baltes, Kühl, Gutzmann, & Sowarka, 1995). This section provides an overview of the two types of cognitive interventions most important for this study, that is, the influence of verbal self-instruction strategies and intensive task training on age differences in task-switching performance.

Verbal Self-Instructions

Since Vygotsky's (1962) and Luria's (1960, 1969) work, it is well known that language has a regulatory function in action control, for instance, by focusing attention to the information most relevant for the task at hand. The first studies providing evidence for verbal self-instruction training date back at least to the 1960ies and 1970ies. Meichenbaum and Goodman (1971), for instance, developed a cognitive self-guidance program mainly based on Vygotsky's (1962, 1988) and Luria's (1960, 1969) developmental theories, describing a gradual internalization of self-directing external speech ("private speech") as a function of age, thus, a developmental progression from external to internal control of behavior[7]. The training program turned out to be effective for improving performance in serial recall tasks (Asarnow & Meichenbaum, 1979) as well as in reasoning tasks among children with inhibitory control deficits (Meichenbaum & Goodman, 1971). Today, verbal self-instruction trainings are well

[7] Vygotsky (1988), for instance, suggested that private speech is a developmental stage preceding inner speech, that is, the transition from social activity to more individualized activity, reflecting the child's gradual individualization. He claimed that private speech gradually develops regarding its structural and functional characteristics, leading to a differentiation from external speech. As a consequence, the vocalization fades away, and "in the end, it becomes inner speech" (Vygotsky, 1988, p.183).

established in the field of cognitive-behavioral therapy (for a review, see Gosch, Flannery-Schroeder, Mauro, & Compton, 2006).

Aside from self-instruction training for children, verbal strategies have also been proposed as compensation for age-associated cognitive deficits, such as memory deficits, in older age (Meichenbaum, 1974). Derwinger and colleagues (2003), for instance, trained older adults to use a mnemonic strategy in a number recall task. Performance improved reliably following training and the training-related gains even increased when support (i.e., verbal cues) was provided during the recall. This result confirms previous research by showing that systematic training can indeed enhance healthy older adults' performance in memory tasks, thus demonstrating the effectiveness of verbal self-instructions and memory plasticity in old age (Stigsdotter Neely, 2000; Verhaeghen, 2000). However, of particular importance for this study was the influence of verbal-self instructions on age differences in executive control functioning in general, and more specifically, on age differences in task-switching performance.

Within models of executive control, the role of verbal processes (i.e., inner speech) is limited to the maintenance of information. In Baddeley's (1986, 2000) working memory model, for instance, inner speech is closely linked to the phonological loop system, and more specific, to the articulatory rehearsal processes responsible for maintaining phonological information in working memory. Based on this model, the influence of verbal processes on executive control functioning has recently been investigated in task-switching studies with adult participants (Baddeley, Chincotta, & Adlam, 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Goschke, 2000; Gruber & Goschke, 2004; Miyake, Emerson, Padilla, & Ahn, 2004; Saeki & Saito, 2004). In these studies, participants were instructed to perform a secondary verbal task (for instance, saying aloud an over-learned sequence of words, such as the days of the week) to disrupt the use of inner speech during task preparation. Nearly all of these studies showed that maintaining and selecting task sets (e.g., Emerson & Miyake, 2003; Saeki & Saito, 2004) was more sensitive to articulatory suppression than switching per se (e.g., Bryck & Mayr, 2005), that is, general switch costs were substantially increased under articulatory suppression conditions. Emerson and Miyake (2003) showed that the increase in general switch costs was most pronounced when external task cues were either abstract or not present, suggesting that inner speech is of major importance for the retrieval and activation of the next task goal, at least when the availability of external cues is limited and the need for endogenous control is enhanced (see Figure 3; cf. Baddeley et al., 2001; Miyake et al., 2004; Saeki & Saito, 2004). Taken together, these results support the view that inner speech plays an important role for the preparation of upcoming tasks by effectively facilitating the retrieval of the phonological representation of the next task goal (see also Mecklinger, von Cramon, Springer, & Matthes-von Cramon, 1999).

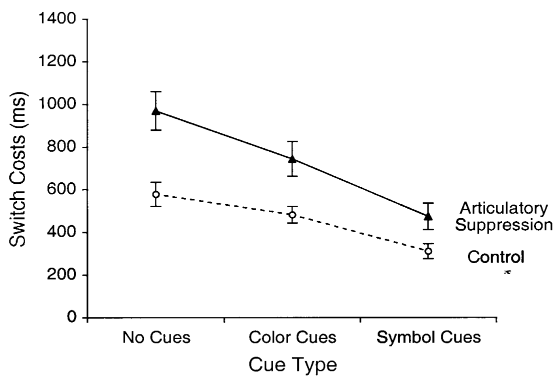

Figure 3: General switch costs as a function of verbalization condition (articulatory suppression, control) and cueing type (color cue, symbol cue, no cue). Figure adapted from Emerson and Miyake (2003).

Recently, studies have not only investigated effects of disrupting inner speech by means of task-irrelevant verbalizations (i.e., articulatory suppression), but also effects of supporting it by means of task-relevant verbalizations (i.e., verbal self-instructions). However, developmental studies focusing on age differences in the use of verbal self-instructions for flexibly switching between task sets are scarce (e.g., Karbach & Kray, 2007; Kray et al., in press; Kray et al., 2004). Nevertheless, they have provided evidence indicating that particularly younger children and older adults can use language to compensate for executive control deficits. A recent study, for instance, examined the influence of verbal processes on age differences in task switching in younger (7 – 9 years of age) and older (11 – 13 years of age) children, and in younger (20 – 27 years of age) and older adults (66 – 77 years of age) (Kray et al., in press). In order to increase the use of inner speech during task preparation, an internally cued switching paradigm without external task cues was applied. The role of verbal processes for task-switching performance was investigated by instructing participants to perform a secondary verbalization task. Three verbalization conditions were compared: Switching performance (1) without verbalization, (2) when subjects named the next task goal during task preparation, and (3) when subjects verbalized irrelevant words (the, the, the [der, die, das]). Compared to the control condition without verbalization, the u-shaped developmental trend for general switch costs was more pronounced when the use of inner speech was disrupted by the verbalization of irrelevant words during task preparation. In contrast, age differences in general switch costs were reduced when subjects named the next task goal during task preparation, especially for younger children and older adults (see Figure 4). Thus, especially younger children and older adults were able to use language for the compensation of age-related deficits in the ability to maintain and select task goals.

Evidence for developmental changes in the use of language for executive control functioning in older age comes from the cognitive neurosciences. In a recent study focusing on training-induced plasticity in older age, Erickson et al. (2007b) found that in contrast to younger adults, older adults showed an increase in activation in the left ventrolateral prefrontal cortex close to the Boca’s area with increasing dual-task training. The authors suggested that after training, older adults seem to increasingly rely on verbal processes to manage and coordinate multiple task demands, indicating that there are age-related changes in the use of verbal processes for efficient task control.

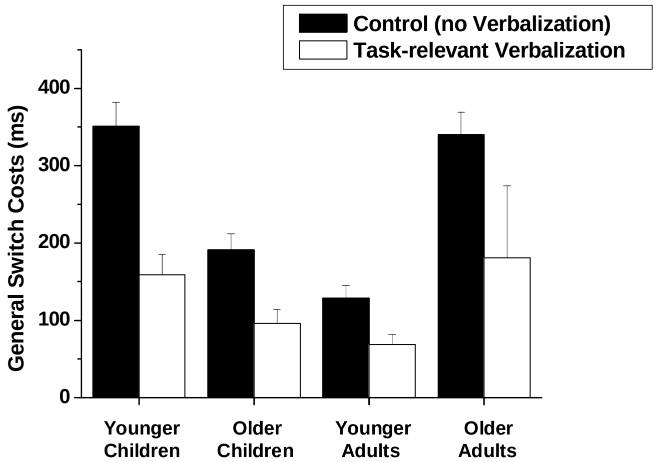

Figure 4: General switch costs (ms) as a function of age group (younger children, older children, younger adults, older adults) and verbalization condition (task-relevant, control). Figure adapted from Kray, Eber, and Karbach (in press).

Over the last years, some studies also showed that even very young children can use language for efficient action control. Kirkham and colleagues (2003), for instance, demonstrated that verbal labeling supported the ability to switch to a new set of rules in 3-year-old children, suggesting that speech helps to redirect attention (cf. Towse, Redbond, Houston-Price, & Cook, 2000). In addition, Müller, Zelazo, Hood, Leone, and Rohrer (2004) found that performance in conflict-control tasks in the same age group improved when children were asked to use verbal labeling during testing. Finally, there is also evidence indicating that children's reorientation ability was related to the productive use of spatial language (cf. Hermer-Vazquez, Spelke, & Katsnelson, 1999), and that action-effect learning in 4-year-olds is strongly mediated by the way the actions and their outcomes are verbally described (Kray, Eenshuistra, Kerstner, Weidema, & Hommel, 2006). In sum, these findings point to an important function of language for the cognitive development in different domains and across a wide range of ages.

Training

Research focusing on training-related benefits in task-switching abilities shows considerable potential for cognitive plasticity, but also its limits. From a theoretical point of view, one may assume that task-switching costs are only a temporary phenomenon, emerging because participants have to execute unfamiliar tasks and because they are not familiar with the process of switching between them. If this was true, intensive training would lead to an automatization of the underlying executive control abilities, resulting in a disappearance of switch costs (Kluwe, 1997; Rogers & Monsell, 1995).

Logan (1988) refers to the process of automatization as a memory-based process. When novices are required to perform a task, they use a general algorithm at first. While practicing the task, domain specific knowledge increases. Eventually, this knowledge allows retrieving specific information directly from memory, so that the algorithm can be dropped: „Automatization reflects a transition from algorithm-based performance to memory-based performance“ (Logan, 1988, p. 493). Assuming that the increasing automatization of the single "component“ tasks involved in task switching leads to faster performance after practice, the actual question is whether this speeding is also present on the level of executive control functions (i.e., general and specific switch costs)?

Indeed, several studies showed that training can reduce general as well as specific switch costs, but that residual switch costs were found even after extensive practice (e.g., Allport et al., 1994; Cepeda et al., 2001; De Jong, 2001; Jersild, 1927; Kramer, Hahn, et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000; Minear, et al., 2002; Rogers & Monsell, 1995). The practice effects observed in these studies have mostly been attributed to task specific effects, such as the strengthening of stimulus-response rules or specific associations between cues and tasks (Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995).

For the purpose of the present study, it was particularly important whether there are age-related differences in the amount of training-related benefits on the level of task-switching abilities. This question is especially important because it sheds light on the potentials and limits of plasticity in executive control functioning in different age groups.

Kramer, Hahn, and colleagues (1999), for instance, examined age differences with respect to training effects by means of a cue-based switching paradigm. Compared to younger adults, older adults showed a larger reduction of specific switch costs as a function of training. After three sessions of training, older adults had reduced their specific switch costs to such an extend that age differences between younger and older adults disappeared. This benefit was still found in a follow-up session two months after the training had ended. In a second experiment, the authors increased the working-memory demands by applying an internally cued paradigm without external task cues, that is, participants had to switch tasks on every fourth trial. Under these conditions, older participants were not able to reduce their specific switch costs.

Kray and Lindenberger (2000) investigated both general and specific switch costs across six sessions of training in younger and older adults by means of an internally cued switching paradigm. General as well as specific costs were reduced as a function of practice, (cf. Bherer et al., 2005) but still substantial in the last training session. Although older adults showed a larger reduction of general switch costs than younger adults (cf. Minear et al., 2002), age differences were still reliable. Further evidence for practice effects in older age comes from the cognitive neurosciences: Erickson and colleagues (2007a) investigated the degree of plasticity in regions involved in the management and coordination of multiple task-sets in older adults by means of a dual-task training approach. They found that the training-induced changes in activation occurred in cortical areas often associated with the largest age-related atrophy, that is, the dorsal and ventral prefrontal cortex (Raz, 2000; West, 1996). The authors concluded “this suggests that age-related functional decline in these regions is not an inevitable process of aging, but that it can be reliably reduced and possibly reversed with training” (Erickson et al., 2007a, p. 9).

When it comes to children, evidence for task-switching training is rare. Results from Cepeda and colleagues (2001) indicated that general switch costs were reduced after training, and that this reduction was larger for children (10-12 years of age) and older adults than for younger adults (see also Kray et al., in press; Figure 5). This is consistent with Eber and Kray (in prep.), showing that children between 8 and 10 years of age were able to reduce general (but not specific) switch costs across two sessions of training.

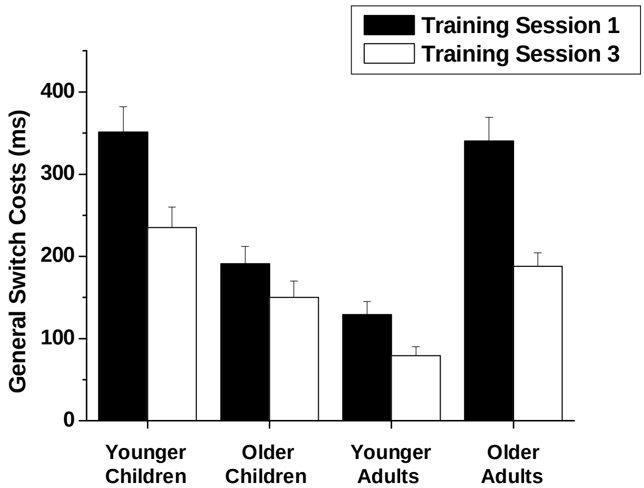

Figure 5: General switch costs (ms) as a function of age group (younger children, older children, younger adults, older adults) and training (session 1, session 3). Figure adapted from Kray, Eber, and Karbach (in press).

In sum, developmental studies investigating training-related benefits in task-switching performance are relatively rare. However, their results indicate that the ability to maintain and select task sets – and in some studies also the ability to switch between them – can be improved by training, pointing to considerable plasticity regarding executive control functioning (e.g., Cepeda et al., 2001; Eber & Kray, in prep.; Kramer, Hahn et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000). Nevertheless, both types of switching costs were still found after intensive practice, suggesting that switch costs are not a temporary phenomenon that disappears when tasks are automatized and that the range of plasticity is limited[8]. In fact, general and specific switch costs seem to reflect constant executive control demands associated with the mechanic component of the cognitive system (Kluwe, 1997; Kray & Lindenberger, 2000). Importantly, the finding that a wide range of age groups showed improved task-switching abilities after training (Cepeda et al., 2001; Kramer, Hahn et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000; Minear et al., 2002) provides evidence for a developmental reserve capacity with respect to executive control. Moreover, these results also show that training is a useful cognitive intervention for reducing age differences in task-set maintenance and selection.

[8] Note, however, that these studies did not apply the testing-the limits approach. Hence, the potential for training-related benefits may not have been fully exhausted in these experiments.

Transfer of Cognitive Training

The literature reviewed in the previous section indicated that intensive training can reduce age-related deficits in executive control abilities, and that cognitive plasticity is considerable across a wide range of ages (see p. 57). However, aside from the mere investigation of training-related benefits, their transferability to new situations is of particular importance for the application of training programs in the clinical and educational context. Therefore, the following section focuses on the concept of transfer. After a short definition, the most important theoretical concepts are outlined, including models with respect to different types of transfer, the measurement of training and transfer benefits, and the mechanisms underlying these effects. The focus is on aspects most relevant for the present study. However, it should be noted that the majority of these theoretical considerations is based on research focusing on cognitive processes other than executive functioning, such as reasoning or memory, forming the basis for most of the work published in the field of transfer research (for reviews, see Klauer, 2001; Rosenbaum, Carlson, & Gilmore, 2001; Schmidt & Bjork, 1992). Also, differential aspects regarding transfer of training are discussed and criteria for the evaluation of training programs are illustrated. Afterwards, empirical evidence for the near and far transfer of cognitive training is reviewed with emphasis on executive control; and finally, the focus is on two methods for improving transfer effects, namely feedback and variable training.

Theoretical Concepts

Definition

Transfer of training is generally defined as the effect of knowledge acquired in a previous situation on performance in a new situation (Mayer & Wittrock, 1996), that is, previously acquired knowledge affecting the way new information is handled (Cormier & Hagman, 1987).

Especially researchers from the field of educational sciences have investigated transfer (e.g., De Corte, 1999; Mayer & Wittrock, 1996; for a review, see Klauer, 2001); some have even claimed that it is one of the most fundamental educational goals (Marini & Genereux, 1995). Therefore, the concept of transfer has often been linked to learning, that is, the human ability to flexibly use the appropriate knowledge and abilities to handle new, unfamiliar situations (Roth-van der Werf et al., 2002). In line with this, it is assumed that transfer is a central adaptive mechanism (Hesketh, 1997; Mayer & Wittrock, 1996), associated with intellectual abilities and intelligent human behavior (cf. Klauer, 1996, 1997).

Types of Transfer

Psychological and educational trainings usually aim at transfer to situations beyond the training context, particularly if the training is designed to improve cognitive abilities. A successful application of training-related improvements in new, unfamiliar situations is referred to as transfer. However, the term “transfer” is used quite inconsistently in the literature, frequently resulting in confusion (for a review, see Barnett & Ceci, 2002). Thus, despite the long tradition of training and transfer research, there is still no consensus whether transfer can be achieved, and if so, under which circumstances and to what extent. Some researchers rather deny that transfer is possible: “The lesson learned from studies of transfer is that, if you want people to learn something, teach it to them. Don’t teach them something else and expect them to figure out what you really want them to do” (Detterman, 1993, p. 21). Other authors, however, point to conditions supporting the occurrence of transfer, such as the similarity between training and transfer tasks, proper instructions, and the type of training (e.g., De Corte, 1999; Klauer, 1989a, 1989b, 1996, 1998; Marini & Genereux, 1995; Mayer & Wittrock, 1996; for reviews, see Klauer, 2001; Rosenbaum et al., 2001; Schmidt & Bjork, 1992).

In order to understand these quite contradictory positions, it is important to distinguish between different forms of transfer, such as near transfer (within tasks) and far transfer (across tasks) (Butterfield & Nelson, 1991; Detterman, 1993). Others have differentiated between specific (specific responses) and general (general principles) transfer (Detterman, 1993; Mayer & Wittrock, 1996; Novick, 1990), as well as between high-road (effortful and conscious) and low-road (automatic) transfer (Salomon & Perkins, 1989). Meanwhile, a couple of models have been proposed allowing to establish criteria for transfer and the quantification of transfer benefits (Barnett & Ceci, 2002; Hasselhorn & Hager, 1996).

Two types of transfer are of particular importance for the present study, namely near and far transfer. Near transfer refers to situations that are structurally identical, but differ regarding details (e.g., the same kind of task structure, but different kind of stimuli), for instance, transfer of training in switching between tasks A and B to switching between tasks C and D. Far transfer, in contrast, refers to situations being different from the original one, such as transfer from task-switching training to other executive control tasks (e.g., the Stroop task) and even to other task domains, such as fluid intelligence.

When it comes to near transfer, there is an ongoing debate on whether it is better described as learning (Brainerd, 1975; Roth-van der Werf et al., 2002; Salomon & Perkins, 1989) because learning is typically defined as a change in behavior in one situation as a consequence of repeated experience in a similar, but different situation (Bower & Hilgard, 1981). Klauer (1989b), in contrast, argued that normal learning merely is a special type of transfer. Consistently, Salomon and Perkins (1989) also point out that it is difficult to draw a hard line between mere learning and transfer. However, they claim that transfer is more likely to be mentioned when learning has side effects that exceed the usual expectations.

Measurement of Transfer

To date, it is widely accepted that an experimental design allowing conclusions regarding the effectiveness of a given training program and the subsequent transfer effects has to meet a number of preconditions. Although these preconditions seem relatively simple and logic at the first glance, surprisingly many training studies fail to meet these criteria (for a review, see Klauer, 2001). Therefore, these preconditions will be briefly summarized in this section.

First, a training experiment must include at least two groups: One or more training groups and a control group. During training, the training group performs tasks requiring some cognitive ability to be trained. The control group, however, should perform tasks that are similar to those of the training group with respect to duration, number of sessions, contact with the experimenter, and the training equipment (e.g., a computer or other test material) and so forth, but these tasks should of course not train the specific ability practiced in the training group. Second, in order to examine transfer effects, the experimental design should not only include a “transfer session” after the training has been completed, but also a baseline measurement before training. Based on this baseline measurement, participants can be matched to the training and the control groups to prevent differences in baseline performance that often make the interpretation of transfer effects difficult.

Therefore, the typical design to assess transfer of training is a pretest-training-posttest design. In these experiments, transfer is defined as the performance improvement at posttest relative to baseline performance at pretest. Thus, pretest and posttest sessions are usually identical, that is, they include the same tasks and measurements. In order to investigate long-term transfer effects, the pretest-training-posttest design can be completed with a follow-up measurement some time after the posttest (detail are provided below in this section).

Assuming that transfer of training was found, it can be quantified along two dimensions: Effect size and effect range. Effect sizes are calculated to quantify the pretest-posttest performance improvements associated with a given type of training, while the effect range refers to the transfer distance, that is, the structural difference between training and transfer tasks: The more different the task structure and the underlying abilities of the transfer tasks are from the training tasks, the larger the transfer distance. However, some authors argue that effect size and effect range are not entirely independent. Salomon and Perkins (1989), for instance, refer to this phenomenon as power-generality trade-off. They assume that the more general a given training is, the weaker it is, so that training and transfer effects cannot be large and broad (i.e., affecting multiple domains) at the same time (cf. Weinert, 1987). According to this framework, training is most useful when effect size and effect range are on medium levels[9]. And indeed, Klauer's (1989b) empirical findings support this notion by showing not only a negative correlation between effects size and effect range, but also a decreasing linear relationship between transfer effect size and transfer distance.

Thus, according to this theory, it seems especially difficult to provide evidence for far transfer effects, because the transfer effect size decreases as a function of transfer distance. However, the verification of small effects requires large sample sizes, which can be problematic in training studies. Thus, in experiments with relatively small sample sizes only relatively large far transfer effects can be found reliably. In a meta-analysis including 302 studies of psychological, educational, and behavioral interventions, effects sizes were analyzed as a function of sample size (Lipsey & Wilson, 1993). In experiments with less than 50 participants (collapsed across experimental and control group), the mean effect size was .58. With a sample size between 50 and 100, the effect size decreased to .52, and with N >

[9] Klauer (2001) has extensively examined the relationship between effect size and effect range for the domain of inductive reasoning. He argues that this relationship can easily be quantified: Assuming that N is the usefulness of training, p the probability that a trained/transferred ability is used, and w the proportion of explained variance of the trained ability relative to the total variance, then N = pw, if W = F(1-p). He further assumes that w is a monotone function of 1 - p, so that the usefulness of N is maximized if both p and w have medium values.

100, the mean effect size was .35 (the relevance of effect sizes for the evaluation of training programs is illustrated below).

What Changes During Training? And What is Subsequently Transferred?

For everyone interested in the transfer of training, the mechanism underlying training-related improvements should be of interest. Put differently, how do training benefits emerge? When training related performance improvements were analyzed as a function of training time, usually logarithmic functions were found (cf. Klauer, 2001). That is, the largest performance improvements occurred after relatively little practice, and although further training constantly lead to better performance, the improvement constantly grew smaller (asymptotic approximation). Fitts (1954) referred to this type of curve as the “law of practice”.

In order to explain this typical course of training-related improvement, different models have been proposed, most of them including assumptions regarding the automatization of the practiced abilities (Anderson, 1982; Logan, 1988; Schneider & Shiffrin, 1977). According to Anderson’s (1982, 1987) analysis of skill acquisition, training improvements mainly result from two types of mechanisms: The first one (specialization) refers to practice-induced improvements at the level of individual operations that become tied to specific processes. The second mechanism (compilation) results in across-operation improvement, so that a sequence of several operations can be replaced with a single, higher-order operation. Thus, compilation would be reflected in improvements in the performance of a more complex task as a whole, leading to improved working-memory efficiency at retrieving task-relevant information and to better transition across operations. This concept is in line with Logan’s (1988) theory that increasing automatization of the single ‘component’ tasks involved in the performance of complex tasks leads to performance improvements after practice, and also fits the interpretation that practice effects observed after task-switching training have been attributed to task specific effects, such as the strengthening of stimulus-response rules or specific associations between cues and tasks (Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995).

Over the years, various researchers have also dealt with the question which processes or abilities are actually transferred after training. More than 100 years ago, Thorndike and Woodworth (1901) published an experiment that was crutial for the development of transfer-related theories. They trained participants in estimating the area of triangles in different sizes. After performance had improved, the area of other geometric shapes, such as circles and trapezes, had to be estimated. However, participants previously trained to estimate the triangles did not perform better than untrained subjects. Based on this finding, Thorndike (1903) proposed his 'identical elements theory', suggesting that transfer depends on having shared elements in training and transfer tasks; the larger the number of such shared elements, the greater the likelihood that transfer will occur. In 1989, Singley and Anderson updated Thorndike's theory by suggesting that the relevant elements are rules applying both in training and transfer tasks, while Schumacher and Gentner (1988) pointed to the importance of a structural match between training and transfer task based on the systematicity and the transparency of the correspondence. MacKay (1982), Kramer, Strayer, and Buckley (1990), as well as Rickard and Bourne (1996) have discussed other versions of the identical elements theory. They assume that the shared elements can be abstract, that is, they pertain to whatever declarative or procedural knowledge is relevant for the task at hand. However, after an extensive review of previous empirical findings, Schmidt and Bjork (1992) suggested that the most important principle is the overlap of processes practiced during training and required during transfer. Importantly, they point out that this overlap of relevant processes does not necessarily mean that there is overlap of the training and transfer conditions. Put differently, this theory assumes that transfer can occur when the transfer tasks require one or more abilities that were trained in the practice phase, regardless of the structure underlying the transfer and training tasks. Thus, it is assumed that near as well as far transfer should be possible.

How Long do Training and Transfer Effects Persist?

When it comes to cognitive training, the goal is not only to enhance specific abilities, but also to achieve a generalization and long-term maintenance of these training related improvements. The question whether or not training can have longer-lasting effects has been a controversial issue for years (for a review, see Klauer, 2001). Some authors assume that training benefits, just like any other memory content, are eventually lost over time. Others, however, argue that training benefits increase over time, because the initial training triggers developmental progress. This ‘head start’ can be used and extended, so that the developmental gap becomes wider (“scissor-effect”; cf. Coleman et al., 1966). Just as these theoretical positions, empirical evidence is ambiguous. Most studies including follow-up measurements after training and posttest were completed found decreasing transfer effects. Whether this transfer was still reliable at follow-up depended on the size of the initial training effect, the time interval between posttest and follow-up, and the sample size (Klauer, 2001).

However, a number of studies also found long-term transfer effects in different age groups. Klauer (2001), for instance, reported relatively constant effects resulting from his inductive reasoning training program for up to 2 years (cf. Adey & Shayer, 1993; Burrmann, 1999). Klingberg and colleagues (2002b, 2005) reported the retention of training and transfer benefits after working-memory training in ADHD children up to a three-month follow-up. Results from the aging literature point into the same direction: Derwinger, Stigsdotter Neely, and Bäckman (2005) investigated the effects of memory training in older adults aged 61-81 years and found that training-related gains were sustained over an 8-month interval. Likewise, a study from Vance et al. (2007) demonstrated that speed-of-processing training for older adults resulted in performance improvements that were robust over a 2-year period (for similar results after fluid-intelligence and attention training, see Blieszner, Willis, & P. B. Baltes, 1981; Plemons, Willis, & P.B. Baltes 1978; Willis, Cornelius, Blow, & P. B. Baltes, 1983). Most striking, however, are the results involving the SIMA-program, designed to maintain and support independent living in older age. Several studies showed that combined memory and psychomotor training had positive long-term effects on cognitive performance for up to five years (e.g., Oswald, 2004; Oswald, Hagen, & Rupprecht, 1998; cf. Ball et al., 2002). Empirical evidence for long-term transfer (more than 2 months) of executive control training in a sample of autistic children comes from Fisher and Happé (2005), and from Kramer, Larish, and colleagues (1999) for younger and older adults (both studies are described below, see p. 72). In sum, these results support the view that training and transfer benefits can indeed be maintained across a longer period of time.

Who Benefits from Training? Are Training and Transfer Benefits Predictable?

Training programs have become a frequently applied type of intervention in populations with cognitive deficits associated with a wide range of conditions, such as schizophrenia, head trauma, multiple sclerosis, dementia, and normal aging (for reviews, see Bissig & Lustig, 2007; Royall et al., 2002), and they can lead to significant changes in behavior and brain function (e.g., Ball et al., 2002; Jennings, Webster, Kleykamp, & Dagenbach, 2005; Nyberg et al., 2003; Rueda et al., 2005). However, although many training programs are successful at the group level, individual differences with respect to the degree of improvement are relatively large (see Bissig & Lustig, 2007). Therefore, the differential aspects of training and transfer are of great interest, especially for the adaptation of training programs to populations with special needs. Specifically, the question is whether individual training and transfer effects can be predicted. Again, there are two controversial theoretical views. The first idea is that training has compensatory effects in the sense that low-performing participants benefit more than high-performing participants. Put differently, the worse subjects perform prior to training, the larger the training and transfer benefits. According to this theory, training would result in reduced within-group variance. The second position is referred to as “Matthew [Matthäus]”-effect[10], assuming that better performers benefit more from training. If this was true, the within-group variability should be increased after training.

Unfortunately, empirical findings regarding training-related changes in variance are very unclear (cf. Ackerman, 1987; Bissig & Lustig, 2007; Klauer, 2001). Some studies showed that the training benefits were smallest for those individuals who needed them most, that is, lower initial cognitive status and more advanced age were associated with smaller training-related improvements (e.g., P. B. Baltes & Kliegl, 1992; Verhaeghen et al., 1992; Yesavage, Sheikh, Friedman, & Tanke, 1990). However, there also is considerable evidence from task-switching studies pointing to larger training benefits in children and older adults compared to younger adults (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). Given that these variance changes are critical for the measurement of inter-group differences, they seem particularly problematic. Moreover, they also affect the calculation of status-benefit correlations often used to provide evidence for one of the contradictory positions (compensatory vs. “Matthew”-effects). While the first one predicts negative correlations between status and training/transfer benefit, the latter one assumes that these correlations are positive[11].

Evaluation of Training and Transfer Effects

The effectiveness of cognitive training programs can be evaluated, and most importantly, compared to other types of training or other training conditions. The consequences for the application of a given type of training are obvious: If we know under

[10] This effect was named after Matthew 13, 12: “For whoever has, to him more shall be given”.
[11] It should be noted that the simple status-benefit correlation is often lower than the true correlation because the pretest error enters the status-benefit correlation twice (Bereiter, 1967). Klauer (2001) suggested using a complex design including parallel versions of the pretest and posttest measures and the application of the Lord (1967) correction factor.

which circumstances transfer is likely to occur, we can systematically vary training characteristics in order to optimize the training and to adapt it to the needs of the participants. Within his research on cognitive training, Klauer (2001) proposed a simple multi-step strategy for the evaluation of training programs. His focus was on the question whether the training not only improved performance on the training task, but also the underlying cognitive abilities. The evaluation program consists of several steps; the most important ones are briefly discussed in this section and illustrated in Figure 6.

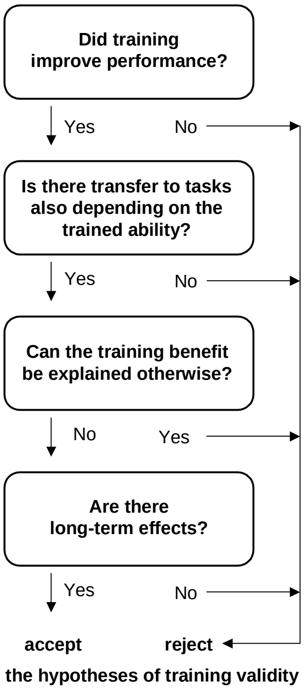

Figure 6: Klauer's strategy for the evaluation of training programs. Figure adapted from Klauer (2001).

Step 1: Confirm that performance has improved. This first step, of course, is a given: If our goal is to train a specific ability, then we have to analyze whether performance is actually improved after training. However, how much improvement is necessary in order to consider training effective? In the literature, two criteria are frequently applied: (1) Klauer (2001) suggested to that the effect size of the training effect should be at least .30, while (2) other authors calculated the proportion of participants showing training-induced benefits (cf. Derwinger et al., 2003), which should be larger than 50%.

Step 2: Analyze transfer to other dependent variables. Klauer (2001) assumed that after successfully training a specific ability, this training-related benefit should influence performance on other tasks relying on this ability. Thus, near and far transfer should be examined.

Step 3: Exclude alternative explanations. In order to exclude alternative explanations for improvements at the end of training, such as motivational or attendance effects, appropriate experimental designs are required, including training groups that only differ regarding one relevant aspect.

Step 4: Show long-term effects. Finally, long-term training effects should be examined (cf. Belmont & Butterfield, 1977; Hasselhorn, 1987) in order to prove that the training resulted in lasting improvement of the respective cognitive ability. However, given that the expression “long-term” is a bit vague and the maintenance of training benefits depends on the frequency the training ability is used after training, Klauer (2001) suggests that the training effect should still be present three months after training has ended.

In sum, it seems not only important to consider training-related benefits and their transferability on the level of group mean performance, but also to investigate the effect sizes and the proportion of transfer as well as the questions how long training and transfer benefits persist and whether they can be predicted.

Empirical Evidence for Near and Far Transfer of Executive Control Training

While most studies with respect to transfer of training have focused on inductive reasoning (e.g., Brown & Kane; 1988; Ferrara, Brown, & Campione, 1986; Roth-van der Werf et al., 2002; for reviews, see Hasselhorn & Hager, 2006; Klauer, 1995, 2001), problem solving (e.g., Butterfield & Nelson, 1991; Crisafi & Brown, 1986; Holyoak, Junn, & Billman, 1984;

Novick, 1988, 1990), fluid abilities (e.g., P. B. Baltes, Kliegl, & Dittman-Kohli, 1988; P. B. Baltes, Sowarka, & Kliegl, 1989; Edwards et al., 2005; Hayslip, 1989) and memory strategies (e.g., Derwinger et al., 2003; Jennings et al., 2005; Pressley, 1982; Ringel & Springer, 1980; Ryan, Ledger, & Weed, 1987; Singer et al., 2003), empirical evidence for the transfer of training in executive control is scarce, and studies adopting a lifespan perspective do not exist. However, there are a few studies focusing on childhood development or cognitive aging indicating that transfer of executive control training can be achieved. In the following section, these studies are reviewed with emphasis on experiments including different age groups.

Transfer of Executive Control Training in Childhood

Klingberg and colleagues (2002b) examined 7 to 15-year-old children with attention-deficit and hyperactivity disorder (ADHD) by means of a training paradigm including adaptively adjusted difficulty levels. They demonstrated that working memory training not only improved performance in other working-memory tasks (near transfer), but also performance in other tasks assumed to rely on executive control, such as the Stroop task, or to fluid intelligence tasks (far transfer) (cf. Klingberg et al., 2005). In the same study, similar positive effects of working memory training were also obtained in a group of younger adults (for near and far transfer of memory training in older adults, see Jennings et al., 2005). In a later study, Klingberg and colleagues (2005) showed that the working-memory training also resulted in a reduction of the parent-rated inattentive symptoms of ADHD, and that the transfer benefits were still found at a follow-up three months later.

Although studies including preschool children usually do not apply the task-switching paradigm (see p. 45), there is evidence for the transfer of executive control training in this age group. Kloo and Perner (2003), for instance, investigated the development of executive control and theory of mind in 3 to 4-year-olds by means of the DCCS (Dimensional Change Card Sort, see p. 45) and the false-belief task. They found that DCCS training improved performance on the false-belief task and vice versa, suggesting a close developmental link between executive abilities and theory of mind. Similarly, Fisher and Happé (2005) trained autistic children (6 – 15 years of age) either in theory of mind tasks or in executive control. Participants were tested before training, after training, and at a two-month follow-up. Results showed performance improvements in theory of mind tasks after both types of training that were still present at follow-up.

Rueda and colleagues (2005) recently examined the efficiency of attentional networks after 5 days of training across the ages of 4 to 6 years. The training included different 'executive' exercises, among them a spatial navigation task, a Stroop-like task and an inhibitory control task. After training, both age groups showed more mature performance regarding behavioral scores of the executive attentional network (measured by the Attention Network Test, basically a modified version of the flanker paradigm), ERP measures and intelligence test scores. Thus, training in executive tasks generalized to other executive tasks (near transfer), as well as to aspects of intelligence quite remote from the training tasks (far transfer). In another study, Dowsett and Livesey (2000) examined effects of experience on the development of inhibitory control by exposing young children (3 – 5 years of age) to training on tasks requiring executive functioning. They showed that practice in a go/nogo task improved performance on that same task; but interestingly, children showed even more improvement in the go/nogo task when they were trained with other executive tasks, namely a modified version of the WCST and a card change task. Hence, inhibitory control was improved via training with tasks requiring executive processes other than response control (far transfer). It should be noted, however, that the practice/training variable in this study was confounded with a feedback/no feedback variable; the positive training effects thus may be partly due to the explicit feedback in the training condition (feedback effects are addressed below). Nevertheless, the results reported in this study point into the same direction as those obtained by Rueda et al. (2005).

Transfer of Executive Control Training in Older Age

Several studies have shown that training can substantially reduce older adults' deficits in dual-task performance (Bherer et al., 2005; Kramer et al., 1995; Kramer, Larish, et al., 1999). Kramer and colleagues (1995) found that younger and older adults can learn to effectively coordinate the performance of two tasks and that older adults benefited more from training than younger adults did. Moreover, the training-related benefits transferred to a novel dual-task situation (near transfer) and were retained for up to 2 months. Thus, executive control skills, such as the coordination of multiple tasks, could be substantially improved in both younger and older adults. However, using a PRP design (psychological refractory period, see p. 39), Maquestiaux and colleagues (2004) showed that extensive practice alone did not foster the development of efficient dual-task strategies. They assumed that an improvement in dual-task performance may only be observed when participants are explicitly trained to perform multiple tasks, for instance by means of adaptive feedback (effects of feedback on transfer are discussed below) or prioritization strategies (cf. Kramer et al., 1995; Kramer, Larish, et al., 1999).

Therefore, Bherer et al. (2005) examined the extent to which age-related deficits in dual-task performance can be moderated by training in younger and older adults. Subjects were provided continuous adaptive feedback and priority instructions (indicating which task to respond to first) during the training sessions. Moreover, the authors assessed whether acquired task coordination skills generalized to untrained stimuli, within as well as across-modalities (i.e., from auditory to visual stimuli). Results revealed that both younger and older adults showed training-related benefits in terms of response speed, general switch costs, specific switch costs, and accuracy, with greater improvements for older adults on the level of accuracy. Together with a number of findings from Kramer and colleagues (1995, 1999) (see also Cepeda et al., 2001; Kray et al., in press; Kray & Lindenberger, 2000; Minear et al., 2002), this argues against the often-reported observation of reduced training benefits for older adults compared to younger adults (Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995). Importantly, in both age groups the training-related improvement with respect to general and specific switch costs generalized to new task combinations involving new stimuli, within as well as across task modalities (near transfer) (cf. Kramer et al., 1995). “Thus, the transfer data suggest that participants learned a somewhat generalizable set of skills that entailed the ability to prepare and to perform multiple tasks as well as the ability to perform multiple tasks concurrently” (Bherer et al., 2005, p. 707).

Finally, Minear (2004) reported a series of five experiments focusing on the transfer of task-switching training. Given that her study is particularly important for the present experiment, it will be reported more extensively. In order to assess the transfer of task-switching training, participants performed an intensive two-day task-switching training (i.e., mixed-task blocks only). This group was compared to a control group performing the same amount of single-task training (i.e., single-task blocks only). The first two experiments showed a reduction of general and specific switch costs after training. However, only the improvement in general switch costs transferred to a new, untrained switching task. This finding was consistent across an internally cued as well as a cue-based switching paradigm. In three further experiments, Minear (2004) investigated whether the effects of training are specific to the context of a particular paradigm, that is, whether training by means of a predictable paradigm transfers to a random paradigm and vice versa. Results replicated the findings from the first two experiments by showing transfer on the level of general switch costs within one paradigm, but no evidence for transfer from one training regimen to another, indicating that the transfer benefits seem to be limited to the paradigm in which one is trained. The author agued that participants in both paradigms improved during training due to strategic shifts in goal selection; however, this change may have been associated with different trial type expectancies after practice in the random group, while the performance improvements in the predictable paradigm may be due to improved task preparation.

Finally, there is another study from Minear and colleagues (2002), which is particularly important for the present study. The authors examined age differences between younger and older adults in the transfer of task-switching training - compared to the training of the two single tasks - to a similar switching task by means of an internally cued switching paradigm. Both younger and older adults showed a substantial reduction of general switch costs after 2 days of training. In contrast to the training of the two single tasks, task-switching training resulted in the transfer of these training gains (i.e., a reduction of general switch costs) to a non-trained similar switching task (see Figure 7). This transfer effect was more pronounced for older adults than for younger adults. This study provides evidence that executive control training can transfer to non-trained but structural similar tasks (i.e., near transfer) in younger and older adults (cf. Bherer et al., 2005; Kramer et al., 1995; Kramer, Larish, et al., 1999). Thus, it seems that training can reduce general and specific switch costs and that particularly the benefits on the level of general switch costs can be transferred to new, non-trained switching tasks in different age groups.

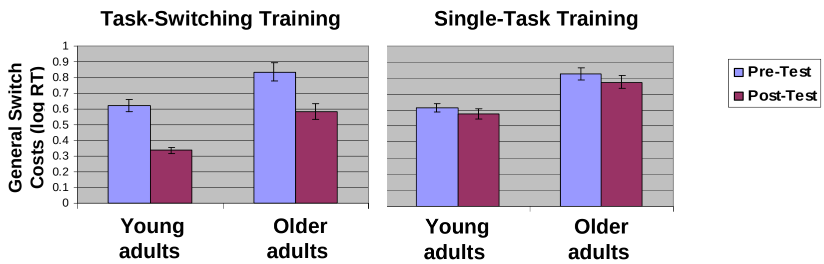

Figure 7: Reduction of general switch costs from pretest to posttest as a function of age group (younger adults, older adults) and training group (single-task training, task-switching training). Figure adapted from Minear, Shah, and Park (2002).

To sum up, there is a growing body of evidence supporting the view that after intensive executive control training, near transfer to structurally similar tasks (Bherer et al., 2005;

Kramer, et al., 1995; Kramer, Larish et al., 1999; Minear et al., 2002) and even far transfer to structurally dissimilar tasks (Dowsett & Livesy, 2000; Fisher & Happé, 2005; Jennings et al., 2005; Klingberg et al., 2002b; Klingberg et al., 2005; Kloo & Perner, 2003; Rueda et al., 2005) is possible in different age groups. However, there is a lack of studies systematically investigating the occurrence of near and far transfer effects based on lifespan samples.

Promoting the Transfer of Cognitive Training

After reviewing empirical evidence for transfer of training, this last paragraph focuses on conditions increasing the occurrence and the amount of transfer. Previous studies have identified a number of potential factors, such as the degree of similarity between training and transfer tasks (e.g., Crisafi & Brown, 1986; Gentner & Toupin, 1986; Holyoak et al., 1984; Roth-van der Werf et al., 2002; Schumacher & Gentner, 1988; but see Novick, 1990), individual differences in intellectual abilities (e.g., Ferrara et al., 1986; Klauer, 1996, 1997), the time interval between training and posttest (e.g., Hayslip, 1989), and the type of instruction during training and posttest (e.g., Brown & Kane, 1988; Crisafi & Brown, 1986; Holyoak et al., 1984; see also Reder, Charney, & Morgan, 1986; Ryan et al., 1987). However, here the focus is on two manipulations particularly important for this study, namely feedback and training variability.

Feedback and Transfer

The modulation of age differences in task-switching abilities by means of verbal processes has been discussed above (see p. 52). Specifically, verbal self-instructions performed during task switching strongly supported the maintenance and selection of task sets (Kray et al., in press). This benefit was most pronounced for younger children and older adults, so that age differences in general switching costs were reduced. These results suggest that verbal self-instructions are a useful tool for reducing action-control deficits in childhood and older age. However, although these findings point to an important function of verbal processes for action control, effects of verbal self-instruction training are not always easily transferable to other situations. Especially older adults and children often fail to spontaneously use verbal strategies in new task situations (Flavell, Beach, & Chinsky, 1966; Meichenbaum, 1974; Ringel & Springer, 1980; cf. Salomon & Perkins, 1989). The tendency that young children do not use language at appropriate points in the task situation, thereby precluding facilitation effects, has been referred to as deficiency hypothesis (Flavell et al., 1966; for a review, see Bjorklund, Miller, Coyle, & Slawinski, 1997). It has been suggested that this speech production deficiency may be due to the absence of knowledge about the value of rehearsing, that is, a lack of awareness regarding the effectiveness of strategy use. Likewise, Salomon and Perkins (1989) pointed to the problem of “inert knowledge” and suggested that explicit instructions emphasizing the usefulness of transfer strategies can foster positive transfer.

One way to raise the children’s awareness of a strategy’s effectiveness is to provide explicit feedback regarding task performance and strategy value. Thereby, an evaluation process is initiated and awareness of the strategy’s effectiveness is increased. In fact, when provided feedback, children are more likely to use a strategy in a new task situation and to show positive transfer effects (Kennedy & Miller, 1976; Ringel & Springer, 1980; cf. Dowsett & Livesey, 2000). Kennedy and Miller (1976), for instance, trained children to verbally rehearse in a serial recall task, resulting in superior task performance. Given the option of rehearsing, only those children provided feedback regarding the strategy’s value persisted in using it. Similarly, Ringel and Springer (1980) explored children's transfer of learning strategies, assuming that a self-monitoring process is essential for evaluating one's own level of performance and the effectiveness of various mnemonic strategies. In fact, only children provided with feedback and strategy instruction continued to rely on the strategy when faced with transfer tasks, and in addition showed positive transfer effects (cf. Dowsett & Livesey, 2000).

Training Variability and Transfer

When researchers examine the transfer of training, they usually ask subjects to engage in practicing some task in a training phase, in which one or more independent variables are manipulated. The nature of the independent variable can be of various types, such as the type of instructions, feedback, or training tasks. Performance on the training tasks is typically analyzed as a function of practice for the different levels of the independent variable. The logic of this kind of paradigm is that those training conditions resulting in most effective performance during this training phase also are the most effective for learning the respective tasks.

However, there is considerable evidence indicating that conditions facilitating performance during training are not always the most effective conditions to support the acquisition of a generalizable skill. In contrast, manipulations decreasing the speed of skill acquisition during training can support its long-term goals (for reviews, see Rosenbaum et al., 2001; Salomon & Perkins, 1989; Schmidt & Bjork, 1992). Among these types of training is variable training, that is, exposing subjects to different material during practice. According to Rosenbaum and colleagues (2001), using the same materials during training (constant training) leads to better performance at the end of training but to worse performance in later transfer tests. By contrast, exposing learners to different materials (variable training) leads to worse performance at the end of training but better performance in later tests, and even to more transfer. The long-term benefit of variable training has been observed with perceptual-motor, verbal and intellectual tasks (for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992; Shapiro & Schmidt, 1982). Thus, the time at which the effectiveness of training is assessed seems to be critical, especially because faster and easier training conditions are often considered to produce more effective learning (see also Bjork, 1994).

When it comes to age differences regarding the influence of variable training on the amount of transfer, empirical evidence is scarce. Sanders, Gonzalez, Murphy, Pesta, and

Bucur (2002), for instance, have shown that high variability training in mental calculation tasks resulted in inferior performance at the end of training, but in transfer to non-trained tasks in young adults. In contrast, there was no difference in performance between the high and the low-variability training condition in older adults. With respect to executive functions, Kramer et al. (1995) showed that dual-task abilities could be trained and transferred in younger and older adults (see p. 57). Interestingly, a greater improvement was found when participants were trained in a variable-priority condition compared to a fixed-priority condition, supporting the view that learning to modulate attention may be crucial in the acquisition of task-coordination skills (cf. Gopher, Weil, & Siegel, 1989). Compatible with these findings is the view that the amount of transfer varies as a function of automatization (cf. Frensch & Sternberg, 1989; Sternberg & Frensch, 1989). Specifically, it is assumed that transfer of training is more likely the more automatized the trained abilities have become. However, this account also assumes that transfer may be impaired if the degree of automatization becomes too large, because subjects fail to flexibly adapt to new task demands. Put differently, if one practices one task or one strategy over and over again, one may fail to adapt this strategy to the changing demands of new, unpracticed task situations.

In sum, there is evidence suggesting that, at least in children, feedback regarding the strategy value can promote transfer. When it comes to adults, variable training can modulate performance in the training phase as well as the amount of transfer after training. Therefore, the present study investigated age differences in the influence of feedback and training variability on the transfer of task-switching training.

General Summary

In the first section of the theoretical part, different concepts of executive functions and their lifespan development have been reviewed. The term ‘executive functions’ refers to higher-level processes organizing lower-level processes in order to regulate behavioral activity allowing individuals to optimally adapt to continuous changes in the environment (cf. Baddeley, 2000; Duncan, 1995; Logan 2000; Norman & Shallice, 1986; Roberts & Pennington, 1996; Smith & Jonides, 1999). While most traditional models (e.g., Baddeley, 1986, 2000; Norman & Shallice, 1986) suggested the existence of a central control system, it is widely accepted these days that executive control is not a unitary construct, but consists of several separable control components, such as shifting, updating, and inhibition (cf. Fisk & Sharp, 2004; Huizinga et al., 2006; Kray & Lindenberger, 2000; Miyake et al., 2000). Empirical evidence indicates that executive control functions are closely linked to intellectual functioning (for reviews, see Kray & Lindenberger, 2007; Lindenberger & Kray, 2005), and that several executive abilities, such as interference control or the ability to maintain and select task-sets on the one hand, and the mechanic component of intellectual abilities on the other hand, have similar developmental trajectories, namely a marked increase from childhood to adolescence followed by a constant decline in older age (for a review, see Craik & Bialystok, 2006).

When it comes to the measurement of executive control, the task-switching paradigm (cf. Kray & Lindenberger, 2000; Rogers & Monsell, 1995; for a review, see Monsell, 2003) has become a well-established instrument to investigate executive control across a wide range of ages. In task-switching studies, participants are usually instructed to perform two simple tasks A and B, either in single-task blocks, in which only task A or B have to be performed separately, or in mixed-task blocks, in which subjects have to switch between both tasks. This design allows calculating two types of switch costs: General switch costs, measuring the ability to maintain and select task sets, and specific switch costs, referring to the ability to switch between them (for details, see p. 112, Method). There is considerable evidence indicating that the ability to select and maintain task sets follows a u-shaped developmental trend across the lifespan (Cepeda et al., 2001; Kray et al., in press; Kray et al., 2004; Reimers & Maylor, 2005), that is, a marked increase from childhood to adolescence followed by a constant decrement in older age (Bherer et al., 2005; Crone et al., 2004; De Jong, 2001; Karbach & Kray, 2007; Kray, 2006; Kray & Lindenberger, 2000; Mayr, 2001; Meiran et al., 2001). In contrast, the ability to switch between two tasks seems to be less affected by age (Crone et al., 2004; Karbach & Kray, 2007; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Mayr, 2001; Reimers & Maylor, 2005; for a review, see Verhaeghen & Cerella, 2002). On a more general level, these findings also support the view that executive control indeed consists of several separable components (cf. Fisk & Sharp, 2004; Huizinga et al., 2006; Kray & Lindenberger, 2000; Miyake et al., 2000).

Of particular importance for the present study was the question whether age-related deficits in task-switching abilities can be improved by means of cognitive training. Cognitive interventions (Kramer & Willis, 2002) provide the opportunity to study age differences in cognitive plasticity, that is, one’s ability to improve performance after training (cf. Singer & Lindenberger, 2000). Prior evidence suggests that cognitive plasticity is considerable across the lifespan (e.g., Brehmer et al., 2007; Cepeda et al., 2001; Derwinger et al., 2003; Kramer, Hahn, et al., 1999; Kramer et al., 1995; Kramer, Larish, et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000; Minear et al., 2002; Schaie & Willis, 1986; Verhaeghen et al., 1992), but seems to be limited in very old age (Singer et al., 2003). Thus, the second section of the theoretical part focused on two types of cognitive interventions most important for the present study, namely verbal self-instruction training and intensive task practice. Prior studies indicated that verbal processes support the retrieval and activation of task goals, especially when the availability of external task cues is limited and the need for endogenous control is enhanced (Baddeley et al., 2001; Bryck & Mayr, 2005; Emerson & Miyake, 2003; Gruber &

Goschke, 2004; Miyake et al., 2004; Saeki & Saito, 2004). In line with this, particularly children and older adults can use verbal self-instructions to compensate for age-related executive control deficits on the level of task-set selection and maintenance (Kray et al., in press; see also Kray et al., 2004). Another way to modulate age-differences in task-switching abilities seems to be intensive training. A number of task-switching studies indicated that both types of switching costs could be reduced - but not eliminated - after practice, especially in children and older adults (Cepeda et al., 2001; Kray et al., in press; Kray & Lindenberger, 2000; Kramer, Hahn, et al., 1999; Minear et al., 2002), again pointing to compensatory effects in age groups characterized by marked executive deficits.

However, aside from investigating mere training-related benefits, their transferability to new, untrained situations is of particular importance for the application of training programs in the clinical and educational context. Therefore, the third section of the theoretical part was dedicated to the concept of transfer, that is, a successful application of training-related benefits in a new, unfamiliar situation. Despite the long tradition of training and transfer research, there is still no consensus whether and to which extent transfer can be achieved (for a review, see Barnett & Ceci, 2002). Most authors differentiate between several forms of transfer (e.g., Butterfield & Nelson, 1991; Dettermann, 1993; Mayer & Wittrock, 1996; Salomon & Perkins, 1989; Novick, 1990). For the purpose of the present study, two types of transfer are particularly important: Near transfer, referring to situations that are structurally similar, but differ regarding perceptual details (e.g., transfer of task-switching training with tasks A and B to tasks C and D), and far transfer, referring to situations with dissimilar task structure (e.g., transfer of task-switching training to the Stroop task). Transfer is usually measured by means of pretest - training - posttest designs, in which transfer is defined as performance improvement at posttest relative to baseline performance at pretest.

In order to explain the processes underlying the occurrence of transfer effects, a number of theoretical models have been put forward dealing with the question what processes and abilities change during training and can subsequently be transferred. Anderson (1982, 1987), for instance, assumes that training-related benefits emerge in two steps: First, specific operations are optimized, and second, several of these specific operations are replaced with a single, higher-order operation, resulting in performance improvements in complex tasks. When it comes to the transfer of training benefits, traditional models assumed that the larger the number of shared elements between training and transfer tasks is, the more likely transfer occurs ('identical elements theory'; Thorndike, 1903; see also Singley & Anderson, 1989). However, in the light of more recent findings, it seems more likely that transfer occurs when the transfer tasks require one or more abilities that had been trained before, regardless of the structure underlying these tasks (for a review, see Schmidt & Bjork, 1992).

Training programs have become a frequently applied type of intervention in populations with executive deficits associated with a wide range of conditions (for reviews, see Bissig & Lustig, 2007; Royall et a., 2002), leading to significant changes in behavior and brain function (e.g., Ball et al., 2002; Jennings et al., 2005; Nyberg et al., 2003; Rueda et al., 2005). However, individual differences with respect to the degree of improvement are relatively large (see Bissig & Lustig, 2007). Therefore, the differential aspects of training and transfer are of great interest, especially for the adaptation of training programs to populations with special needs, such as children and older adults. However, evidence regarding the prediction of training benefits is ambiguous – some studies found that lower initial cognitive status predicted less training benefits (Verhaeghen et al. 1992; Yesavage et al., 1990), while others found that it was associated with larger training benefits (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002).

Previous research indicated that the transferability of cognitive training seemed to be limited. Positive transfer is most often confined to near transfer, that is, performance in new, non-trained tasks only improves when these tasks are structurally similar to the training tasks (near transfer), but not if they are structurally dissimilar (far transfer). Thus, it seems that cognitive training primarily taps into task-specific components that cannot be transferred to new structurally dissimilar tasks (e.g. Derwinger, et al., 2003; Klauer, 1989a, 1989b; Roth-van der Werf et al., 2002; but see Kramer et al., 1995). However, a number of recent studies suggest that a larger generalization of training-related benefits can be achieved in different age groups. For instance, working memory as well as executive control training in children was transferable to structurally similar and dissimilar tasks (Dowsett & Livesey, 2000; Fisher & Happé, 2005; Kloo & Perner, 2003) as well as to aspects of intelligence quite remote from the training tasks (Klingberg et al., 2002b; Klingberg et al., 2005; Rueda et al., 2005). Evidence for the transfer of executive control training in adults mostly comes from dual-task studies, indicating that younger as well as older adults can transfer training-related benefits to novel dual-task situations (Kramer et al., 1995; Kramer, Larish, et al. 1999). Meanwhile, this finding has also been replicated for task-switching performance, that is, younger and older adults were able to transfer training-related benefits on the level of switch costs to new untrained switching tasks (Bherer et al., 2005; Minear et al., 2002).

Finally, reviewing the literature also suggests that a number of experimental manipulations can serve to manipulate the occurrence and the amount of transfer (for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Most important for this study is the finding that explicit feedback indicating the value of certain training strategies, such as verbal self-instructions, can foster transfer in children (Kennedy & Miller, 1976; Ringel & Springer, 1980; for e review, see Bjorklund et al., 1997). Moreover, transfer in adults can be increased by means of variable training, that is, exposing participants to different training tasks or conditions during training (Kramer et al., 1995; Sanders et al., 2002; for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992; Shapiro & Schmidt, 1982). The aim of the present study was to examine age differences in the near and far transfer of task-switching training and its modulation by different types of training. Based on relevant previous findings, the research design along with the hypotheses is presented in the next section.

3. Statement of Problem and Research Hypotheses

The review of the literature provided in the previous section presented considerable evidence for age-related changes in executive functioning, pointing to the multidirectionality and the multidimensionality of cognitive development across the lifespan (cf. Baltes, 1990). Most important in the context of the present study are findings with respect to age differences in task-switching abilities (Bherer et al., 2005; Cepeda et al., 2001; Crone, Bunge et al., 2006; Crone et al., 2004; Karbach & Kray, 2007; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray et al., 2002; Kray & Lindenberger, 2000; Mayr, 2001; Meiran et al., 2001; Reimers & Maylor, 2005). Although a number of previous experiments have assessed the effect of intensive task-switching training (e.g., Allport et al., 1994; Cepeda et al., 2001; De Jong, 2001; Jersild, 1927; Kramer, Hahn, et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000; Minear, 2004; Minear et al., 2002; Rogers & Monsell, 1995), the transferability of these training-related gains to new, untrained task situations has widely been neglected (but see Minear, 2004; Minear et al., 2002). Even though one task-switching study indicated that transfer of training-related benefits is possible in younger and older adults (Minear et al., 2002), there is no such evidence based on a sample including children as well as younger and older adults within one study, thereby allowing the direct comparison of age differences with respect to near transfer and a systematic investigation of far transfer based on the same tasks and paradigms within these age groups.

Given that the transferability of training-related gains in executive functioning is especially important not only for experimental psychology, but even more for the application of cognitive training programs in the clinical and educational context, it is certainly promising to investigate the conditions mediating and supporting the occurrence of transfer. In addition, it seems important to examine whether different groups of participants show differential benefits associated with different types of training, so that training programs can be adapted to the needs of different populations. Therefore, the general aim of this study was to examine age differences in the near and far transfer of task-switching training in children (8 – 10 years of age), younger adults (18-27 years of age), and older adults (63 – 76 years of age) under different training conditions. More specifically, the first goal was to investigate age differences in the near transfer of task-switching training to a similar switching task and the far transfer of task-switching training to other ‘executive’ tasks (Stroop task, working memory) and to another task domain (fluid intelligence). The second aim was to investigate whether the type of training modulated the amount of transfer. Since previous findings showed that particularly children and older adults can use verbal self-instructions to compensate for age-related deficits in general switching abilities (Kray et al., in press), the aim of the present study was to investigate whether these benefits associated with the verbalizations can be transferred to a similar switching task and to other tasks relying on verbal rehearsal processes (verbal working memory) after training. However, it seems that at least in children, the transfer of verbal strategies can be supported by means of explicit feedback indicating the value of the verbalization strategy during training (cf. Bjorklund, et al., 1997; Flavell et al., 1966; Kennedy & Miller, 1976; Ringel & Springer, 1980). Therefore, the present study also assessed age differences in the influence of feedback on the amount of task-switching and verbal self-instruction transfer. Finally, we know that transfer in adults can be increased by means of variable training (i.e., exposing participants to different material or changing task demands during training) (Kramer, Larish, et al., 1999; Sanders et al., 2002; for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Therefore, another goal of this study was to investigate the influence of variable training tasks (i.e., different training tasks in each training session) on the amount of transfer.

Overview of Study Design

In order to investigate age differences in the near and far transfer of task-switching training, a pretest - training - posttest design including four sessions of intensive training was applied to children, younger adults, and older adults. An alternating-runs paradigm (i.e., without external task cues) was chosen to increase participants reliance on internal verbal cueing during task performance (see p. 52). At pretest and posttest, participants performed a switching task similar to the one applied during training in order to investigate near transfer of task-switching training to a similar switching task. To examine far transfer of task-switching training, they also performed a battery of cognitive tasks at pretest and posttest, including other ‘executive’ measures (the Stroop task as well as verbal and visuospatial working memory tasks) and measures of fluid intelligence. Finally, to show that task-switching training does not result in transfer to tasks not relying on executive control, the cognitive test battery also included a number of control tasks (verbal sped, perceptual speed, and knowledge).

However, the present study also aimed at identifying the ‘optimal’ training conditions, that is, the training conditions yielding the largest transfer effects in each one of the age groups. Therefore, participants were assigned to one of five training conditions. The first two conditions were included to examine the ‘mere’ transfer of task-switching training. Specifically, the first group - serving as a control group - was only trained in single-task performance (i.e., single-task blocks), so that the training of executive control processes should be low. In contrast, the second group was only trained in task switching (i.e., mixed-task blocks), so that training in executive control should be intense (cf. Minear, 2004; Minear et al., 2002). Comparing the posttest performance of these two groups indicated whether participants in different age groups were generally able to transfer task-switching training benefits to other tasks. The remaining three training groups served to investigate whether this transfer can be promoted by means of different training conditions. Therefore, the switching training was combined with verbal self-instructions, feedback (indicating the value of this verbalization strategy), and training variability (i.e., different training tasks in each training session) (for details, see p. 118).

Research Predictions

The presentation of the research predictions is divided into three parts: The first part focuses on the task-switching training sessions, the second one on age differences in near transfer of task-switching training to a similar switching task, and the third one on age differences in far transfer to other 'executive control tasks' and other task domains. For each of these parts, empirical evidence is briefly subsumed and the corresponding predictions are presented.

Age Differences in Task-Switching Training Benefits

Given that the focus of the present study was on age differences in the near and far transfer of task-switching training rather than on training-related benefits in task-switching abilities, this part is kept relatively short. However, it should be noted that although it primarily is a control analysis, the inspection of the training data is very important for the interpretation of the subsequent transfer effects. Thus, the aim was to investigate age differences in the effects of the intensive four-session task-switching training on specific switching abilities as well as the role of training type for these training-related benefits. The present study included four task-switching training groups: One was only trained in task-switching, the second one additionally received verbal self-instruction training, and for the remaining two groups, the task-switching and verbal self-instruction training was either combined with feedback indicating the value of the verbalization strategy, or with training variability (for details, see p.

118). The training sessions for all four task-switching training groups completely consisted of mixed-task blocks, so that only specific switch costs could be inspected[12].

Prior research indicates that specific switch costs can be reduced - but not eliminated - by training in younger and older adults; however, there were no age differences in the amount of training-related benefits between younger and older adults (Bherer et al., 2005; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). For children, evidence for a reduction of specific switch costs after task-switching training is lacking.

Regarding the modulation of switch costs by means of verbal processes, prior evidence has shown that general switch costs (Baddeley et al., 2001; Saeki & Saito, 2004) are more sensitive to articulatory suppression than specific switch costs (Bryck & Mayr, 2005). So far, there is evidence for a reduction of general switch costs, particularly in children and older adults, when verbal self-instructions (i.e., task-relevant verbalizations) are performed during task preparation (Kray et al., in press; see also Goschke, 2000). However, the influence of the verbalizations on specific switch costs in prior studies was less pronounced.

Finally, the question is whether feedback and training variability have an effect on training-related benefits on the level of specific switching abilities. Feedback indicating the value of the verbalization strategy has been shown to support the occurrence of transfer benefits (Kennedy & Miller, 1976; Ringel & Springer, 1980), but not to modulate training performance. However, evidence from other experimental paradigms indicates that training-related benefits are modulated by training variability in young adults. More specifically, variable training is known to slow down skill acquisition during training, but to be superior in terms of retention and transfer afterwards (Sanders et al., 2002; for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Based on these findings, the predictions are:

[12] General age differences in both types of switching costs were inspected based on pretest performance; the respective hypotheses are presented below.

Prediction 1: (a) Specific switch costs will be reduced to a similar degree in younger and older adults as a function of training. *(b)* Given that the training in the present study was relatively intense, this reduction is also expected for children. *(c)* However, specific switch costs in all age groups will still be reliable after training.

Prediction 2: The influence of verbal self-instructions on specific switch costs and age differences therein is an open question. However, given that no external task-cues were provided during training, so that participants had to particularly rely on internal verbal cueing in order to maintain the task sequence, performing verbal self-instructions may lead to a reduction of specific switch costs compared to the group practicing task-switching without verbal self-instructions.

Prediction 3: Specific switch costs will not be modulated by feedback indicating the value of the verbalization strategy. That is, specific switch costs in the group performing verbal self instructions during task-switching training and receiving feedback will be similar to the group that performed the same type of training without being provided feedback.

Prediction 4: Variable training will result in larger specific switch costs than training involving the same tasks in each training session.

Prediction 5: Training-related benefits, (i.e., the reduction of specific switch costs from the first o the last training session) should be smaller after variable training than after training involving the same tasks in each session. The influence of verbalizations and feedback on training-related benefits on the level of specific switch costs is an open question.

Near Transfer of Task-Switching Training

One of the main goals of this study was to investigate age differences in the near transfer of task-switching training on the level of general as well as specific switch costs. Most previous studies indicated that age differences were more pronounced for general than for specific switch costs with larger costs for children and older adults than for younger adults (e.g., Cepeda et al., 2001; Crone et al., 2004; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Mayr, 2001; Verhaeghen & Cerella, 2002). However, only very few studies to date (Minear et al., 2002; see also Bherer et al., 2005) have provided evidence that task-switching training generalizes to non-trained, but structurally similar tasks (near transfer) in younger and older adults. Minear and colleagues (2002; see also Minear, 2004) found this transfer only on the level of general switch costs, and it was also more pronounced for older than for younger adults. However, in the Bherer et al. (2005) experiment, transfer was present for both types of switching costs, but there were no age differences in the amount of transfer. The aim of the present study was to replicate near transfer of task-switching training in younger and older adults and to extend this finding to childhood by comparing effects resulting from training only involving the two single tasks with effects resulting from task-switching training in children, younger, and older adults. Thus, the predictions were:

> *Prediction 6:* Age differences will be more pronounced on the level of general switch costs than on the level of specific switch costs. General switch costs will be characterized by a u-shaped age function, that is, the costs will be larger in children and older adults than in younger adults.

Prediction 7: Near transfer (i.e., the reduction of general and specific switch costs from pretest to posttest) will be larger for the groups that were trained in task switching than for the groups only trained in single-task performance.

Prediction 8: The reduction of general switch costs from pretest to posttest (i.e., near transfer) will be more pronounced for older adults than for younger adults. However, the amount of near transfer in children is a fully open question.

Also in the focus of the present study was the question whether near transfer can be modulated by means of verbal self-instructions, feedback, and training variability. It has been demonstrated for memory or reasoning tasks that verbal self-instruction training resulted in greater performance improvements than practicing the tasks without verbal strategies (Asarnow & Meichenbaum, 1979; Derwinger et al., 2003; Kennedy & Miller, 1976; Meichenbaum & Goodman, 1971). With respect to task switching, Kray et al. (in press) showed that verbal self-instructions proved to be effective for enhancing the selection and maintenance of task sets (i.e., general switch costs), especially in children and older adults. However, the influence of the verbalizations on specific switch costs was less pronounced. In the present study, subjects will be instructed to label the upcoming task goal during the preparation interval, that is, to say aloud the alternating task sequence (cf. Kray et al., in press; Kray et al., 2004). The question is whether performance improvements associated with verbal self-instructions performed during training can be transferred to a similar switching task after training. Based on findings from Kray et al. (in press), the hypotheses for this study are:

Prediction 9: The reduction of general switch costs from pretest to posttest will be larger for the groups trained in task switching and the use of verbal self-instructions than for the groups only trained in task switching without the verbal strategy.

Prediction 10: This near transfer of task-switching and verbal self-instruction training may be more pronounced for children and older adults compared to younger adults.

Prediction 11: For specific switch costs, there should be less or no difference in the amount of transfer between the groups that were trained in task switching and verbal self-instructions and those only trained in task switching without the verbalizations.

Although the findings from Kray and colleagues (in press) point to an important function of verbal processes for action control, effects of verbal self-instruction training are not always easily transferable to other situations. Especially children fail to spontaneously use verbal strategies in new task situations (Flavell et al., 1966; Ringel & Springer, 1980; Salomon & Perkins, 1989). It has been suggested that this lack of transfer is due to subjects not evaluating the outcome of their own actions and not being aware of the training strategy's value (Flavell et al., 1966). One way to raise the children's awareness of a strategy's effectiveness is to provide explicit feedback regarding their task performance and the strategy value (cf. Dowsett & Livesey, 2000; Kennedy & Miller, 1976; Ringel & Springer, 1980). Thereby, an evaluation process is initiated and awareness of the strategy's effectiveness is increased. In sum, there is evidence suggesting that at least in children, feedback regarding the value of a verbal training strategy can promote transfer of this strategy to a similar task after memory training. Thus, participants in the present study periodically received feedback indicating the usefulness of the verbalization strategy (for details, see p. 119). The aim was to investigate whether the increase in transfer associated with feedback in other paradigms is also found after task-switching and verbal self-instruction training, that is, whether the amount of near transfer can be modulated by means of explicit feedback.

Prediction 12: At least for children, the reduction of general switch costs from pretest to posttest (i.e., near transfer) may be larger for the groups receiving feedback emphasizing the value of the verbal strategy than for the groups only receiving task switching and verbal self-instruction training without feedback. This modulation of verbal self-instruction transfer by means of feedback should not be found – or at least to a smaller extent – for adults.

Prediction 13: Given that the influence of verbal processes on near transfer with respect to specific switch costs should be limited, there probably will be no modulation of this near transfer by feedback regarding the verbal strategy. That is, the pretest-posttest reduction of specific switch costs in this group will be similar to the task-switching training group.

Several studies have focused on other conditions supporting the occurrence of transfer. These experiments indicated that some types of training are known to slow down skill acquisition during training, but to be superior in terms of retention and transfer afterwards (for a review, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Among these types of training is variable training, that is, exposing subjects to different material during practice. Sanders and colleagues (2002), for instance, have shown that high variability training in mental calculation supported transfer to non-trained tasks in young adults. Likewise, transfer of dual-task training was increased in younger and older adults when training tasks were variable (Kramer et al., 1995). The aim of this study was to investigate whether variable training also promotes the near transfer of task-switching training. Therefore, participants in the variability group were trained with different tasks and stimuli in each training session. The corresponding prediction is:

Prediction 14: Near transfer of task-switching training will be larger after variable training than after training involving the same tasks in each training session, at least for adults. That is, the reduction of general switch costs from pretest to posttest will be larger in the variable training group than in the groups practicing the same tasks in each training session. Effects regarding children are an open question.

Far Transfer of Task-Switching Training

Aside from near transfer to a similar switching task, this study also investigated far transfer to other ‘executive control tasks’, namely the Stroop task as well as to verbal and visuospatial working memory tasks. Given that these transfer tasks share executive control demands with the switching task applied during training, such as the inhibition of currently irrelevant information and the online maintenance of task-relevant information, it seems reasonable to expect transfer effects (cf. Schmidt & Bjork, 1992). Also, far transfer to another task domain (fluid intelligence) was investigated. Prior evidence for far transfer of executive control training is very limited – however, there are a few studies indicating that far transfer (of executive control training other than task switching) to other executive control tasks (Dowsett & Livesey, 2000; Fisher & Happé, 2005; Kloo & Perner, 2003; Rueda et al., 2005) and even to aspects of fluid intelligence (Klingberg et al., 2005; Klingberg et al., 2002b; Rueda et al., 2005) can be achieved in children. Evidence for far transfer of executive control training in adults is lacking, and so are findings for the modulation of far transfer by means of verbalization, feedback, and variability. It should also be noted that no prior task-switching studies have investigated far transfer of training. Thus, the aim of this study was to provide first evidence for far transfer of task-switching training to other ‘executive’ tasks and to another task domain in different age groups. Given that transfer is usually less pronounced the more dissimilar the training tasks and transfer tasks are (cf. Klauer, 2001), one would also expect less modulation of these far transfer effects by the type of training (i.e., verbalizations, feedback, and variability). Since there is no prior evidence for far transfer of task-switching training, most of the following predictions are relatively unspecific. The hypotheses are structured along the different far transfer measures (i.e., the Stroop task, verbal working memory, visuospatial working memory, and fluid intelligence):

Prediction 15: If task-switching training improves executive control processes, such as the ability to inhibit currently irrelevant information, far transfer (i.e., the reduction of Stroop interference from pretest to posttest) should be larger after task-switching training than after single-task training[13].

Prediction 16: If task-switching training also fosters executive control processes on the level of task maintenance, then far transfer to verbal and visuospatial working memory (i.e., an increase of correctly recalled items from pretest to posttest) should be larger after task-switching training than after single-task training.

Prediction 17: Also, given that especially verbal working memory is supposed to rely on internal verbal rehearsal processes, this far transfer may be larger for participants receiving additional verbal-self-instruction training. For children, this effect may only be found when feedback emphasizing the value of the verbalization strategy was provided during training.

[13] This phrasing may sound confusing – transfer is of course only expected after task-switching training, and not after single-task training. However, given that participants performed the tasks for the second time at posttest (the pretest being the first time), there may also be a certain performance increment at posttest simply reflecting retest effects. Therefore, transfer effects after task-switching training should exceed this retest effect. This note applies to all transfer measures.

Prediction 18: Consistent with prediction 16 (verbal working memory), far transfer to visuospatial working memory (i.e., an increase of correctly recalled items from pretest to posttest) should be larger after task-switching training than after single-task training.

Prediction 19: Given that executive control and intellectual abilities seem to be closely related (see p. 34), far transfer to fluid intelligence (i.e., an increase of correctly solved items from pretest to posttest) should - if at all - be larger after task-switching training than after single-task training.

Finally, participants additionally performed control measures not supposed to rely on executive functioning, namely verbal speed, perceptual speed, and knowledge. There is neither empirical evidence nor theoretical reasons suggesting that executive control training should transfer to performance in these tasks. Thus, the last prediction is:

Prediction 20: Assuming that task-switching training primarily enhances executive control processes, there should be no transfer of task-switching training to measures not supposed to rely on executive control. That is, there should be no difference between the task-switching and the single-task training groups with respect to the pretest-posttest improvements in perceptual speed, verbal speed, and knowledge.

II Empirical Part

4. Method

Participants

Overall, 216 participants were recruited for the study. Children and older adults were drawn off Saarland University's subject pool or recruited by means of flyers handed out in schools and at University events; younger adults were recruited by means of on-campus placards. However, two younger adults and four older adults did not complete all experimental sessions. Therefore, the final sample included 70 children, 70 younger adults, and 70 older adults (see Table 1). All participants were German native speakers in order to control the influence of language. They were paid € 60 for participating in the eight sessions of the present study. For each participant, testing took approximately eight weeks (with one session per week).

Demographic characteristics of the effective sample are summarized in Table 1. To indicate the representativeness of the sample, two psychometric tests were used, one from the fluid domain and one from the crystallized domain of intelligence (a description of both tests is provided in the "Measures" section, see p. 103). Consistent with previous studies and the two-component model of intelligence (cf. P. B. Baltes et al., 1998; P. B. Baltes et al., 1999; see also theoretical part, p. 34), there were differential age trends for both domains of intelligence. On the one hand, a reliable u-shaped age trend ($t(207) = -16.13$, $p < .001$) was found for a test of perceptual speed of processing, the Digit-Symbol Substitution Test, indicating that perceptual speed of processing improved during childhood and declined in older age, and that older adults performed better than children (all p's <.001). On the other hand, a linear age trend ($t(207) = 29.35$, $p < .001$) was observed for a test of semantic knowledge, the Spot-a-Word Test, suggesting that semantic knowledge increased during childhood and adulthood. Thus, the sample is characterized by the typical pattern of developmental changes in fluid and crystallized abilities across the lifespan.

Table 1: Descriptive Statistics for the Participants: Means (SD) for Age, Perceptual Speed (Digit-Symbol Substitution Test), and Knowledge (Spot-a-Word Test), Age Range, and Gender Distribution

	Age group		
Statistic	Children	Younger adults	Older adults
n	70	70	70
Age range	8.1 - 10.1	18.0 - 27.5	63.8 - 76.8
Male/female	38/32	35/35	30/40
Mean age	9.3 (0.6)	22.4 (2.6)	68.7 (3.0)
Digit-Symbol Substitution Test	34.4 (7.7)	65.4 (10.8)	49.8 (10.7)
Spot-a-Word Test	10.4 (3.4)	23.4 (3.9)	27.8 (3.6)

Study Design

In order to examine transfer of training, this study adopted a pretest - training - posttest design. Transfer was defined as performance improvement at posttest relative to baseline performance at pretest. Therefore, the pretest and posttest sessions were identical, including (1) baseline measurements of task-switching performance, (2) performance in both single tasks, and (3) a battery of cognitive measures with other executive tasks, working memory, fluid intelligence, and control measures (details are provided in the “Measures” section, see p. 103).

The training phase consisted of four sessions à 45 minutes. During training, participants in each age group were assigned to one of five training conditions. Thus, all participants had to complete eight sessions, two sessions each for pretest and posttest assessment as well as four sessions of intensive training (see Table 2).

Table 2: Schedule of the Present Study

Pretest *Session 1 + 2*	**Training** *Session 3-6*	**Posttest** *Session 7 + 8*
Task switching and single tasks (tasks A + B)	Training (e.g., task C + D)	Task switching and single tasks (tasks A + B)
Cognitive Battery: - Other executive tasks - Working memory - Fluid intelligence - Control measures		Cognitive Battery: - Other executive tasks - Working memory - Fluid intelligence - Control measures

Measures

The following section provides an overview of the tasks applied at pretest, posttest, and in the four training sessions. First, the tasks of the cognitive battery will be described in detail; second, the task-switching paradigm used in this study will be presented along with the switching tasks applied at pretest and posttest and during training (see Table 2).

Pretest and Posttest Assessment

In addition to the typical marker tests of mechanics (Digit-Symbol Substitution Test) and pragmatics (Spot-a-Word Test), this study assessed a number of cognitive abilities to investigate far transfer of task-switching training to these cognitive domains. The selection of psychometric tests for these abilities was guided by considerations of validity and reliability with mostly two or three indicators for each measured construct (see Table 3). Most of the tests were adapted from previous studies, such as the Berlin Aging Study (cf. Lindenberger, Mayr, & Kliegl, 1993) or a comprehensive working memory study from the Kane lab (cf. Kane et al., 2004).

Cognitive Battery

To determine the transfer of executive control training, a total of 16 tests was applied at pretest and posttest. The aim was to examine seven cognitive domains: Inhibitory control (Color Stroop, Number Stroop), verbal working memory (Reading Span, Counting Span, 2-back Task), visuospatial working memory (Symmetry Span, Navigation Span), fluid intelligence (Raven's Standard Progressive Matrices, Figural Reasoning, Letter Series), knowledge (Spot-a-Word Test), perceptual speed (Digit-Symbol Substitution Test, Digit-Letter Substitution Test), and verbal speed (Letter Articulation Rate, Digit Articulation Rate, Word Articulation Rate) (see Table 3). Six tests were applied in a paper-pencil version (Raven's Standard Progressive Matrices, Figural Reasoning, Letter Series, Digit-Symbol Substitution Test, and Digit-Letter Substitution Test) and the remaining tasks were computerized. A detailed description of each test procedure is provided below.

Color Stroop (cf. Salthouse & Meinz, 1995). In this task, subjects saw words (red, blue, green, yellow, hat, book, tree, and flea [rot, blau, grün, gelb, Hut, Buch, Baum und Floh]) that were presented in red, blue, green, or yellow font. Participants had to indicate the font color of

Table 3: Overview of Psychometric Measures

Construct	Indicator	Source
Inhibition	Color Stroop	Salthouse & Meinz, 1995
	Number Stroop	Salthouse & Meinz, 1995
Verbal working memory	Reading Span	Kane et al., 2004
	Counting Span	Kane et al., 2004
	2-back Task	McElree, 2001
Visuospatial working memory	Symmetry Span	Kane et al., 2004
	Navigation Span	Kane et al., 2004
Fluid intelligence	Raven's Standard Progressive Matrices	Raven, 1988
	Figural Reasoning	Lindenberger et al., 1993
	Letter Series	Lindenberger et al., 1993
Knowledge	Spot-a-Word Test	Lehrl, 1977
Perceptual speed	Digit-Symbol Substitution Test	Wechsler, 1982
	Digit-Letter Substitution Test	Lindenberger et al., 1993
Verbal speed	Letter Articulation Rate	Kail, 1997
	Digit Articulation Rate	Kail, 1997
	Word Articulation Rate	Kail, 1997

Note. The working memory tasks were adapted from Kane et al., (2004). Given that the sample in this study only consisted of younger adults, a few adjustments regarding the length and difficulty of the tasks were made. Details are provided in the respective task descriptions.

the stimuli as quickly as possible. Each of the four colors was mapped to one of four response buttons on an external keypad. The words were presented in uppercase 18-point font against a black background. In congruent trials, color names were identical to the font color (e.g., "red" presented in red). In incongruent trials, the color words were interfering with the font color (e.g., “blue” presented in yellow) and in neutral trials the words were not semantically linked to colors (e.g., “hat” presented in green). This design allows calculating facilitation (congruent vs. neutral trials) as well as interference effects (incongruent vs. neutral trials)[14]. Trials started with the presentation of the stimulus for 2000 ms or until the subject responded, followed by a response-stimulus interval of 700 ms. Participants first performed two practice blocks à 12 trials. Afterwards, they worked through 4 experimental blocks à 24 trials, yielding a total of 120 trials. All blocks consisted of an equal number of response types (red, blue, green, yellow), and stimulus types (congruent, incongruent, neutral).

Number Stroop (cf. Salthouse & Meinz, 1995). In the number version, design and procedure were identical to the color version. Instead of color words, participants saw stimuli (1, 2, 3, 4, X, M, A, and H) that were presented one-, two-, three- or fourfold (e.g., 222, 44, AAAA) and their job was to decide how many stimuli were presented. In congruent trials, the number of stimuli was identical to their value (e.g., 22, 333). In incongruent trials, the number of stimuli interfered with their value (e.g., 111, 4) and in neutral trials the stimuli did not represent numerical information (e.g., AA, MMM).

Reading Span (cf. Kane et al., 2004). In this task, participants had to recall letters against a background reading task. In each trial, they were presented an understandable or a nonsensical sentence, followed by a to-be-remembered letter (e.g., “The glaring red rubber boat was never so in love. X” [“Das knallrote Gummiboot war noch nie so verliebt. X”]) presented in a 13-point font. The English sentences from Kane et al. (2004) were substituted by German phrases that were understandable and suitable for children. Each sentence consisted of 7-14 words (*M* = 10.5 words). As soon as the sentence appeared, the subject read it aloud, verified aloud whether it made sense or not (it made sense half the time) and

[14] Note that age differences in facilitation and interference are analyzed elsewhere (Kray, Karbach, & Kersken, in prep.). Given that the focus of the present study was on executive control, only interference effects were analyzed.

then read the letter. For instance, the participant had to say, “The glaring red rubber boat was never so in love, no, X”. When the participant read the letter, the experimenter pressed a button that cleared the screen for 500 ms, either followed by the next stimulus (i.e., sentence and a letter) or the recall cue. When the recall cue was presented, the participant recalled each letter from the preceding set in the order of their appearance. The set size ranged from two to five sentence-letter combinations per trial. The nine letters used were chosen to be phonologically distinct (B, F, H, J, L, M, Q, R, X). Letters were repeated across sets, but not within sets, and all were used approximately equally often in the task. For reasons of time, the 12-trial procedure applied by Kane and colleagues (2004) was shortened to eight trials (two trials each for the set size of 2, 3, 4, or 5 sentence-letter problems). Response sheets presented eight rows of blank spaces, with each row representing one set, and subjects wrote the letters they recalled from each set in the appropriate ordinal position. The test score was the number of correctly recalled trials.

Counting Span (cf. Kane et al., 2004). In this task, participants recalled digits against a background counting task. Presented on a gray background, each display included different geometric shapes: 3-9 dark blue circles; 1, 3, 5, 7, or 9 dark blue squares; and 1-5 green circles. The number of the three different shapes was approximately balanced across displays in the task. Subjects were instructed to count the number of dark blue circles in each display and to repeat the total number after finishing counting. For instance, if three dark blue circles were presented, the participant should have said, “One, two, three…three”. After the subject had repeated the total count, the experimenter blanked the screen for 500 ms either followed by the next display or the recall cue. When the recall cue was presented, participants repeated each total from the preceding set in order of their appearance. Digits were repeated across sets, but not within sets, and all numbers were used approximately the same number of times in the task. Consistent with the Reading-Span task, set sizes ranged from two to five displays per trial, with a total of eight trials. Response sheets presented eight rows of five blank spaces, with each row representing one set, and subjects recalled the digits from each set in the appropriate ordinal position. The test score was the number of correctly recalled trials.

2-back Task[15] *(cf. McElree, 2001).* In this task, participants were presented a sequence of digits, one at a time, and were required to press the space bar when the digit presented on the screen was identical to the digit presented two positions back in the sequence. Subjects first performed two practice blocks à 29 trials, followed by four experimental blocks à 36 trials, resulting in a total of 202 trials. The target probability was 25 %, and the proportion of hits (i.e., correct responses to targets) and false alarms (i.e., erroneous responses to non-targets) was presented after each block. Blocks started with the presentation of the word “attention [Achtung]” in the middle of the white computer screen, followed by the presentation of the first stimulus for 1500 ms. The next stimulus was presented immediately thereafter. The test score was the PR score (i.e., the number of hits – the number of false alarms).

Symmetry Span (cf. Kane et al., 2004). Subjects were instructed to recall sequences of locations marked by red squares in a 4 x 4 matrix against a background symmetry-judgment task. In the symmetry task, participants were shown two letters and instructed to decide whether these letters were symmetrical along a vertical axis (they were half the time). After the subject gave an oral response to the letter display, the experimenter blanked the screen for 500 ms, followed by the 4 x 4 (5 cm x 5 cm) matrix with one of the 16 squares filled in red, presented for 650 ms (see Figure 8). Red square locations were never repeated in one set and each of the 16 squares appeared in red approximately equally often in the task. After the to-be-remembered matrix, either another pair of letters or the recall cue was presented. When the recall cue appeared, participants recalled the sequence of red-square locations in the previous displays in the order of their appearance. Set sizes again ranged from two to five

[15] Although this task was applied at pretest and posttest, it was dropped from the analysis because especially children and older adults had severe problems to perform the task and the retest reliability was relatively low in these age groups (.16 and .25, respectively). The same was true for the correlations between the 2-back task and the remaining two verbal WM tasks (.34 and .35, respectively, see Appendix, Table 19).

symmetry-matrices per trial (eight trials in total). Response sheets presented eight rows of five 4 x 4 matrices, each row representing one set. Participants drew one X in each matrix corresponding to the red square in that display. The test score was the number of correctly recalled trials.

It should be noted that in the Kane et al. (2004) study, an 8 x 8 matrix was presented instead of letters in the background task. In this matrix, some squares were filled in black, and participants decided whether the black-square design was symmetrical along the vertical axis. However, since pilot testing indicated that this task was way too complicated for children, the matrices in the background task were substituted with the letters.

Navigation Span (cf. Kane et al., 2004). In this task, subjects recalled the paths of moving balls across the screen against a background task of counting the corners of polygons. In the background task, a polygon[16] was presented against a gray background with a red asterisk and an arrow in one corner of the polygon (see Figure 8). Participants started counting aloud the corners at the asterisk, mentally navigating in the direction of the arrow along the corners of the polygon. After navigating around the entire polygon, the subject said “finish [Ende]”. At this point, the experimenter pressed a key, erasing the polygon and presenting a gray box (approximately 20 cm x 20 cm) of 400 x 400 pixels that presented a ball display. Immediately after the onset of the gray box, one blue ball (1.5 cm in diameter) appeared in one of eight locations inside the box. The eight locations were either in one of the four corners, in the middle of the top or bottom “row”, or in the middle of the leftmost or rightmost “column” (see Figure 8). Within one second, the ball then traveled vertically, horizontally, or diagonally to the opposite side of the box. Paths were repeated across sets, but not within sets, and all were presented approximately equally often in the task. When the ball finished its way across the box, the experimenter presented another polygon or the recall cue. Participants recalled the sequence of ball paths in the preceding displays in the order of

[16] In the original task version applied by Kane et al. (2004), letters instead of polygons were used.

their appearance as soon as the recall cue appeared. Consistent with the Symmetry-Span task, set sizes ranged from two to five to-be-remembered displays, with a total of eight sets. Response sheets presented eight rows of five squares, with each row corresponding to one set. Participants drew an arrow into each square in the correct order to indicate the movement of the ball in that display. Again, the test score was the number of correctly recalled trials.

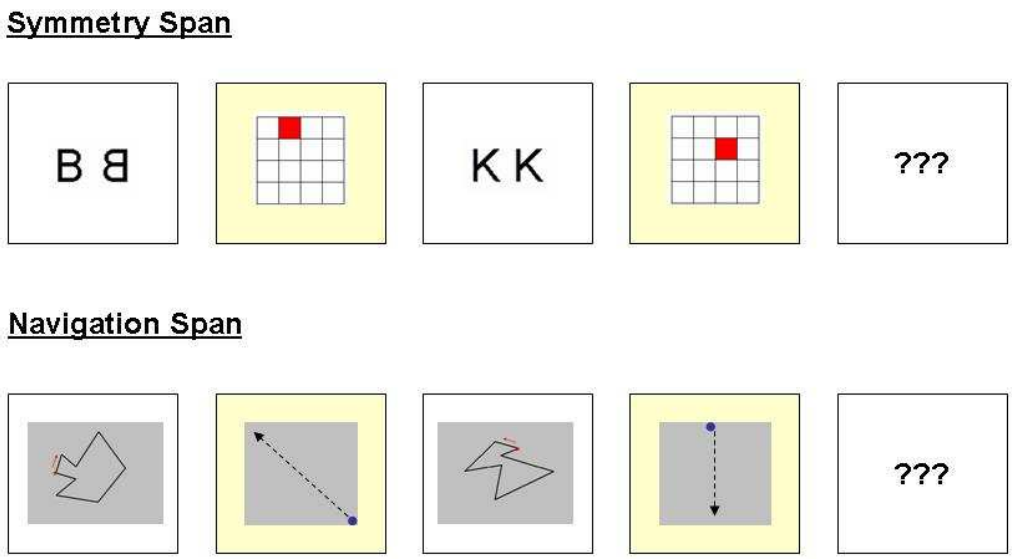

Figure 8: Illustration of the visuospatial working memory tasks used in this study. The boxes within each task represent single items. For illustration purposes, background task items are displayed in white boxes, to-be-recalled items in yellow boxes. The question marks depict the recall cue that followed each set for every task. The dashed lines in the navigation span display represent the direction that the circle moved in (within 1 second).

Raven's Standard Progressive Matrices (Raven, 1988). Items presented a pattern of eight black-and-white figures arranged in a 3 x 3 matrix with one figure missing. Figures ranged from simple geometrical shapes to complex patterns. Participants were instructed to select one of eight figures presented below the matrix that would best complete the pattern.

Following three practice items, subjects had 2 x 10 minutes to complete 15 test items increasing in difficulty, resulting in a total of 30 trials. The test score was the number of correctly solved items.

Figural Reasoning (cf. Lindenberger et al., 1993). This test was adapted from Lindenberger and colleagues (1993). Items in this test followed the format "A is to B as C is to?". Problems were presented in a booklet, with the stimulus in the upper half and five response alternatives in the lower half (see Figure 9). Subjects indicated their response by naming the corresponding number[17]. Items were presented one by one. Before the test phase, subjects received instructions and performed three practice trials. The experimenter terminated the test phase when subjects committed three consecutive errors or after they had answered all 16 items. The test score was the number of correctly solved items.

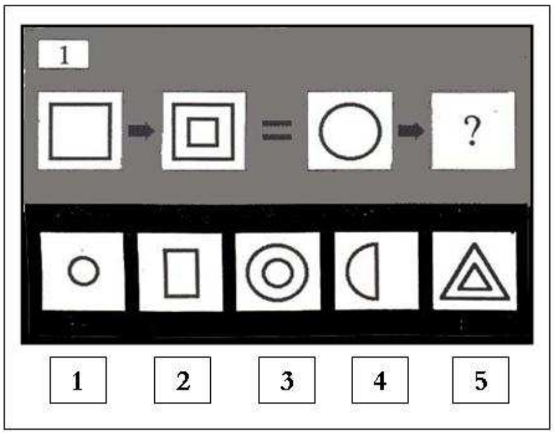

Figure 9: Item from the figural analogies test. Items were presented one by one. Subjects indicated their response by naming the corresponding number. The correct response in this example was "3".

[17] In the original version applied by Lindenberger et al. (1993), items were presented on a computer screen and participants responded manually via touch-screen.

Letter Series (cf. Lindenberger et al., 1993). This test was also adapted from Lindenberger et al. (1993) and consisted of 16 items, each containing five letters followed by a questions mark (e.g., a c e g i ?). Items were displayed in booklets with the problem in the upper part of the page and five response alternatives (i.e., letters) in the lower part. Items followed simple rules such as +1, -1 or +2, +1. Participants indicated their response by naming the letter that logically fitted the position of the question mark. Items were presented one by one. Before the test phase, subjects received instructions and performed three practice trials. The experimenter terminated the test phase when subjects committed three consecutive errors or after they had answered all 16 items. The test score was the number of correctly solved items.

Spot-a-Word Test (cf. Lehrl, 1977). Thirty-five items were presented successively on the screen, each containing one word and four pronounceable nonwords, numbered from one to five. Participants were instructed to identify the one word and to press the corresponding number on the keyboard. Items were drawn from a widely used German vocabulary test (Lehrl, 1977). Three practice items were provided prior to the test phase; testing time was limited to five minutes. The test score was the number of correctly solved items.

Digit-Symbol Substitution Test (Wechsler, 1982). The paper-pencil version of this test was applied (from the Wechsler Adult Intelligence Scale; Wechsler, 1985). The test sheet displayed nine digit-symbol mappings. Below, 100 digits without the corresponding symbols were displayed. Participants were instructed to fill in as many symbols as possible within 90 s. The test score was the number of correctly added symbols.

Digit-Letter Substitution Test (cf. Lindenberger et al., 1993). This test was identical to the Digit-Symbol Substitution Test (Wechsler, 1982), except that participants had to write letters instead of symbols. In contrast to Lindenberger et al. (1993), this test was applied in the same manner as the Digit-Symbol Substitution Test, that is, participants were instructed to write as many letters as possible within 90 s. The test score was the number of correctly added letters.

Letter Articulation (Kail, 1997). The measurement of the articulation rate was adapted from Kail (1997). Participants had to repeat aloud pairs of letters as rapidly as possible, five times. After showing the subjects the letters to be repeated, the experimenter said “go!” and measured the amount of time needed to say the letters. This procedure was repeated on four trials, each including a unique pair of letters (R-A; Q-H; M-F; B-I). The articulation rate was averaged across trials.

Digit Articulation (Kail, 1997). Articulation rate for digits was measured similarly, using a unique pair of digits on each trial (7-4; 5-8; 1-6; 2-9).

Word Articulation (Kail, 1997). The same procedure was used for the measurement of word articulation rate (dog-fish; hat-robe; book-pen; leg-hand).[18] For all three articulation measures, the dependent variable was the articulation time (ms).

Measurement of Task Switching

Apparatus. We used IBM-compatible computers for data collection. Stimuli were presented on a CTX 17-inch color monitor on black background and buttons located on the left- and right-hand side of an external keypad registered the responses. To control stimulus presentation and reaction time measurements, the software package “ERTS” (Experimental Run Time System) was used.

The Switching Paradigm. In order to investigate age differences in task-switching performance, an internally cued task-switching paradigm was used (cf. Rogers & Monsell, 1995). To ensure that executive control components related to the process of switching tasks per se can be separated from those related to the process of maintaining and selecting two

[18] Note that in German these were all one-syllable words [Hund-Fisch; Hut-Kleid; Buch-Stift; Bein-Hand].

task sets, this paradigm was completed with a non-switch baseline (cf. Kray & Lindenberger, 2000). That is, not only mixed-task blocks, but also single-task blocks were administered.

Participants were instructed to perform two simple tasks A (e.g., classifying pictures as fruit or vegetable) and B (e.g., classifying pictures as large or small). In single-task blocks, they only had to perform task A or task B. In mixed-task blocks, they were asked to switch tasks on every other trial (i.e., AABBAABB…). Since we know that participants strongly rely on internal cueing when external cues are absent (e.g., Baddeley et al., 2001; Emerson & Miyake, 2003), no external task-set cues were provided. That is, the task sequence in mixed-task blocks was predictable and subjects knew in advance that they had to switch tasks on every second trial.

To maximize executive control demands, the experiment was designed to meet the following criteria: First, the stimuli were all ambiguous, that is, they represented both attributes of Task A as well as of Task B. In Figure 10, for example, the attributes “fruit” and “large” are presented simultaneously. This simultaneous activation of both stimulus attributes results in a strong interference at the stimulus level, because subjects have to be able to inhibit the stimulus information for the currently irrelevant task (e.g., the attribute “large”, while performing Task A) and to select the correct response button for the relevant task (i.e., the button on the right-hand side to select the “fruit”-category) (cf. Rogers & Monsell, 1995). Second, in half of the trials the responses of both tasks were mapped onto the same button, inducing high interference on the response level as well. For instance, the features “fruit” and “large” were both mapped onto the left response button (see Figure 10). Thus, every time participants had to switch tasks, a reconfiguration process was necessary to decouple the stimulus-response (S-R) mappings. Thus, irrelevant S-R mappings from the preceding trial had to be inhibited and those for the currently relevant task had to be activated (cf. Rogers & Monsell, 1995).

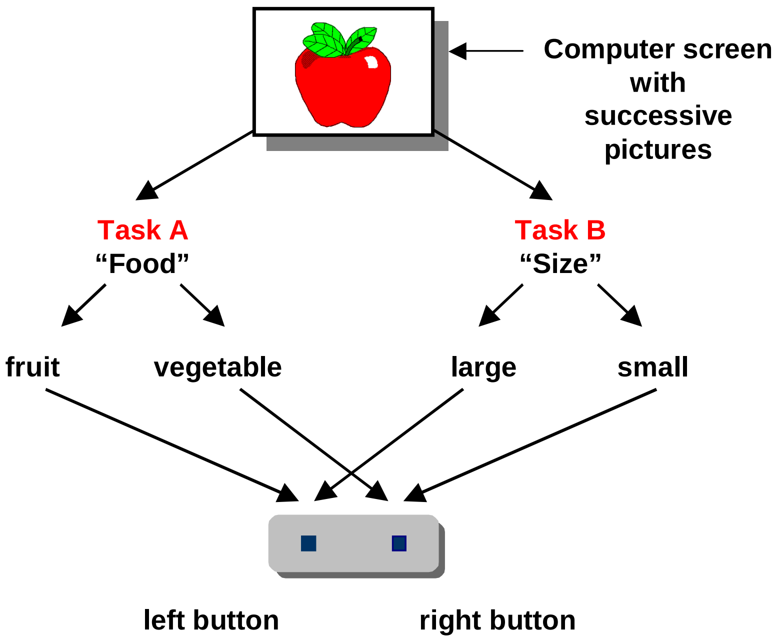

Figure 10: Task-switching scheme

Operationalization of Task-Switching Abilities. As mentioned above, the task-switching paradigm used in this study allows the separation of two executive processes, namely the selection and maintenance of two task sets and the switch between two task sets. Accordingly, two measures of executive control were operationalized (cf. p. 41):

(1) General switch costs were defined as the difference in performance between mixed-task blocks and single-task blocks:

General switch costs = mean (mixed blocks) – mean (single blocks)

(2) Specific switch costs were defined as the difference in performance between switch (AB, AB) and nonswitch (AA, BB) trials *within* mixed-task blocks:

Specific switch costs = mean (switch trials) – mean (nonswitch trials)

It has often been argued that both types of costs are not fully independent. General switch costs (as well as all types of dual-task costs) always include the switching between tasks and specific switch costs also include the ability to maintain task sets in working memory. Even if one defines general switch costs as difference in performance between single and non-switch trials (which has sometimes been suggested by reviewers) one can still argue that non-switch trials are measured in a situation where subjects are required to switch.

Nevertheless, there is evidence (via a confirmatory factor analysis) that both types of task-switching costs are indeed separable. Kray and Lindenberger (2000) have shown that a model with two latent factors provided a significantly better fit than a one-factor model. However, it should be noted that there was a substantial correlation between both factors (.50).

Thus, given that it seems quite difficult to reach theoretical independence between these two components, this study aimed at a definition providing at least statistical independence. That is, general and specific switch costs are defined as two orthogonal within-subjects contrasts. The first contrast (general switch costs) compares means of single-task trials against means in non-switch and switch trials (-2 1 1), and the second one (specific switch costs) compares means of non-switch trials against means of switch trials (0 -1 1).

Tasks and Stimuli. At pretest and posttest, participants were instructed to perform two simple tasks A (i.e., classifying pictures as fruit or vegetable) and B (i.e., classifying pictures as large or small). If the picture showed a fruit (food task) or was large (size task), subjects had to press the left response key with the left index finger. If the picture showed a vegetable (food task) or was small (size task), they were instructed to press the right response key with the right index finger (for details, see Figure 10). The same two response keys were used for both task sets.

Stimuli consisted of 32 fruit and vegetable pictures (16 fruit and 16 vegetables) which were all presented in a larger and a smaller version, resulting in a total of 64 stimuli. All pictures were presented and named prior to the experiment to make sure that participants were able to correctly identify the fruit and vegetables and assign them to the corresponding response categories (i.e., fruit, vegetable, small, large). The assignment of response labels to response keys was constant across subjects and experimental sessions (i.e., pre- and posttest). Above the external keyboard, a small instruction sign was presented showing the response assignment.

Procedure

In order to give participants the opportunity to get used to the assignment of response keys, each session started with two single-task practice blocks, consisting of 17 trials each. That is, the subjects only performed the food task or the size task within one block (first food, then size). Afterwards, they worked through 20 experimental blocks, eight single and twelve mixed blocks. The sequence of blocks was constant across subjects[19]. Each experimental block consisted of 17 trials, yielding a total of 22 blocks x 17 trials = 374 trials. Single as well as mixed blocks consisted of an equal number of response types (left/right), tasks (food/size), and stimulus types (fruit/large, fruit/small, vegetable/large, vegetable/small). The sequence of stimuli in each block was randomly selected.

Before the experiment started, visual and verbal instructions were provided. In addition, an instruction window appeared before each block, indicating which type of task (food, size, or both) had to be performed next. Participants were instructed to perform as quickly and as accurately as possible. After each block, feedback was provided showing the subjects' mean reaction times (RT) and error rates.

[19] The exact sequence of blocks was: Single (food) – single (size) – mixed – mixed – single (food) – single (size) – mixed – mixed – single (size) – mixed – mixed - single (food) – mixed – mixed - single (size) – mixed – mixed - single (food) – mixed – mixed.

Trial Procedure. Trials started with the presentation of a fixation-cross for 1400 ms, followed by the presentation of the target, and a 25 ms response-fixation-cross interval (RFI) (see Figure 11). The target remained visible on the screen until the subject responded.

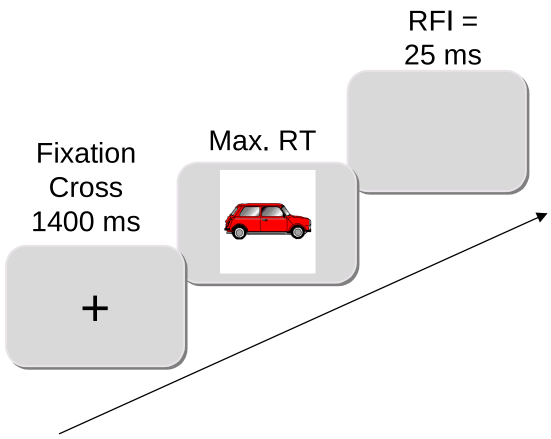

Figure 11: Trial procedure. RFI = Response-Fixation-Cross Interval.

Session Procedure. Pretest and posttest sessions were identical with the exception that participants (or in case of children, their parents) additionally completed a consent form and a demographic questionnaire at the beginning of the first pretest session. As mentioned above, pretest and posttest included task-switching and single-task performance (with tasks A and B) as well as the cognitive test battery. An overview of the session schedule is provided in Table 4. The sequence of tasks within each session was constant across participants. Each session took about 70 minutes.

In the first pretest and posttest session, respectively, participants had to perform the tasks for perceptual speed of processing, verbal working memory, visuospatial working memory, and fluid intelligence (except of the Raven SPM). A description of each task is provided in the “Cognitive Battery” section and in Table 3 (see p. 104). In the second pretest and posttest session, subjects performed the task switching and the single tasks, the Stroop tasks, the Spot-a-Word Test and the Raven SPM, and the articulation rate was measured. All participants were tested individually.

Table 4: Schedule for the Pretest and Posttest Sessions

Pretest 1/Posttest 1 *Session 1/7*	**Pretest 2/Posttest 2** *Session 2/8*
Demographics, consent form*	1. Task-switching + single-task performance
1. Digit-Symbol Substitution Test	2. Raven Standard Progressive Matrices set I
2. Counting Span	3. Color Stroop task
3. Figural Reasoning	4. Number Stroop task
4. Symmetry Span	5. Spot-a-Word Test
5. Letter Series	6. Articulation Rate
6. Reading Span	7. Raven Standard Progressive Matrices set II
7. Digit-Letter Substitution Test	
8. Navigation Span	
9. 2-back Task	

Note. * Demographic variables and consent were only obtained in session 1.

Training Sessions

The goal of this study was to investigate age differences in the transfer of task-switching training. In addition, the aim was to explore whether transfer of training can be modulated by variations in the type of task-switching training. Therefore, participants were assigned to one of five groups during training. Within each age group, participants were matched to these training groups based on their pretest performance in task switching (general switch costs), speed of task execution (single-task RT), perceptual speed (Digit-

Symbol Substitution score), and fluid intelligence (Raven score) to prevent baseline differences between the training groups. The treatment for each training group is described in the following section.

Training Groups

Single-Task Training (Group 1). In the first group, subjects only practiced the two single tasks C and D, so that training in executive control should be low. That is, all four training sessions consisted of blocks in which either task C or task D had to be performed separately. In line with the Minear et al. (2002) study, this group served as a control condition to show that intensive training in single-task performance does not promote transfer in terms of executive control abilities.

Task-Switching Training (Group 2). Since it has been shown that intensive training in executive control can be transferred to new task situations (Bherer et al., 2005; Kramer et al., 1995; Minear et al., 2002), subjects in the second group received practice in mixed-task blocks only, so that training in executive control should be intense. Thus, participants performed four sessions of intensive switching training with tasks C and D. Note that group 1 and 2 performed the identical number of tasks and trials, with the only difference being that group 1 only performed single-task blocks, while group 2 only performed mixed-task blocks.

Task-Switching + Verbal Self-Instruction Training (Group 3). In the third group, subjects received the same treatment as the second group, i.e., mixed blocks with task C and D only. Given that the use of verbal self-instructions can facilitate task switching (Kray et al., in press), participants were in addition instructed to use a verbal self-instruction strategy, that is, to verbalize the upcoming task goal during task preparation (details of the procedure are described below).

Task-Switching + Verbal Self-Instruction Training + Feedback (Group 4). The fourth group received the same switch + verbalization training as the third group. Since we know that it can support transfer of training in children (Kennedy & Miller, 1976; Ringel & Springer, 1980; cf. Dowsett & Livesey, 2000), subjects were in addition provided explicit feedback regarding task performance and the usefulness of the verbalization strategy. Specifically, the experimenter emphasized the subject's performance improvements and attributed them to the verbalization strategy three times per training session (after the first and second third and at the end of the session) and pointed to the value of the verbal self-instructions for improving task performance. In case participants did not show any performance benefits, the experimenter repeated the task instructions and stressed the usefulness of the verbalizations to facilitate task switching.

Task-Switching + Verbal Self-Instruction Training + Training Variability (Group 5). The fifth group received the same switch and verbalization training as the third group. Given that variable training can foster transfer to new task situations in adults (Kramer, Larish, et al., 1999; Rosenbaum et al., 2001; Sanders et al., 2002), training tasks varied in this group, that is, tasks and stimuli were different in each training session. Thus, in contrast to groups 1-4, participants practiced task C and D in the first training session, but task E and F in the second, G and H in the third, and I and J in the fourth training session (a detailed description of all training tasks is provided below).

For practical reasons, the training groups will be referred to as "single", "switch", "verbalization", "feedback", and "variability" group in the results section.

Tasks and Stimuli

In the four training sessions, the switching paradigm was basically identical to the one used at pretest and posttest. However, participants performed different tasks including different stimuli, that is, participants in groups 1-4 had to perform tasks C and D in all four training sessions. In task C ("transportation" task), they had to decide whether the pictures showed planes or cars, and in task D whether one or two planes/cars were presented (“number” task). If the picture showed a plane (transportation task) or if there was only one object (number task), subjects had to press the left response key with the left index finger. If the picture showed a car (transportation task) or if there were two objects (number task), they were instructed to press the right response key with the right index finger (see Table 5). Again, the same two response keys were used for both task sets. The experimenter presented verbal and visual instructions at the beginning of each session.

Stimuli consisted of 32 plane and car pictures (16 planes and 16 cars) that were all presented in a version with just one or with two vehicles visible on the screen, resulting in a total of 64 stimuli. To prevent effects of associative learning on task-switching costs (Kray & Eppinger, 2006; see also Waszak et al., 2003), a new set of pictures was presented in every training session, resulting in a total of 4 sessions x 64 stimuli = 256 pictures. All stimuli were presented prior to the experiment to make sure that participants were able to correctly assign them to corresponding response categories. The assignment of answers to response keys was constant across subjects and experimental sessions (i.e., training sessions 1-4). Above the external keyboard, a small instruction sign was presented showing the response assignment.

As described above, group 5 (switch + verbalization + training variability) was trained with different tasks and stimuli in each training session (see Table 5). The design of the tasks was identical to those used in training groups 1-4 (see above). Participants from group 5 also performed task C (transportation task) and D (number task) in the first training session, but task E (hobby task) and F (stoplight task) in the second training session. In the hobby task, participants had to classify hobby-related items as sports or music articles, and in the stoplight task, they had to decide whether the pictures were red or green. In the third training session, task G (animal task; classifying pictures as fish or bird) and H (direction task; classifying pictures as normal or rotated) were introduced. In training session four, subjects worked with tasks I (plant task; classifying pictures as tree or flower) and J (color task; classifying pictures as gray or colored) (see Table 5).

Table 5: Overview of Stimuli, Task Sets, and Response Assignments

Session	Stimuli (pictures)	Task sets	Response Left	Response Right
Pretest/Posttest	fruit / vegetable	A: food	fruit	vegetable
		B: size	large	small
Training 1-4 (Group 1-4), Training 1, Group 5	car / plane	C: transportation	car	plane
		D: number	one	two
Training 2, Group 5	sports / music	E: hobby	sports	music
		F: stoplight	red	green
Training 3, Group 5	fish / bird	G: animal	fish	bird
		H: direction	normal	rotated
Training 4, Group 5	tree / flower	I: plant	tree	flower
		J: color	gray	colored

Note. The German labels for tasks and responses in each task were one or two-syllable words that were familiar to all age groups and easy to pronounce [task labels: Essen/Größe, Fahrzeug/Anzahl, Hobby/Ampel, Tierart/Richtung, Pflanze/Farbe; response labels: Obst/Gemüse, groß/klein, Auto/Flugzeug, eins/zwei, Sport/Musik, rot/grün, Fisch/Vogel, normal/gedreht, Baum/Blume, grau/bunt]. Training 1-4 refers to the four training sessions.

Procedure

Trial Procedure. The trial procedure applied during training was identical to the one at pretest and posttest (see Figure 11).

Session Procedure. In all five training groups, participants started with two practice blocks à 17 trials[20] followed by 24 experimental blocks à 17 trials, resulting in a total of 17 trials x 26 blocks x 4 sessions = 1768 trials of practice. That is, all five training groups performed the same number of trials during training. After each block, a feedback window on the screen indicated the subject's mean RT and proportion of errors in the previous block. All groups were offered a short break after completing the first half of the experiment. Other than that, the session procedure varied as a function of training group. Group 1 (single-task training) started each session with two single-task practice blocks (one with task D and one with task D), followed by 24 alternating experimental single-task blocks with tasks C and D. Group 2 (switch training) started each session with two mixed-task training blocks, followed by the 24 experimental mixed-task blocks. Again, it should be noted that the paradigm applied during training was identical to the one at pretest and posttest, that is, no external task cues were provided and tasks had to be switched every other trial (i.e., CCDDCCDD…). Blocks always started with task C. This procedure was identical for group 3 (switch + verbal self-instruction training). However, participants were in addition instructed to perform a verbal self-instruction, that is, to verbalize the next task goal during task preparation (cf. Kray et al., in press). Specifically, subjects had to say aloud "transportation [Fahrzeug]" or "number [Anzahl]" as soon as the fixation-cross appeared in each trial, depending on what task had to be performed next. In case participants stopped verbalizing during one of the blocks, they were reminded to continue using the verbal self-instruction after completing that given block. For group 4 (switch + verbal self-instruction training + feedback), the experimenter additionally provided feedback after blocks 8, 16, and 24 (see above). The session procedure for group 5

[20] The short sequence of 17 trials per block was chosen for the following reason: Participants had to internally maintain the task sequence (AABBAABB…) throughout blocks. However, if they failed to switch tasks at the appropriate point in time, they lost this sequence, so that the remaining trials in this block were erroneous. In order to prevent large error rates possibly resulting from one failed task switch, a small number of trials per block was chosen, so that participants had the opportunity to start over in the following block.

(switch + verbal self-instruction training + variability) was identical to group 3, except that the experimenter introduced new training tasks, stimuli, and task goals to be verbalized at the beginning of each session.

Data Analysis

Task-Switching and Stroop-Task Data

Analyses of the task-switching and Stroop-task data were restricted to mean reaction times (RT) for correct responses[21] and proportion of errors. Practice blocks and the first trial in each block were not analyzed.

In order to examine age differences as well as training and transfer effects in general and specific switch costs, two orthogonal contrasts were specified: In the first one, performance in single-task blocks was compared to performance in mixed-task blocks (general switch costs). The second contrast compared performance on nonswitch trials to performance on switch trials within mixed-task blocks (specific switch costs).

In order to examine age differences, two contrasts were defined for the factor Age Group: Given that quadratic age trends have been reported for different aspects of executive control, a quadratic contrast was specified as well as a contrast comparing children with adults.

For the analysis of condition-specific age differences in task-switching and in the Stroop task, raw latencies can be problematic. Children and older adults tend to respond slower than younger adults regardless of the task demands or conditions. When it comes to older age, the “general slowing hypothesis” suggests that age effects in response time tasks

[21] For task switching, latencies slower than 4000 ms were excluded from the analysis (Pretest and posttest: Children: 2.30%; younger adults: 0.09%; older adults 0.86%. Training: Children: 1.33%; younger adults: 0.01%; older adults 1.13%).

can be represented by a proportional factor (Brinley, 1965; Cerella, 1985; Salthouse, 1985). Thus, age by condition interactions could be confounded with age differences in baseline conditions. Therefore, age effects based on difference scores (such as switch costs or interference effects) with respect to raw latencies could simply reflect developmental increases or age-related slowing rather than condition-specific effects.

A number of methods have been proposed to deal with this methodological problem (Brinley, 1965; Cerella, 1990; Chapman, Chapman, Curran, & Miller, 1994; Kliegl et al., 1994; Salthouse, 1988). The present study used log-transformed latencies to control for age-related differences in baseline performance. Compared to the analysis of raw latencies, this procedure has several additional benefits: First, children and older adults often show larger variability in performance than younger adults. Thus, the assumption of homogeneous variances between groups is often violated. This mostly can be avoided when analyses are based on log-transformed reaction times. Second, switch costs and interference costs are calculated as differences between logarithms, that is, they are equivalent to ratio scores. As a consequence, age by condition interactions are relatively independent of age differences in baseline conditions (cf. Meiran, 1996). This fact is of particular relevance when baseline differences are large, which is often the case in research on lifespan cognitive development. However, every analysis was also conducted for raw latencies and any significant differences are reported.

Cognitive Battery

For the verbal and visuospatial working memory (WM) tasks and for fluid intelligence, analyses were based on accuracy (% correct). To account for differences in baseline performance, the pretest-posttest difference in performance was measured relative to baseline performance at pretest. Unless reported otherwise, results of this analysis were consistent with those based on the pretest-posttest comparison not corrected for differences in baseline performance.

Finally, analyses for the control measures were based on the number of correctly solved items (perceptual speed, knowledge) and RT (verbal speed). Again, the pretest-posttest difference in performance was measured relative to baseline performance at pretest in order to account for differences in baseline performance. The overall level of significance applied to all analyses in the present study was 5 %.

To examine how significant and how broad transfer in this study was, Cohen's (1977) *d*, or the standardized mean difference in performance between pretest and posttest was calculated (cf. Verhaeghen et al., 1992). That is, the pretest-posttest difference (for each training and age group) was divided by the pooled standard deviation for both test occasions. All *d*-values were then corrected for small sample bias using the Hedges and Olkin (1985) correction factor (*d'*). For instance, a pretest-posttest effect size *d'* = 1 indicates that the mean difference between pretest and posttest corresponds to one standard deviation.

Missing Values

Missing values were generally rare in this study. However, for technical reasons training data for two children (fourth training session) and one older adult (third training session) in the single-task training group were lost. These data were replaced with those from the preceding sessions. Also, training data from the first training session of one younger adult in the variability group were lost, which were replaced by those from the second training session. Unfortunately, training data for two children (feedback and variability group) and one older adult (feedback group) were completely lost, so that the analysis of training data was restricted to 207 instead of 210 subjects.

5. Results

This chapter is divided into five parts. The first part focuses on the matching procedure used to assign participants in each age group to one of the five training conditions, and the second part describes results for the training data collected in training sessions 1-4. The third part presents results for age-related changes in near transfer of task-switching training to a similar switching task, and the fourth one deals with findings regarding age-related changes in far transfer of training to other ‘executive’ tasks and other task domains, and includes the analysis of the control variables. Part five is focused on the evaluation of the training program, comprising the inspection of transfer effect sizes, transfer range, proportion of transfer as well as the prediction of transfer effects. Within each section, the presentation of results is structured along the research hypotheses presented in chapter 3 (see p. 87).

Matching of the Training Groups

In order to control for differences in baseline performance between the training groups, participants in each age group were matched to the training conditions based on pretest performance in speed of task execution (single-task RT), general switch costs, perceptual speed (Digit-Symbol Substitution score), and fluid intelligence (Raven score). Control analyses were performed for each of these criteria to make sure the matching procedure was successful (see Table 6). Data were submitted to a two-way ANOVA with the between-subjects factors Age Group (children, younger adults, older adults) and Training Group (single, switch, verbalization, feedback, variability).

Speed of Task Execution. Analysis of the single-task RT revealed a quadratic age effect, $F(1, 195) = 226.15$, $p < .0001$, $\eta^2 = .47$, indicating that children and older adults responded slower than younger adults. Also, children showed longer latencies than older adults, $F(1, 195) = 42.58$, $p < .0001$, $\eta^2 = .09$. Neither the main effect for training group ($p = .41$) nor the interaction with age group reached significance ($p = .97$).

General Switch Costs. Results for general switch costs revealed a quadratic age effect, $F(1, 195) = 24.32$, $p < .0001$, $\eta^2 = .01$, with larger costs for children and older adults than for younger adults, but no difference between children and older adults ($p = .11$). There was neither a significant effect for training group ($p = .77$) nor an age group × training group interaction ($p = .99$).

Perceptual Speed. Results for the Digit-Symbol Substitution Test scores showed a significant quadratic age effect, indicating that younger adults performed better than children and older adults, and older adults also outperformed children (all p's < .001). Neither the main effect for training group ($p = .80$) nor the interaction between age group and training group was significant ($p = .98$).

Fluid Intelligence. For Raven scores, there also was a significant quadratic age effect showing better performance in younger adults than in children and older adults, $F(1, 195) = 27.85$, $p < .0001$, $\eta^2 = .02$, without a difference between children and older adults ($p = .92$). Neither the main effect for training group ($p = .31$) nor the interaction between age group and training group was reliable ($p = .70$).

In sum, none of the control analyses performed for the four matching criteria revealed any baseline differences between the training groups at pretest, indicating that the matching procedure was successful. Thus, there are no pre-training differences between the training groups that could render the interpretation of training and transfer effects more complicated. In addition, it should be noted that all further analyses are based on log-transformed latencies, so that possible inter-group differences are accounted for (for details, see Method, p. 124).

Table 6: Means (M) and Standard Deviations (SD) for Speed of Task Execution, General Switch Costs, Perceptual Speed, and Fluid Intelligence as a Function of Age Group (Children, Younger Adults, Older Adults) and Training Group (Single, Switch, Verbalization, Feedback, Variability) at Pretest

	Matching criteria							
Training group	Speed of task execution		General switch costs		Digit-Symbol score		Raven score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Children							
Single	1000	184	363	227	34.8	8.1	23.6	3.5
Switch	1040	194	363	148	36.1	8.8	23.6	2.1
+ verbalization	973	148	400	182	33.2	5.9	23.1	2.3
+ + feedback	979	195	403	156	33.3	8.6	22.8	2.7
+ + variability	996	297	357	179	34.7	7.6	22.6	2.3
	Younger adults							
Single	570	118	170	184	64.9	8.2	27.8	1.6
Switch	545	67	149	91	67.9	11.1	26.8	1.9
+ verbalization	525	105	174	88	64.2	9.9	26.6	1.9
+ + feedback	567	155	178	164	63.4	11.8	27.1	2.5
+ + variability	604	91	186	118	66.4	13.4	27.8	1.8
	Older adults							
Single	758	175	345	243	50.1	13.5	23.9	3.9
Switch	818	262	363	217	47.8	8.5	22.1	2.7
+ verbalization	705	121	364	184	49.6	10.0	23.2	3.3
+ + feedback	837	256	389	173	49.4	11.9	22.3	3.4
+ + variability	765	215	394	243	51.9	10.0	23.9	1.9

Note. Single = single-task training (group 1); switch = task-switching training (group 2); verbalization = task-switching + verbal self-instruction training (group 3); feedback = task-switching + verbal self-instruction training + feedback (group 4); variability = task-switching + verbal self-instruction training + training variability (group 5).

Training Data

Before transfer effects were analyzed, data from the four training sessions were inspected. Although the main focus of the present study is on transfer rather than training effects, the results of the training data form an important basis for the interpretation of the subsequent transfer results. Thus, in order to examine the influence of extensive practice on single-task and task-switching performance, two sets of analyses were performed. The first one focused on the single-task training group (group 1) and the second one on the groups that were trained in task switching (groups 2-5). Data for group 1 were subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and the within-subjects factor Session (training 1, 2, 3, 4,). Data for groups 2-5 were subjected to a four-way ANOVA including the additional between-subjects factor Training Group (switch, verbalization, feedback, variability) and the within-subjects factor Trial Type (nonswitch, switch). Means and error rates for all experimental conditions are provided in the Appendix (Table 14 – 16).

Single-Task Training (Group 1)

Latencies. Analysis of the single-task training data revealed a quadratic age effect, $F(1, 39) = 33.74$, $p < .0001$, $\eta^2 = .36$, with slower latencies for children and older adults than for younger adults, and slower responses for children than for older adults, $F(1, 39) = 20.80$, $p < .0001$, $\eta^2 = .22$. In addition, there was a significant main effect for session[22], $F(3, 117) = 5.51$, $p < .01$, $\eta^2 = .13$, revealing a general reduction of latencies from the first to the last training session, $F(1, 39) = 7.25$, $p = .01$, $\eta^2 = .15$ (see Figure 12, left panel).

[22] Based on mean RT, the main effect for session was not significant.

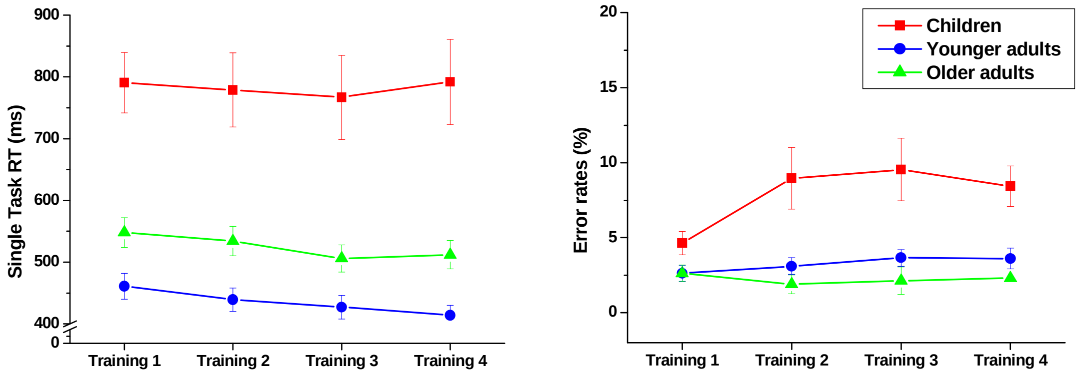

Figure 12: Mean RT (ms, left panel) and accuracy (error rates, right panel) for the single-task training group as a function of age group (children, younger adults, older adults) and session (training 1, 2, 3, 4). Error bars refer to standard errors of the mean.

Accuracy. The analysis on the level of error rates showed a main effect for age group, $F(2, 39) = 10.82$, $p < .001$, $\eta^2 = .36$, indicating that error rates were generally higher in children than in adults, $F(1, 153) = 21.04$, $p < .0001$, $\eta^2 = .35$, but that there was no difference between younger and older adults ($p = .44$). The main effect for session, $F(3, 117) = 3.64$, $p < .05$, $\eta^2 = .07$, interacted with age group, $F(6, 117) = 3.13$, $p < .01$, $\eta^2 = .13$. Post-hoc comparisons showed that in contrast to older adults, error rates in children and younger adults generally increased from the first to the last session, $F(1, 13) = 8.94$, $p = .01$, $\eta^2 = .41$, and $F(1, 13) = 6.97$, $p < .05$, $\eta^2 = .34$ (see Figure 12, right panel).

Task-Switching Training (Groups 2-5) (Predictions 1 - 5)

Results of the overall ANOVA on the level of latencies are presented in Table 7. All main effects were significant, and so were a number of the two-way interactions as well as a three-way interaction between session, training group, and trial type. The overall results for error rates were generally consistent with those based on latencies. Except for the factor

Training Group, all main effects reached significance, as well as a few two-way interactions and four of the three-way interactions (see Table 7).

Table 7: ANOVA Results for the Training Data Based on Log-Transformed RT and Accuracy (% Errors) for the Task-Switching Training Groups (Groups 2-5)

	Log-RT				Accuracy (% errors)		
Effect	*df*	*F*	*p*	η^2	*F*	*p*	η^2
Age group	2, 153	135.58	> .0001	.61	31.07	> .0001	.28
Training group	3, 153	3.75	.012	.02	0.51	.678	.01
Age group × training group	6, 153	1,42	.205	.02	1.40	.218	.04
Session	3, 459	131.43	> .0001	.36	5.15	.002	.03
Session × age group	6, 459	2.01	.067	.01	10.60	> .0001	.11
Session × training group	9, 459	21.29	> .0001	.18	3.34	.001	.05
Session × age group × training group	18, 459	1.52	.082	.03	1.29	.194	.04
Trial type	1, 153	455.73	> .0001	.66	215.05	> .0001	.53
Trial type × age group	2, 153	18.49	> .0001	.06	8.84	.001	.04
Trial type × training group	3, 153	7.10	> .0001	.04	3.31	.022	.02
Trial type × age group × training group	6, 153	1.36	.235	.01	2.32	.036	.03
Session × trial type	3, 459	54.29	> .0001	.22	.44	.727	.01
Session × trial type × age group	6, 459	1.01	.418	.01	2.29	.035	.03
Session × trial type × training group [23]	9, 459	5.42	> .0001	.07	2.02	.035	.04
Session × trial type × age group × training group	18, 459	0.70	.801	.02	1.29	.189	.04

[23] Based on mean RT, there were also interactions between session and age group, $F(6, 495) = 6.39$, $p < .0001$, $\eta^2 = .04$, and between session, age group, and training group, $F(18, 459) = 2.13$, $p < .01$, $\eta^2 = .04$. These interactions disappeared for log-transformed RT.

In order to inspect the pattern of age differences regarding training-related benefits within each of the training conditions, separate analyses were performed for these groups. Since there were no specific expectations regarding the course of practice effects across the four sessions of training, the following analyses are focused on the comparison between sessions one and four. However, in order to disentangle the significant interactions with the factor Training Group, a follow-up ANOVA including all four training groups and the training sessions one and four was performed. Of special importance for the interpretation of the subsequent transfer effects is the significant three-way interaction between session, trial type, and training group, because it allows determining whether the type of task-switching training modulated the amount of training related benefits (i.e., the reduction of specific switch costs from the beginning to the end of training). First, the results for each of the training groups are presented separately, followed by the most important analysis, namely the disentanglement of the interactions with the factor Training Group.

Results for latencies in each training group revealed a quadratic age effect, showing slower RT in children and older adults than in younger adults, and also faster RT in older adults than in children (all p's < .05; see Figure 13). In addition, specific switch costs were reliable in all training groups, both on the level of latencies and accuracy (all p's < .001). With respect to latencies, a quadratic age function was found for specific switch costs under all training conditions, that is, costs were larger for children and older adults than for younger adults (all p's < .05). Given that these effects were consistent across training conditions and also in line with the overall analysis, they will not be reported separately for each training group. Instead, the focus will be on interactions with the factor Session and only significant effects will be reported.

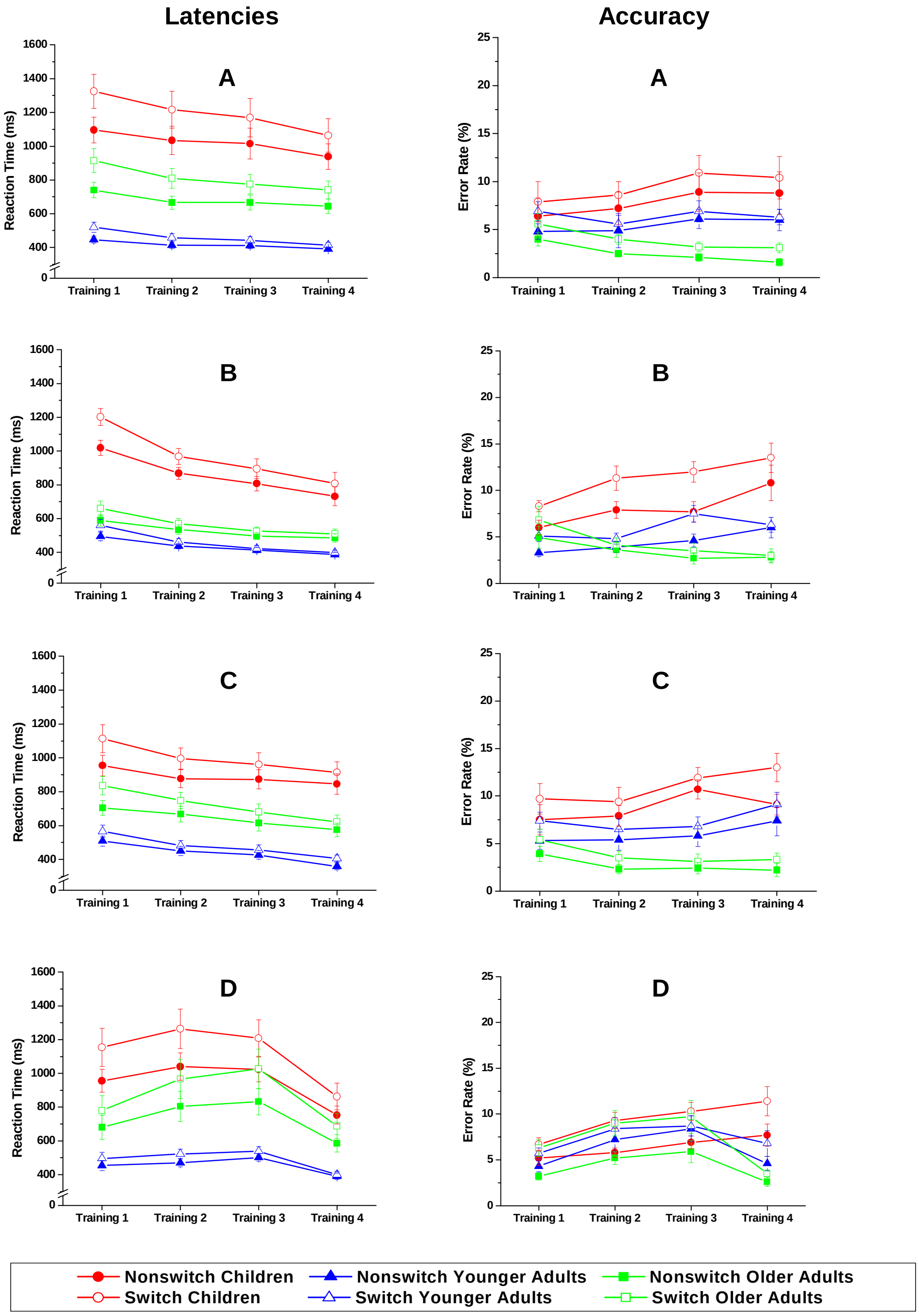

Figure 13: Mean RT (ms, left panel) and accuracy (error rates, right panel) as a function of age group (children, younger adults, older adults), session (training 1, 2, 3, 4), and trial type (nonswitch, switch). A: Task-switching training (group 2), B: Task-switching + verbal self-instruction training (group 3), C: Task switching + verbal self-instruction + feedback (group 4), D: Task switching + verbal self-instruction + variability (group 5). Error bars refer to standard errors of the mean.

Task-Switching Training (Group 2)

Latencies. RT was generally reduced from the first to the fourth training session, $F(1, 39) = 52.67$, $p < .0001$, $\eta^2 = .60$. A session × trial type interaction, $F(1, 39) = 56.08$, $p < .0001$, $\eta^2 = .75$, indicated that specific switch costs were also reduced from the first to the fourth training session (see Figure 13). This reduction was not modulated by age group ($p = .82$).

Accuracy. Results based on error rates showed that children generally committed more response errors than adults, $F(1, 39) = 5.45$, $p < .05$, $\eta^2 = .12$, without a reliable difference between younger and older adults ($p = .16$). No interactions with session were found.

Task-Switching and Verbal Self-Instruction Training (Group 3)

Latencies. RT was reduced from the first to the last session, $F(1, 39) = 82.89$, $p < .0001$, $\eta^2 = .64$, and this reduction was larger for children than for adults, $F(1, 39) = 6.07$, $p < .05$, $\eta^2 = .05$, but equal for younger and older adults ($p = .38$). An interaction between session and trial type, $F(1, 39) = 45.10$, $p < .0001$, $\eta^2 = .54$, showed that specific switch costs were generally reduced from training session one to four (see Figure 13). The interaction with age group was not significant ($p = .50$).

Accuracy. Again, error rates were larger for children than for adults, $F(1, 39) = 18.41$, $p = .0001$, $\eta^2 = .32$, but there was no difference between younger and older adults ($p = .57$). In contrast to older adults, children and younger adults made more response errors in the last training session than in the first one, $F(1, 39) = 27.82$, $p < .0001$, $\eta^2 = .39$, and $F(1, 39) = 17.73$, $p = .0001$, $\eta^2 = .25$.

Task Switching, Verbal Self-Instructions, Feedback (Group 4)

Latencies. RT was reduced from the first to the last session, $F(1, 37) = 74.40$, $p < .0001$, $\eta^2 = .65$. Consistent with the previous groups, specific switch costs were reduced from the first to the last training session, $F(1, 37) = 52.38$, $p < .0001$, $\eta^2 = .56$, but this reduction was not modulated by age group ($p = .84$).

Accuracy. The ANOVA based on error rates also revealed that children made more response errors than adults, and that younger adults committed more errors than older adults, $F(1, 37) = 14.07$, $p < .001$, $\eta^2 = .13$, and $F(1, 37) = 7.28$, $p < .05$, $\eta^2 = .24$, respectively.

Task Switching, Verbal Self-Instructions, Variability (Group 5)

Latencies. Analysis for the variability group also showed a general reduction of RT from the first to the last training session, $F(1, 38) = 74.85$, $p < .0001$, $\eta^2 = .62$, that was more pronounced in children than in adults, $F(1, 38) = 7.75$, $p < .01$, $\eta^2 = .06$, but equal for younger and older adults ($p = .36$). Furthermore, specific switch costs were generally reduced from the first to the last training session, $F(1, 38) = 16.09$, $p < .001$, $\eta^2 = .25$ (see Figure 13). However, there were no age differences in the reduction of specific switch costs ($p = .28$)[24].

Accuracy. Analysis on the level of error rates showed that children committed more response errors than adults, $F(1, 38) = 13.77$, $p < .001$, $\eta^2 = .25$, without a difference between younger and older adults ($p = .13$). In contrast to adults, children made more errors in the last session than in the first one, $F(1, 38) = 10.43$, $p < .01$, $\eta^2 = .20$, but there was no difference between younger and older adults ($p = .10$).

Finally, and most importantly, results for the follow-up analysis disentangling the interactions with the factor Training Group are reported. In this analysis, data were subjected to a four-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (switch, verbalization, feedback, variability), and the within-

[24] Based on mean RT, this reduction was larger for children than for adults, $F(1, 38) = 14.00$, $p < .001$, $\eta^2 = .19$.

subjects factors Session (training 1 and 4) and Trial Type (nonswitch switch). However, the focus was on interactions with the factor Training Group.

Latencies. The analysis based on latencies showed a trial type × training group interaction, $F(3, 153) = 3.68$, $p = .01$, $\eta^2 = .01$, indicating that specific switch costs were smaller in the groups performing verbal self instructions during training (groups 3 - 5) than in the task-switching training group without verbalizations, $F(1, 153) = 8.95$, $p < .01$, $\eta^2 = .01$, but that there was no difference between the verbalizing groups (all *p*'s > .16). This interaction was not modulated by age group ($p = .15$). Importantly, the interaction between session and trial type[25] was qualified by training group, indicating that the reduction of specific switch costs from the first to the last training session was smaller for the variability group (group 5) than for the remaining training groups, $F(1, 153) = 12.18$, $p < .001$, $\eta^2 = .03$, and that there was no difference between the groups 2 – 4 (all *p*'s > .81). Note that this difference between the variability group and the remaining training groups was not modulated by age group ($p = .63$).

Accuracy. On the level of accuracy, none of the interactions with the factor Training Group reached significance (all *p*'s > .18).

Summary. Thus, to sum up the results for the training phase, analyses for the single-task training group showed that latencies were reduced as function of practice in all age groups; however, in contrast to older adults, children and younger adults showed an increase in error rates at the same time.

When it comes to the task-switching training groups, effects of age group and training group were most pronounced on the level of latencies: Specific switch costs were characterized by a quadratic age function, indicating that costs were larger for children and

[25] On the level of mean RT, the interaction between session, trial type, and age group also reached significance, $F(2, 153) = 8.38$, $p < .0001$, $\eta^2 = .05$, showing that the reduction of specific switch costs as a function of training was larger for children than for adults, $F(1, 153) = 16.51$, $p < .0001$, $\eta^2 = .05$, without a difference between younger and older adults ($p = .64$).

older adults than for younger adults (cf. Kray et al., in press). Furthermore, specific switch costs were reduced when verbal self-instructions were performed (confirming prediction 2), while neither the additional feedback (confirming prediction 3) nor the variable training tasks (disproving prediction 4) modulated specific switch costs.

Most importantly, specific switch costs were reduced - but not eliminated - as a function of training in all age groups (cf. Bherer et al., 2005; Kray & Lindenberger, 2000; Kramer, Hahn, et al., 1999) and this reduction occurred to a similar degree in all age groups (confirming predictions 1a-1c). However, while this reduction was less pronounced in the variability group (confirming prediction 5), there neither was an influence of verbal self-instructions nor of feedback. It should be noted, however, that the variability group is not completely comparable with the remaining training groups, because the results may be confounded with differences in task difficulty.

Effects on the level of accuracy were less pronounced and generally in line with those based on latencies. However, it should be noted that similar to the single-task training group, children – and sometimes also younger adults – showed an increase of error rates from the first to the last training session, pointing to a speed-accuracy trade-off. Importantly, this decrease of accuracy was only found on the level of absolute error rates, but not on the level of switch costs.

Age-Related Differences in the Near Transfer of Task-Switching Training to a Similar Switching Task

This section is divided into two parts: The first part focuses on task switching at pretest in order to make sure that the general pattern of age-related differences in performance found in this study was consistent with previous findings. The second part deals with near transfer of task-switching training to a similar switching task.

Analysis of Pretest Task-Switching Data (Prediction 6)

In order to examine age-related differences in task-switching abilities at pretest, data were subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and the within-subjects factor Trial Type (single, nonswitch, switch). Results for mean RT and accuracy are shown in Figure 14 (right and left panel). In order to demonstrate the effects of log-transformation as a means to account for age differences in baseline performance, results based on log-transformed latencies are exemplarily shown in addition (see Figure 14, middle panel).

Latencies. Analysis revealed a significant quadratic age effect, indicating that younger adults responded faster than older adults and children, $F(1, 195) = 206.43$, $p < .0001$, $\eta^2 = .48$. Post-hoc comparisons showed that children also responded slower than older adults, $F(1, 195) = 23.71$, $p < .0001$, $\eta^2 = .05$. In addition, there was a main effect for trial type, $F(2, 390) = 1022.19$, $p < .0001$, $\eta^2 = .82$, with significant general and specific switch costs, $F(1, 195) = 1041.29$, $p < .0001$, $\eta^2 = .82$, and $F(1, 195) = 922.35$, $p < .0001$, $\eta^2 = .83$. In line with previous findings, there was a quadratic age function for general switch costs, indicating that they were larger for children and older adults than for younger adults, $F(1, 195) = 24.32$, $p < .0001$, $\eta^2 =$

.02, but that there was no difference between children and older adults (p = .11). However, no age differences were found for specific switch costs[26].

Table 8: Mean RT (ms) and Standard Deviations (SD) at Pretest as a Function of Age Group (Children, Younger Adults, Older Adults) and Trial Type (Single, Nonswitch, Switch); General Switch Costs and Specific Switch Costs as a Function of Age Group (Children, Younger Adults, Older Adults)

	Trial type						Switch costs			
Age group	Single		Nonswitch		Switch		General		Specific	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children	998	204	1195	257	1554	352	377	176	359	181
Younger adults	543	110	613	159	817	276	172	131	204	143
Older adults	776	211	979	308	1316	440	371	208	337	186

Accuracy. Analysis based on error rates showed that children committed more response errors than adults, $F(1, 195) = 29.54$, $p < .0001$, $\eta^2 = .12$, but that the difference between younger and older adults failed to reach significance (p = .08). In line with the latencies, there was a significant effect for trial type, $F(2, 390) = 68.16$, $p < .0001$, $\eta^2 = .24$, yielding general switch costs as well as specific switch costs, $F(1, 195) = 69.02$, $p < .0001$, $\eta^2 = .23$, and $F(1, 195) = 66.48$, $p < .0001$, $\eta^2 = .24$. General switch costs were also larger for children than for adults, $F(1, 195) = 14.93$, $p < .0001$, $\eta^2 = .05$, but there was no difference between younger and older adults (p = .16). Consistent with the analysis based on RT, no age differences were found for specific switch costs (p = .21).

[26] The analysis based on mean RT also revealed a quadratic age effect for specific switch costs, $F(1, 195) = 31.53$, $p < .0001$, $\eta^2 = .04$, that disappeared for log-transformed RT (see Figure 14).

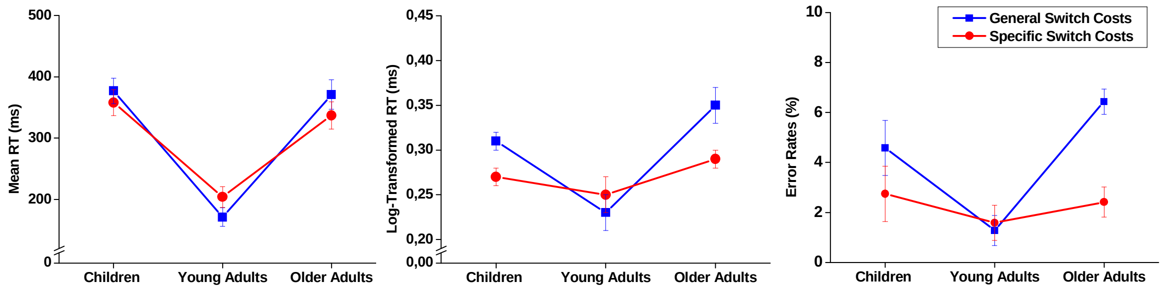

Figure 14: General and specific switch costs at pretest based on mean RT (left panel), log-transformed RT (middle panel), and error rates (right panel) as a function of age group (children, younger adults, older adults). Error bars refer to standard errors of the mean.

Summary. Thus, in line with previous studies, results for mean latencies and accuracy showed reliable general switch costs and specific switch costs. Age differences for general switch costs followed a quadratic developmental function (cf. Cepeda et al., 2001; Kray et al., in press; Kray et al., 2004; Reimers & Maylor, 2005), but there were no age differences for specific switch costs when age differences in baseline performance were accounted for by means of log-transformation (cf. Kray et al., 2004; Reimers & Maylor, 2005; see also Figure 14) (confirming prediction 6).

Near Transfer of Task-Switching Training: The Influence of Verbal Self-Instructions, Feedback, and Training Variability (Predictions 7-14)

In order to examine near transfer to a similar switching task, pretest and posttest data were submitted to a four-way ANOVA with the between-subjects factors Age Group (children, younger adults, older adults) and Training Group (single, switch, verbalization, feedback, variability), and the within-subjects factors Session (pretest, posttest) and Trial Type (single, nonswitch, switch). Mean RT and error rates for all experimental conditions are provided in the

Appendix (Table 17 and Table 18). Given that the pattern of age differences in the speed of responding as well as in general and specific switch costs was completely consistent with the pretest data, the effects are not presented again. Instead, the focus is on interactions with the factors Session and Training Group.

Latencies. ANOVA based on latencies revealed a main effect for session, showing that RT decreased from pretest to posttest, $F(1, 195) = 484.32$, $p < .0001$, $\eta^2 = .68$. Session interacted with age group, $F(2, 195) = 4.06$, $p < .05$, $\eta^2 = .01$, showing that this decrement was more pronounced for children and younger adults than for older adults (both *p*'s = .01), and with trial type, $F(2, 390) = 233.52$, $p < .0001$, $\eta^2 = .48$, showing that both types of switch costs decreased from pretest to posttest, general switch costs: $F(1, 195) = 278.90$, $p < .0001$, $\eta^2 = .52$, and specific switch costs: $F(1, 195) = 167.94$, $p < .0001$, $\eta^2 = .40$[27].

However, most important for the present study were interactions between the factor Training Group and other experimental factors. While the main effect for training group was not significant (p = .34), the analysis showed interactions between session × training group, $F(4, 195) = 5.36$, $p < .001$, $\eta^2 = .03$, session × training group × trial type, $F(8, 390) = 7.00$, $p < .0001$, $\eta^2 = .06$, and session × training group × trial type × age group, $F(16, 390) = 2.19$, $p < .01$, $\eta^2 = .04$.

In order to disentangle these interactions, several contrasts were specified for the factor Training Group: Comparing groups 1 and 2 showed that the reduction of general switch costs from pretest to posttest was larger after task-switching training (group 2) than after single-task training (group 1), $F(1,156) = 25.11$, $p < .0001$, $\eta^2 = .05$, and that this transfer effect was more pronounced for children and older adults than for younger adults, $F(1,156) = 4.57$, *p*

[27] Analysis based on mean RT also revealed a session × trial type × age group interaction, $F(4, 390) = 6.22$, $p < .0001$, $\eta^2 = .02$, with a quadratic age function for the reduction of general switch costs from pretest to posttest, $F(2, 195) = 8.71$, $p < .001$ $\eta^2 = .02$. That is, children and older adults showed a larger reduction of general switch costs from pretest to posttest than younger adults.

< .05, η^2 = .03 (see Figure 15)[28]. That is, based on log-transformed RT, children reduced their general switch costs by 62%, younger adults by 41%, and older adults by 56%. Comparisons of group 2 and 3 (p = .96) and group 3 and 4 (p = .59) indicated that near transfer was neither modulated by verbal self-instructions performed during task-switching training nor by additional feedback indicating the value of the verbalization strategy. Finally, a comparison between group 2/3/4[29] and 5 revealed that transfer (i.e., the reduction of general switch costs from pretest to posttest) was reduced in children and increased in adults when training tasks were variable[30], $F(1, 65) = 9.17$, $p < .01$, $\eta^2 = .07$, and $F(1, 130) = 8.88$, $p < .01$, $\eta^2 = .02$ (see Figure 15).

With respect to specific switch costs, the reduction from pretest to posttest was also larger after task-switching training (group 2) than after single-task training (group 1), $F(1,156) = 6.27$, $p = .01$, η^2 = 01, but this near transfer was neither modulated by verbalizations, feedback, and variability (all p's >.20), nor by age (p = .24).

[28] Aside from the log-transformation as a means of controlling for age differences in baseline performance, hierarchical regression analysis served to examine whether age differences in the amount of transfer in the switch group (group 2) were still present after removing the effects of age-related changes in general switch costs at pretest. Using reduction of general switch costs as the dependent variable, general switch costs at pretest were first entered into the regression procedure, followed by age, and the quadratic function of age. Although age added a significant amount of unique variance, $R^2\Delta = .05$, $F\Delta\ (1, 39) = 4.57$, $p < .05$, the quadratic function of age did not (p = .30).

[29] Given that there was no difference between groups 2, 3, and 4, data were collapsed across these groups to increase statistical power. However, the same pattern was found when group 2 was compared separately to group 5 (all p's < .05).

[30] Again, hierarchical regression analysis was used as a second method to examine whether the age differences in the amount of transfer in the variability group (group 5) were still present after removing the age-related changes in general switch costs at pretest. General costs at pretest were entered first into the model, followed by age, and a square root transformed function of age. Both age and the square root age function added a significant amount of unique variance, $R^2\triangle = .11$, $F\triangle\ (1, 39) = 10.10$, $p < .01$, and $R^2\triangle = .09$, $F\triangle\ (1, 39) = 9.80$, $p < .01$.

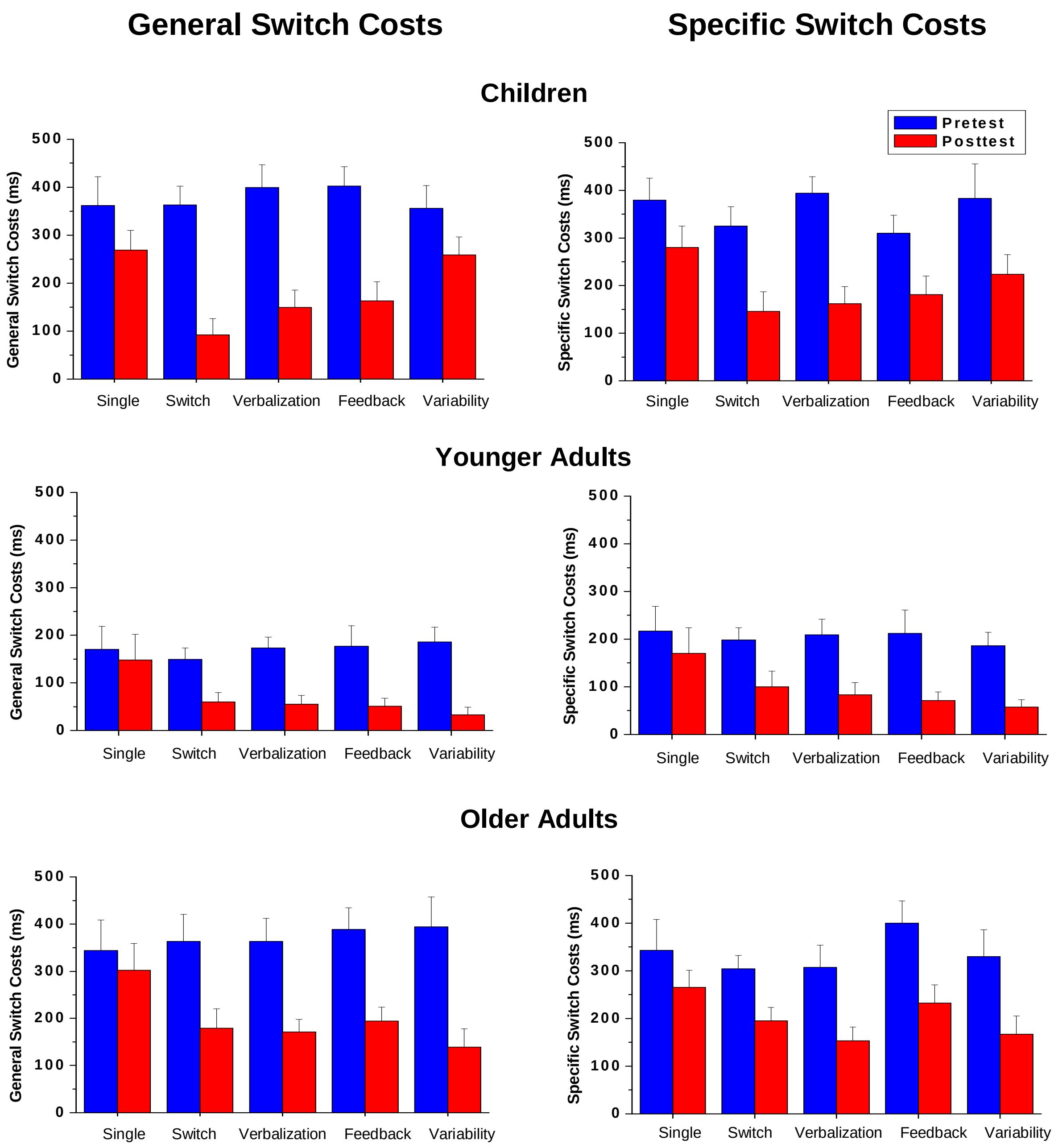

Figure 15: General switch costs (left panel) and specific switch costs (right panel) on the level of mean RT as a function of age group (children, younger adults, older adults), training group (single, switch, verbalization, feedback, variability), and session (pretest, posttest). Error bars refer to standard errors of the mean.

Accuracy. Analysis based on error rates yielded a main effect for session, $F(1, 195) = 6.95$, $p < .01$, $\eta^2 = .03$, that was modulated by age group, $F(2, 195) = 8.70$, $p < .001$, $\eta^2 = .07$, indicating that children and younger adults committed more errors at posttest than at pretest, while older adults showed a reduction of error rates at posttest, $F(1, 195) = 17.37$, $p < .0001$, $\eta^2 = .07$. Also, there was a session $\times$ training group interaction, $F(4, 195) = 3.40$, $p = .01$, $\eta^2 = .06$. Post-hoc comparisons showed that this interaction was caused by the feedback group (group 4) committing more errors at posttest than the remaining groups, $F(1, 195) = 9.85$, $p < .01$, $\eta^2 = .04$. No further interactions reached significance.

Summary. Results clearly showed that the reduction of general switch costs from pretest to posttest was larger after task-switching training than after single-task training (confirming prediction 7), that is, there was near transfer from task-switching training to a similar switching task, especially in children and adults (confirming prediction 8). This near transfer was not modulated by verbal self-instructions (disproving predictions 9 and 10) and feedback (disproving prediction 12). Interestingly, it was reduced in children and increased in adults when the training tasks were variable (confirming prediction 14). In addition, the task-switching training also resulted in near transfer on the level of specific switch costs (confirming prediction 7), but there were no modulations by age group or by the type of training (confirming predictions 11 and 13). Transfer effects were restricted to the level of RT.

Far Transfer of Training to Other Executive Tasks and Other Task Domains

Aside from near transfer to a similar switching task, the aim of this study also was to assess far transfer to other executive abilities (inhibitory control, WM) and to another task domain (fluid intelligence). Accordingly, this section is divided into three parts. The first part focuses on the structure of the cognitive abilities assessed with the tasks in the cognitive test battery (see p. 103). Given that two or three indicators were used to measure each construct in order to increase the reliability and validity of measurement, the first step was to examine whether data for each construct can be collapsed across tasks for the analysis of far transfer effects. The second part analyzes far transfer of task-switching training to other 'executive' tasks, namely to the Stroop task, to verbal and visuospatial WM tasks as well as to another task domain, that is, fluid intelligence. In the third part, the control measures are investigated. Before transfer effects were analyzed for each of the transfer domains, pretest performance was inspected to make sure that the pattern of age-related differences found for each domain was consistent with previous studies.

Structure of Cognitive Abilities

In order to examine far transfer of task-switching training to other executive tasks and other task domains, a total of 16 tests was used in the cognitive test battery to investigate seven domains of cognitive abilities: Inhibitory control (Color Stroop, Number Stroop), verbal working memory (Reading Span, Counting Span), visuospatial working memory (Symmetry Span, Navigation Span), fluid intelligence (Raven's Standard Progressive Matrices, Figural Reasoning, Letter Series), knowledge (Spot-a-Word Test), perceptual speed (Digit-Symbol Substitution Test, Digit-Letter Substitution Test), and verbal speed (Letter Articulation Rate, Digit Articulation Rate, Word Articulation Rate) (see Table 3). In order to investigate whether the tasks are reliable indicators for the respective constructs, the ability structure was tested by means of confirmatory factor analysis (CFA) using structural equation modeling (with the software package AMOS, Arbuckle, 2005). The advantage of this approach is that intercorrelations between constructs at the latent level are corrected for measurement errors (Nachtigall, Kroehne, Funke, & Steyer, 2003).

Prior to model fitting, the raw data were checked to examine whether they were consistent with the assumption of multivariate normality. Kurtosis estimates did not exceed 1 or -1 for any of the measures[31], suggesting that the distributional properties of the data warranted the use of standard maximum likelihood chi-square estimation procedures.

Analyses were based on z-transformed data, and model fitting on the variance-covariance matrix. A chi-square test compared the observed covariance matrix with the model covariance matrix. Given that the model represents the null hypothesis, non-significant results indicate that the model does not differ from the empirical data. Given that the power of the chi-square test extremely depends on the sample size, it has been suggested to rely on the chi-square/degrees of freedom ratio instead of the chi-square *p*-value. This index should be smaller than two (Schermelleh-Engel, Mossbrugger, & Müller, 2003). In addition, the Comparative Fit Index (CFI), the Non-Normed Fit Index (NNFI), and the Root Mean Square Error of Approximation (RMSEA) will be reported as indexes of incremental fit (Bentler, 1989; Hu & Bentler, 1999). According to Bentler (1989), values larger than .90 are desirable for the CFI and the NNFI. In samples including less than 250 subjects, the RMSEA should be smaller than .08 (Hu & Bentler, 1999). Also, chi-square values, degrees of freedom, and corresponding *p*-values for all models are reported (cf. Raykov, Tomer, & Nesselroade, 1991). Table 9 provides an overview of the model-fitting procedure.

In a first step, a six first-order factor model structure with the factors inhibitory control, verbal WM, visuospatial WM, fluid intelligence, perceptual speed, and verbal speed was

[31] The only exception was Figural Reasoning (4.67).

specified[32] (M1). Unfortunately, this model was not admissible, indicating that the specified model structure did not fit the data. The inspection of the correlation matrix showed that the correlations between the respective indicators for each construct were high, that is, .51 for verbal WM, .57 for visuospatial WM, .45-.56 for fluid intelligence, .92 for perceptual speed, and .87-.92 for verbal speed. However, when it comes to inhibitory control, the correlation between the interference effects for the Color Stroop version and the Number Stroop version was not significant (-.10). The complete correlation matrix is provided in the Appendix (Table 19).

Therefore, in the second step, the initial model was modified and a five first-order factors model (M2) with the factors verbal WM, visuospatial WM, fluid intelligence, perceptual speed, and verbal speed was fit to the data (see Figure 16). Inhibitory control was dropped from the model, because the inspection of the correlations suggested that both indicators (Color Stroop interference and Number Stroop interference) could not be loaded on the same factor. This modified model showed satisfactory fit indexes for the whole sample including all three age groups (M2) and also for each of the age groups separately (see Table 9). Inspecting the model for each of the age groups[33] was important because some studies have indicated that the structure of intellectual abilities changes from childhood to adolescence and to older age (e.g., Lindenberger & Baltes, 1997; Reinert, 1970; Schmidt & Botwinik, 1989). However, consistent with prior findings, the model specified in the present study fitted each of the age groups (cf. Bickley, Keith, & Wolfe, 1995; Kray & Lindenberger, 2000; Schaie, Willis, Jay, & Chipur, 1989; Zelinski & Lewis, 2003), indicating that the five-factor structure seems to be stable across a wide range of ages.

[32] Given that the factor “knowledge” was only represented with one indicator task, it was not included into the model. For the factor “inhibitory control”, the interference effects in the color and the number version of the Stroop task served as indicators.

[33] Although the separate models for each age group are important from a developmental perspective, it should be noted that the sample size per age group in this study (*n* = 70) was way below the critical limit (N = 100) for structural equation modeling (Bühner, 2004).

Table 9: Summary of the Model-Fitting Procedures

Model (Description)	χ^2	df	*p* value	χ^2/df	RMSEA	NNFI	CFI
M1: Six first-order factors	Solution not admissible[34]						
<u>M2:</u> Five first-order factors model (without inhibitory control)	63.77	44	.03	1.45	.05	.97	.99
M2: Children	52.76	44	.17	1.20	.05	.99	.99
M2: Younger adults	61.76	44	.04	1.40	.08	.99	.99
M2: Older adults	42.20	44	.55	1.00	.00	.91	.99

Note. CFI = Comparative Fit Index, NNFI = Non-Normed Fit Index, RMSEA = Root Mean Square Error of Approximation.

Inspection of the model M2 indicated that the correlations between the latent variables were consistently on a high level. Given that all five domains are assumed to represent abilities from the mechanic component of intelligence (i.e., memory, fluid intelligence, (verbal and perceptual) speed), this finding is not surprising and consistent with previous studies (cf. Duncan et al. 2000; Kray & Lindenberger, 2000; Lindenberger et al., 1993). Also, the correlation between measures with high executive control demands (i.e., WM measures) was higher (.90) than between these ‘executive’ tasks and the speed measures (-.51 - .70). However, although high correlations between working memory and fluid intelligence are in line with previous findings (Engle, Tuholski, Laughlin, & Conway, 1999; Fry & Hale, 1996), those between both WM factors (.90) and between visuospatial WM and fluid intelligence (.94) are particularly high. The same pattern was found for each of the age groups, but especially for children and older adults (children: .80 and .96; younger adults .74 and .74; older adults .86 and .87). Given that the WM data are based on span measures (i.e., the number of correctly

[34] In case a model completely fails to fit, not all fit indexes are provided, and those indexes provided cannot be interpreted.

recalled trials, see p. 125) and not on the number of correctly solved items within each trial, one may assume that this measurement failed to properly differentiate within children and older adults. This view is supported by the fact that the variability in the performance of the WM tasks was noticeably larger in younger adults than in children, and mostly also larger than in older adults (see Appendix, Table 24), resulting in higher correlations within these age groups.

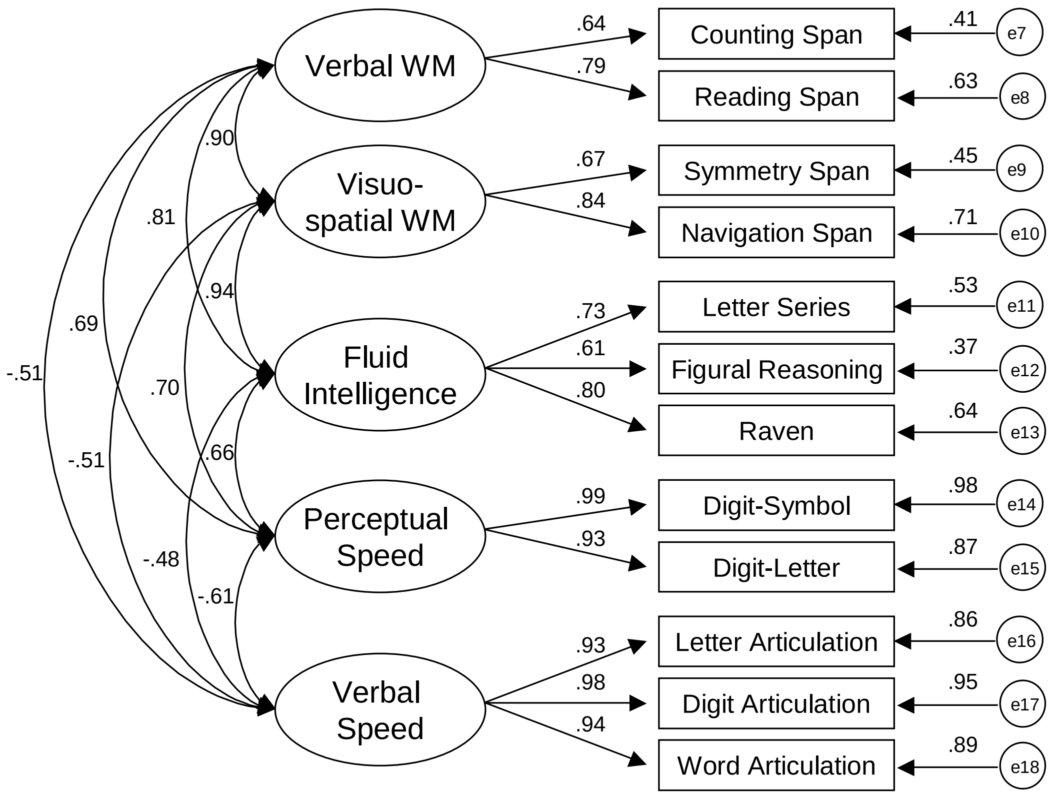

Figure 16: Accepted model M2 with standardized parameter estimates.

It should be noted that, especially based on the intercorrelations between the latent variables, the model could of course be further modified. However, given that the primary aim of this analysis was to identify a proper model for pooling the data for the analysis of far transfer effects (i.e., investigating whether the data of the respective indicator tasks of each construct can be collapsed for this analysis) rather than to examine the structure of the cognitive abilities, further model modifications will be set aside here. Given that the intercorrelations between the indicator tasks were high and M2 yielded very satisfactory fit indices, the analysis of far transfer was based on this structure including five first-order factors (Figure 16) and separate analyses for both versions of the Stroop task and the Spot-a-Word Test.

Far Transfer to Other Executive Tasks: The Stroop Task (Prediction 15)

Based on the expectation that far transfer to the Stroop task should not - or at least less - be modulated by verbal self-instructions and training variability, the first analysis examined whether the task-switching training groups (2-5) showed a different amount of transfer. Therefore, data for each of the task versions (Color and Number Stroop) were subjected to a four-way ANOVA with the between-subjects factors Age Group (children, younger adults, older adults) and Training Group (switch, verbalization, feedback, variability), as well as the within-subjects factors Session (pretest, posttest) and Trial Type (neutral, incongruent). The mean performance on the level of latencies and accuracy is provided in the Appendix (Table 20 - Table 23). Given that there were no substantial interactions of the factor Training Group with other experimental variables, neither on the level of latencies nor accuracy, data were collapsed across groups 2-5 to increase the statistical power and subjected to a four-way ANOVA with the between-subjects factors Age Group (children, younger adults, older adults) and Training Group (single task, task switching), and the within-subjects factors Session (pretest, posttest) and Trial Type (neutral, incongruent). Since the CFA showed that interference effects in both task versions were not correlated, the color and the number version were analyzed separately. However, analyses for both task versions showed quadratic age functions with faster latencies in younger adults than in children and older adults as well as faster performance at posttest than at pretest (all *p*'s $< .0001$). Also, interference effects were significant in both task versions on the level of latencies and accuracy (all *p*'s $< .0001$). Thus, these effects will not be reported separately for each task version – instead, the focus is on interactions with the factors Age Group and Training Group.

Color Stroop

Latencies. An interaction between session and age group[35], $F(2, 204) = 4.68$, $p = .01$, $\eta^2 = .03$, showed that the speeding of RT from pretest to posttest was larger for children than for adults, $F(1, 204) = 7.16$, $p < .01$, $\eta^2 = .03$, but there was no difference between younger and older adults ($p = .14$). In addition, this speeding of RT was more pronounced for the task-switching training group than for the single-task training group, $F(1, 204) = 7.92$, $p < .01$, $\eta^2 = .03$. Interference effects were larger for adults than for children, and also larger for older adults than for younger adults, $F(1, 204) = 7.16$, $p < .01$, $\eta^2 = .02$, and $F(1, 204) = 7.73$, $p < .01$, $\eta^2 = .02$. Importantly, there was an interaction between session, trial type, age group, and training group, $F(2, 204) = 4.79$, $p < .01$, $\eta^2 = .03$. Post hoc comparisons indicated that children showed a reduction of interference from pretest to posttest, $F(1, 68) = 4.31$, $p < .05$, $\eta^2 = .09$, but this effect was not modulated by the type of training ($p = .17$, see Figure 17, upper panel). In contrast, interference in adults interacted with session and training group, $F(1, 136) = 7.85$, $p < .01$, $\eta^2 = .05$, showing that interference increased from pretest to posttest after single-task training, but that it was reduced after task-switching training ($F(1, 26) = 4.45$, $p < .05$, $\eta^2 = .13$, and $F(1, 110) = 7.86$, $p < .01$, $\eta^2 = .05$; see Figure 17, upper panel). Thus, adults showed far transfer to interference control in the Stroop task after task-switching training, but not after singe-task training. Children, however, also showed this far transfer after single-task training. There were no age differences in the amount of transfer after task-switching training (all *p*'s > .15).

[35] This interaction failed to reach significance on the level of mean RT ($p = .07$).

Accuracy. A main effect for age group indicated that children made more errors than adults, $F(1, 204) = 10.24$, $p < .01$, $\eta^2 = .04$. No further main effects or interactions reached significance. Thus, there was no evidence for far transfer (i.e., a reduction of interference from pretest to posttest) on the level of accuracy.

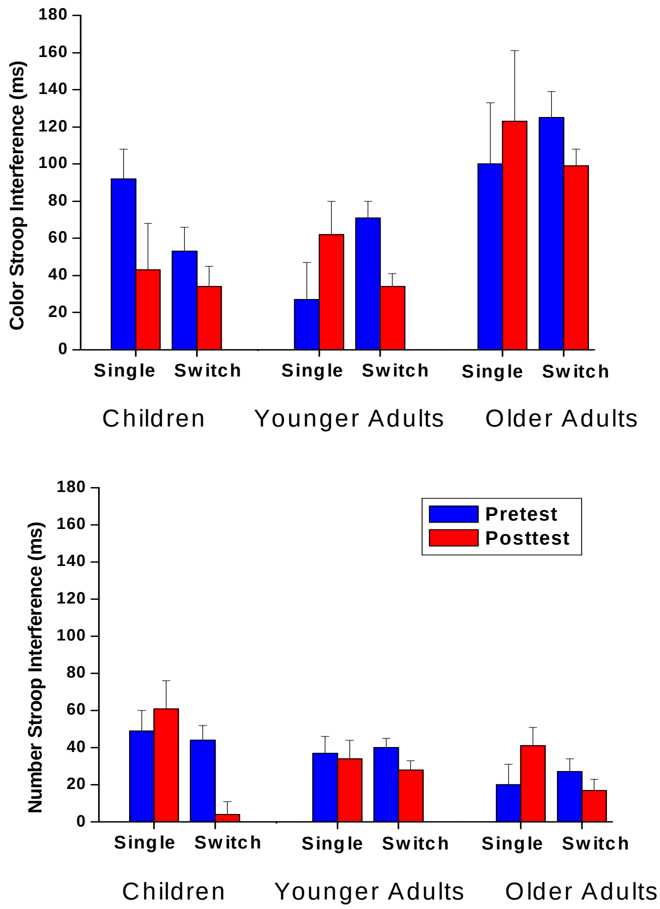

Figure 17: Color Stroop (upper panel) and Number Stroop (lower panel) interference effects (ms) as a function of age group (children, younger adults, older adults), training group (single task, task switching), and session (pretest, posttest). Error bars refer to standard errors of the mean.

Number Stroop

Latencies. An interaction between session, age group, and training group, $F(2, 204) = 4.09$, $p < .05$, $\eta^2 = .03$, showed that the speeding of RT from pretest to posttest in children and younger adults was more pronounced in the task-switching training group than in the single-task training group, whereas the reverse effect was found in older adults. Interference was larger in younger adults than in older adults, $F(2, 204) = 5.86$, $p < .05$, $\eta^2 = .01$, but there was no difference between children and younger or older adults ($p = .54$ and $.07$). An interaction between trial type, age group, and training group, $F(2, 204) = 4.17$, $p < .05$, $\eta^2 = .01$, pointed to larger interference effects in younger adults than in children and older adults in the task-switching training group, $F(1, 165) = 17.06$, $p < .0001$, $\eta^2 = .38$, but there was no difference between children and older adults ($p = .76$). Importantly, there was a session $\times$ trial type $\times$ training group interaction, $F(2, 204) = 11.63$, $p < .001$, $\eta^2 = .03$, showing that interference effects were generally increased from pretest to posttest after single-task training and reduced after task-switching training, $F(1, 39) = 6.00$, $p < .05$, $\eta^2 = .14$[36], and $F(1, 165) = 10.63$, $p = .001$, $\eta^2 = .08$[37] (see Figure 17, lower panel). However, the interactions with age group failed to reach significance on the level of log-transformed RT (all *p*'s > .06). Thus, results for the number version also showed far transfer of task-switching training to interference control in the Stroop task in all age groups.

Accuracy. Children made more response errors than adults, and younger adults also made more errors than older adults, $F(1, 204) = 25.08$, $p < .0001$, $\eta^2 = .23$, and $F(1, 204) = 9.30$, $p < .01$, $\eta^2 = .09$. There was a main effect for training group, showing that the single-task training group committed less response errors than the task-switching training group, $F(1, 204) = 5.03$, $p < .05$, $\eta^2 = .02$. A session $\times$ age group interaction, $F(2, 204) = 7.28$, $p < .001$, $\eta^2 = .06$,

[36] Analysis based on mean RT yielded a quadratic age effect, $F(1, 39) = 4.85$, $p < .05$, $\eta^2 = .09$, indicating that this increase was only found in children and older adults, but not in young adults.
[37] Based on mean RT, this reduction of interference effects was larger for children than for adults, $F(1, 165) = 7.11$, $p < .01$, $\eta^2 = .04$.

revealed that in contrast to adults, children increased their accuracy from pretest to posttest, $F(2, 204) = 9.79$, $p < .01$, $\eta^2 = .04$. No further main effects and interactions reached significance. However, consistent with the results for the Color Stroop task, there was no evidence for far transfer (i.e., a reduction of interference from pretest to posttest) on the level of accuracy.

Although the reduction of Stroop interference from pretest to posttest after task-switching training was consistent with the initial expectations (see prediction 15), the increase of interference effects after single-task training (in younger and older adults in the color task and in children and older adults in the number task) was somewhat unexpected. To investigate whether this increase in interference costs (i.e., the difference in performance between incongruent and neutral trials) was caused by a more pronounced RT speeding from pretest to posttest in neutral trials or a less pronounced speeding in incongruent trials, separate analyses were performed for neutral and incongruent trials. And indeed, when it comes to younger and older adults, posttest RT for the color task was faster than pretest RT for neutral trials, $F(1, 136) = 53.48$, $p < .0001$, $\eta^2 = .29$, but less for incongruent trials, $F(1, 136) = 39.41$, $p < .0001$, $\eta^2 = .12$ (see Table 10). A similar pattern was found for children and older adults in the number task. Thus, the benefit at posttest was more pronounced for neutral trials than for incongruent trials, resulting in larger interference effects for the single-task training group at posttest.

Summary. Thus, despite of a few small differences, the general pattern of results for both task versions was consistent: All age groups showed a reduction of interference effects from pretest to posttest after task-switching training, that is, they showed far transfer from task-switching training to the Stroop task (confirming prediction 15). After controlling for differences in baseline performance, there were no age differences in the amount of transfer. In contrast to the initial expectations, children also showed far transfer (i.e., a reduction of interference effects from pretest to posttest) after single-task training in the Color Stroop task.

Table 10: Stroop Task Mean RT (ms) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single Task, Task Switching), Session (Pretest, Posttest), Trial Type (Neutral, Incongruent), and Task Version (Color, Number)

	Single-Task Training						Task-Switching Training					
	Neutral		Incongruent		Interference		Neutral		Incongruent		Interference	
Session	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children (Color Stroop)												
Pretest	898	119	991	131	93	62	977	159	1030	162	53	104
Posttest	967	215	1011	148	44	96	896	136	931	155	35	88
Younger adults (Color Stroop)												
Pretest	675	118	703	148	28	76	628	122	699	148	71	69
Posttest	596	94	658	132	62	70	554	85	589	112	35	56
Older adults (Color Stroop)												
Pretest	864	193	964	280	100	126	884	186	1009	237	125	106
Posttest	804	200	927	303	123	145	822	174	922	204	100	73
Children (Number Stroop)												
Pretest	912	103	961	111	49	44	966	130	1010	128	44	64
Posttest	885	135	986	159	101	56	892	123	897	135	5	59
Younger adults (Number Stroop)												
Pretest	586	82	623	76	37	35	564	91	605	95	41	38
Posttest	549	69	584	89	35	37	514	71	543	93	29	38
Older adults (Number Stroop)												
Pretest	779	165	800	171	21	44	743	100	770	106	27	52
Posttest	705	114	746	140	41	38	701	107	719	112	18	47

Far Transfer to Other Executive Tasks: Verbal Working Memory (Predictions 16 and 17)

Aside from far transfer of task-switching training to the Stroop task, this study also investigated far transfer to WM abilities. As described in the Method section, two indicator tasks were used to measure verbal WM (Counting Span and Reading Span). Based on the results of the CFA, data were collapsed across both tasks.

First, data for the verbal WM abilities (% correct) were subjected to an ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) to examine the pattern of age-related differences at pretest. Results showed a main effect for age group, $F(2, 209) = 45.10$, $p < .0001$, $\eta^2 = .30$, as well as a quadratic age function, revealing better performance in younger adults than in children and older adults, and also better performance in older adults than in children (all p's < .0001). Thus, age differences in verbal WM abilities at pretest were consistent with prior findings (for reviews, see Hitch, 2006; Park & Payer, 2006), indicating that verbal WM abilities constantly improve during childhood and decline again in older age.

Second, far transfer of task-switching training to verbal WM was inspected. The initial hypothesis regarding far transfer of task-switching training was that transfer should be more pronounced in the task-switching training groups (2-5) than in the single-task training group (1). Also, the focus was on whether verbal self-instruction training (groups 3-5) could be transferred to verbal WM tasks (prediction 17). Therefore, the first analysis examined whether the training groups 3-5 (i.e., the groups performing verbal self-instruction during training) showed different amounts of transfer. Data (transfer relative to baseline performance, see p. 125, Method) were subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (verbalization, feedback, variability). Since neither the main effects for training group nor the interactions with age group reached significance (all p's > .15), data were collapsed across groups 3-5 to increase statistical power. Mean performances for all experimental conditions are provided in the

Appendix (Table 24). To investigate far transfer of task-switching and verbal self-instruction training, data were then subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (single task, task switching, task switching + verbal self-instructions). Results showed a reliable main effect for training group, $F(2, 209) = 3.15$, $p < .05$, $\eta^2 = .03$. Post-hoc comparisons indicated that transfer was larger after task-switching training than after single-task training, $F(1, 209) = 6.17$, $p = .01$, $\eta^2 = .03$, but that there was no difference between the task-switching training group (group 2) and the task switching + verbal self-instruction groups (3-5, $p = .69$)[38] (Figure 18). Neither the main effect for age group nor the age group × training group interaction reached significance (p = .11 and .53). Thus, results for verbal WM showed larger performance improvements after task-switching training than after single-task training, that is, there was far transfer of task-switching training to verbal WM abilities in all age groups (confirming prediction 16). However, there was no far transfer of verbal self-instruction training (disproving prediction 17).

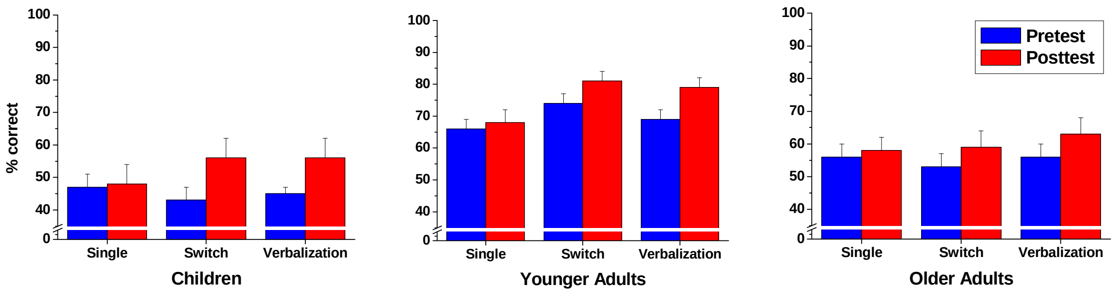

Figure 18: Mean performance for verbal WM (% correct) as a function of age group (children, younger adults, older adults), training group (single task, task switching, task switching + verbalization), and session (pretest, posttest). Error bars refer to standard errors of the mean.

[38] Note that results did not change when data were not collapsed across groups 3-5, and group 3 was separately compared to groups 1 and 2: Transfer was still larger in group 3 than in group 1, and there was no difference between groups 2 and 3 ($p < .05$ and $p = .89$).

Far Transfer to Other Executive Tasks: Visuospatial Working Memory (Prediction 18)

In line with the analysis for verbal WM, data for the visuospatial WM abilities (% correct) were subjected to an ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) to examine the pattern of age-related differences at pretest. Results showed a main effect for age group, $F(2, 209) = 60.67$, $p < .0001$, $\eta^2 = .37$, along with a quadratic age function, indicating better performance in younger adults than in older adults and children, and also better performance in older adults than in children (all *p*'s < .05). Thus, the age differences with respect to visuospatial WM found in this study were generally consistent with previous findings (e.g., DeLuca, 2003; for reviews, see Hitch, 2006; Park & Payer, 2006), indicating that visuospatial WM abilities increase from childhood to adolescence and decline again in older age.

For the analysis of far transfer, it was first tested whether the task-switching training groups (groups 2-5) showed different amounts of transfer by subjecting the data (transfer relative to baseline performance, see Method) to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (switch, verbalization, feedback, variability). However, neither the main effect for training group nor the interaction with age group reached significance ($p = .23$ and .93, respectively). Thus, data were collapsed across groups 2-5. Mean performance for all experimental conditions is shown in the Appendix (Table 24).

To investigate far transfer, data were then subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (single task, task switching). Results showed a reliable main effect for training group, $F(1, 204) = 5.34$, $p < .05$, $\eta^2 = .03$, indicating that transfer was larger after task-switching training than after single-task training. Neither the main effect for age group nor the age group $\times$ training group interaction reached significance (p = .25 and .86)[39].

It should be noted that several[40] participants completely failed to answer correctly at pretest. As a result, the difference in performance between pretest and posttest could not be calculated relative to the baseline performance pretest. In the analysis reported above, these missing values were replaced by the respective group means. However, in order to make sure that this procedure did not change the pattern of results, an additional analysis was performed without these subjects. The results were completely consistent with those reported above: The amount of transfer was not different in the task-switching training groups (groups 2 - 5) (p = .32), but there was more transfer after task-switching training than after single-task training, $F(1, 186) = 4.48$, $p < .05$, $\eta^2 = .02$. Again, neither the main effect for age group nor the age group $\times$ training group interaction reached significance (p = .31 and .88)[41].

In sum, all age groups showed larger performance improvements from pretest to posttest after task-switching training than after single-task training, that is, there was far transfer of task-switching training to visuospatial WM abilities (confirming prediction 18).

[39] Note that the pattern of results did not change when data were not collapsed across groups 2-5. When the single-task training group (group 1) was compared separately to the task-switching training group (group 2), transfer was still larger after task-switching training than after single-task training, $F(1, 78) = 7.12$, $p < .01$, $\eta^2 = .08$, and neither the main effect for age group nor the age group x training group interaction were significant (p = .33 and .79).

[40] Seven children, one younger adult, and ten older adults; four participants per training condition at most.

[41] Also, results did not change when data were not collapsed across groups 2-5. A separate comparison of group 1 and 2 still showed more transfer after task-switching training than after single-task training, $F(1, 69) = 5.55$, $p < .05$, $\eta^2 = .07$, and no effect for age group or age group x training group (p = .42 and .83).

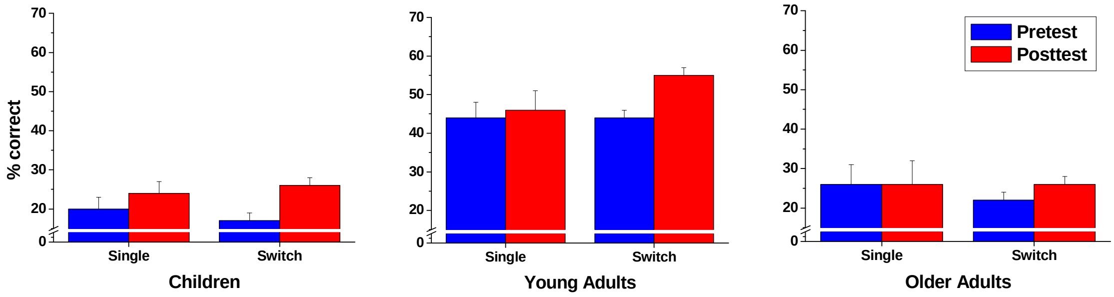

Figure 19: Mean performance for spatial WM (% correct) as a function of age group (children, younger adults, older adults), training group (single task, task switching), and session (pretest, posttest). Error bars refer to standard errors of the mean.

Far Transfer to Other Another Task Domain: Fluid Intelligence (Prediction 19)

In order to examine the pattern of age differences at pretest, data for the fluid intelligence tasks (% correct) were also subjected to an ANOVA with the between-subjects factor Age Group (children, younger adults, older adults). Results showed a main effect for age, $F(2, 209) = 64.84$, $p < .0001$, $\eta^2 = .39$, with better performance in younger adults than in children and older adults, but the difference between children and older adults failed to reach significance ($p = .09$). These findings are consistent with prior studies and the two-component model of intelligence (cf. P. B. Baltes et al., 1998; P. B. Baltes et al., 1999).

In line with the previous analyses for far transfer, it was first tested whether the task-switching training groups (groups 2-5) showed different amounts of transfer by subjecting the data (transfer relative to baseline performance) to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (task-switching, verbalization, feedback, variability). However, neither the main effect for training group nor the interaction with age group reached significance ($p = .81$ and $.82$). Thus, data were collapsed across groups 2-5 to increase statistical power. Mean performance for all experimental conditions is shown in the Appendix (Table 24).

In order to investigate far transfer, data were then subjected to a two-way ANOVA with the between-subjects factor Age Group (children, younger adults, older adults) and Training Group (single task, task switching). Results showed a reliable main effect for training group, $F(1, 204) = 6.68$, $p = .01$, $\eta^2 = .01$, indicating that transfer was larger after task-switching training than after single-task training (see Figure 20). Neither the main effect for age group nor the age group × training group interaction reached significance (p = .20 and .58, respectively)[42].

Hence, there also was far transfer from task-switching training to another task domain, namely fluid intelligence (confirming prediction 19), but there were no age differences in the amount of transfer.

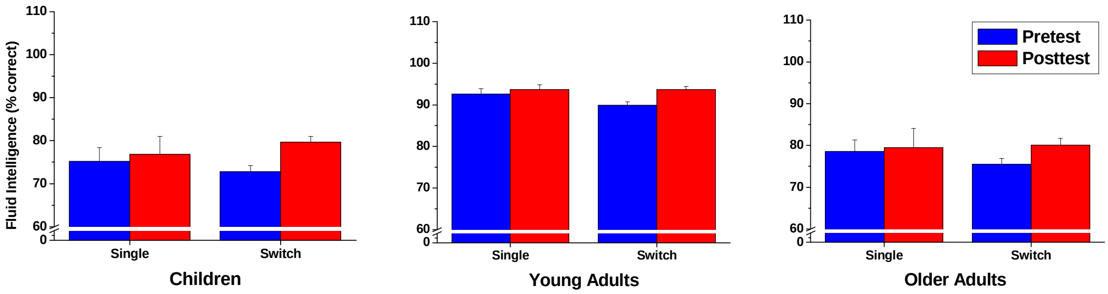

Figure 20: Mean performance for fluid intelligence (% correct) as a function of age group (children, younger adults, older adults), training group (single task, task switching), and session (pretest, posttest). Error bars refer to standard errors of the mean.

[42] The pattern of results did not change when data were not collapsed across groups 2-5. When the single-task training group (group 1) was compared separately to the task-switching training group (group 2), transfer was still larger after task-switching training than after single-task training, $F(1, 78) = 5.63$, $p < .05$, $\eta^2 = .07$, and neither the main effect for age group nor the age group x training group interaction were significant (p = .53 and .87).

Control Variables (Prediction 20)

Finally, this study also included measures for three constructs not supposed to rely on executive control, namely perceptual speed, verbal speed, and knowledge. These measures were included to show that intensive task-switching training does not result in far transfer to these abilities. Therefore, the next set of analyses focused on transfer of task-switching training to the control measures. The mean performance for all experimental conditions is provided in the Appendix (Table 25).

To examine age differences at pretest, data for every construct were subjected to an ANOVA with the between-subjects factor Age Group (children, younger adults, older adults); for the analysis of far transfer, data (transfer relative to baseline performance, see Method) were subjected a two-way ANOVA with the additional between-subjects factor Training Group (single, switch, verbalization, feedback, variability).

Perceptual Speed

Pretest data showed a main effect for age group and a quadratic age function, indicating that younger adults performed better than children and older adults; and older adults also outperformed children (all p's < .0001). However, when it comes to far transfer, neither the main effects for age group and training group nor their interaction reached significance (all p's > .18).

Verbal Speed

Pretest data showed a main effect for age group and a quadratic age function, revealing that younger adults verbalized faster than children and older adults; and older adults also verbalized faster than children (all p's < .0001). Regarding far transfer, there was a main effect for age group, indicating that the increase in verbal speed from pretest to posttest was smaller for older adults than for younger adults and children (all p's < .05). Nonetheless, neither the main effect for training group nor the interaction with age group reached significance (all p's > .24).

Knowledge

Pretest data showed a main effect for age group and a linear age function (see sample description), indicating that younger adults performed better than children, and that older adults outperformed younger adults (all p's < .0001). However, with respect to far transfer, there neither were main effects for age group (p = .07) and training group nor an interaction between them (both p's > .49).

All in all, pretest data for the control measures were consistent with the two-component model of intelligence (cf. P. B. Baltes et al., 1998; P. B. Baltes, 1999), but there was no far transfer of task-switching training to tasks not supposed to rely on executive control (confirming prediction 20).

Evaluation of the Training Program

This last chapter of the results section is dedicated to the evaluation of the training program. First, the focus is on two different ways for evaluating the effectiveness of the task-switching training program. The analyses reported above have focused on the comparison of different training conditions, such as single-task and task-switching training, based on mean performance (on the level of mean RT, log-transformed RT, and accuracy) within these training conditions. However, there are at least two other ways to quantify transfer of training and to compare the effectiveness of different types of training (see p. 70). First, the effect sizes for the different training and transfer conditions can be calculated. Second, aside from the group means, the proportion of participants actually showing training and transfer benefits within each training condition can be calculated. In order to consider a given training effective, effect sizes should be at least .30, and more than 50 % of the participants should show training and transfer effects (cf. Derwinger et al., 2003; Klauer, 2001). Therefore, effect sizes (ES) as well as the proportion of participants showing training and transfer benefits are analyzed in this section, structured along the results for near and far transfer reported above[43].

Second, the focus was on differential aspects of the training. The question was, which participants benefited most after training and whether individual transfer effects can be predicted. That is, the aim was to examine whether the task-switching training rather results in compensatory effects (i.e, worse performers benefit most) or more in “Matthew”-effects (i.e., better performers benefit most).

[43] These analyses are restricted to the measures yielding transfer effects. Therefore, the control variables are not analyzed.

Inspection of Training and Transfer Effect Sizes

In order to examine the effectiveness of the four different task-switching training conditions and the range of transfer across near and far transfer tasks, Cohen's (1977) *d*, or the standardized mean difference in performance between the beginning and the end of training (for training effects; and between pretest and posttest for transfer effects) was calculated (cf. Verhaeghen et al., 1992). Subsequently, all d-values were corrected for small sample bias using the Hedges and Olkin (1985) correction factor (*d'*) (for a detailed description, see p. 125, Method).

First, ES for the training benefits associated with the four different task-switching training conditions were analyzed. As shown in Figure 21, ES for the task-switching training (group 2) were relatively high in all three age groups (*d'* = .85-.98). When the switching training was combined, with the verbal self-instructions, ES increased again in all age groups, particularly for children (*d'* = 1.21-.1.88). Also in children, ES dropped slightly when feedback (group 4) was provided (*d'* = 1.09), but especially when training tasks were variable (group 5; *d'* = .58). While ES for younger adults were stable across training groups 3-5, older adults showed the largest ES when feedback was provided (*d'* = 1.73), but just as children, a marked decrease when training tasks were variable (*d'* = .17).

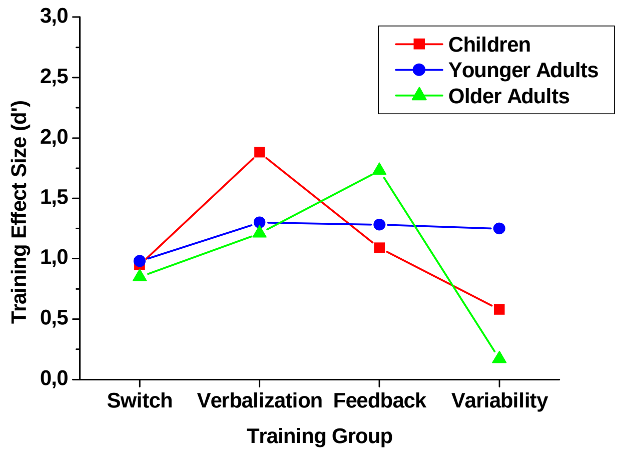

Figure 21: Effect size (d') for the training benefits on the level of specific switch costs as a function of age group (children, younger adults, older adults) and training group (switch, verbalization, feedback, variability).

Second, ES for near transfer to a similar switching task were analyzed. Pretest-posttest ES for the different training groups are shown in Figure 22. When it comes to general switch costs, there were larger ES for task-switching (*d*' = .98-2.15) than for single-task training (*d*' = .11-.55) in all age groups, but particularly for children. The ES for adults increased again when the switching training was combined with verbalizations (group 3) (*d*' = 1.42-1.45). In older adults, they were on a similar level when feedback (group 4) and variability (group 5) came into play (*d*' = 1.30-1.59); in younger adults, ES in the feedback condition were similar to the verbalization condition, and maximized in the variability group (*d'* = 1.28-1.30). However, the reverse effect was found for children: The verbalizations (*d*' = 1.53), the feedback (*d*' = 1.74), and even more the variable training (*d*' = .70) resulted in substantially smaller ES. Regarding specific switch costs, results for adults were similar: In all age groups, ES were larger after task-switching (*d*' = .88-1.14) than after single-task training (*d*' = .22-.60); for adults, they were on a similar level in the verbalization (*d*' = 1.07-1.16) and the feedback (*d*'

= 1.06-1.03) condition, and in younger adults maximized in the variability group (*d*' = 1.59). In children, ES were largest in the verbalization (*d*' = 1.96) condition, and reduced when the training was combined with feedback (*d*' = .89) and variability (*d*' = .73).

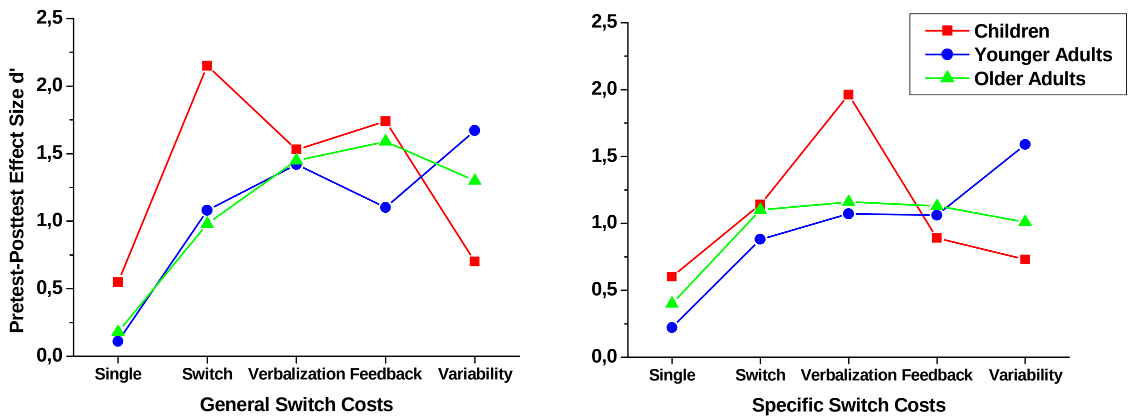

Figure 22: Effect size (d') for near transfer benefits on the level of general switch costs (left panel) and specific switch costs (right panel) as a function of age group (children, younger adults, older adults) and training group (single, switch, verbalization, feedback, variability).

Another goal of this analysis was to examine the range of far transfer to other executive tasks and other task domains. Effects sizes for far transfer after task-switching and single-task training are shown in Figure 23. Consistent with previous findings (cf. Klauer, 2001), ES were larger for near transfer to a similar switching task than for far transfer to other executive tasks and to another task domain. However, ES after task-switching training were still relatively large even for far transfer, with most values > .70 for children, > .60 for younger adults, and > .40 for older adults, and were quite consistent across the far transfer tasks. In contrast, ES for single-task training were generally small or even negative[44], and substantially smaller than those for task-switching training under all experimental conditions.

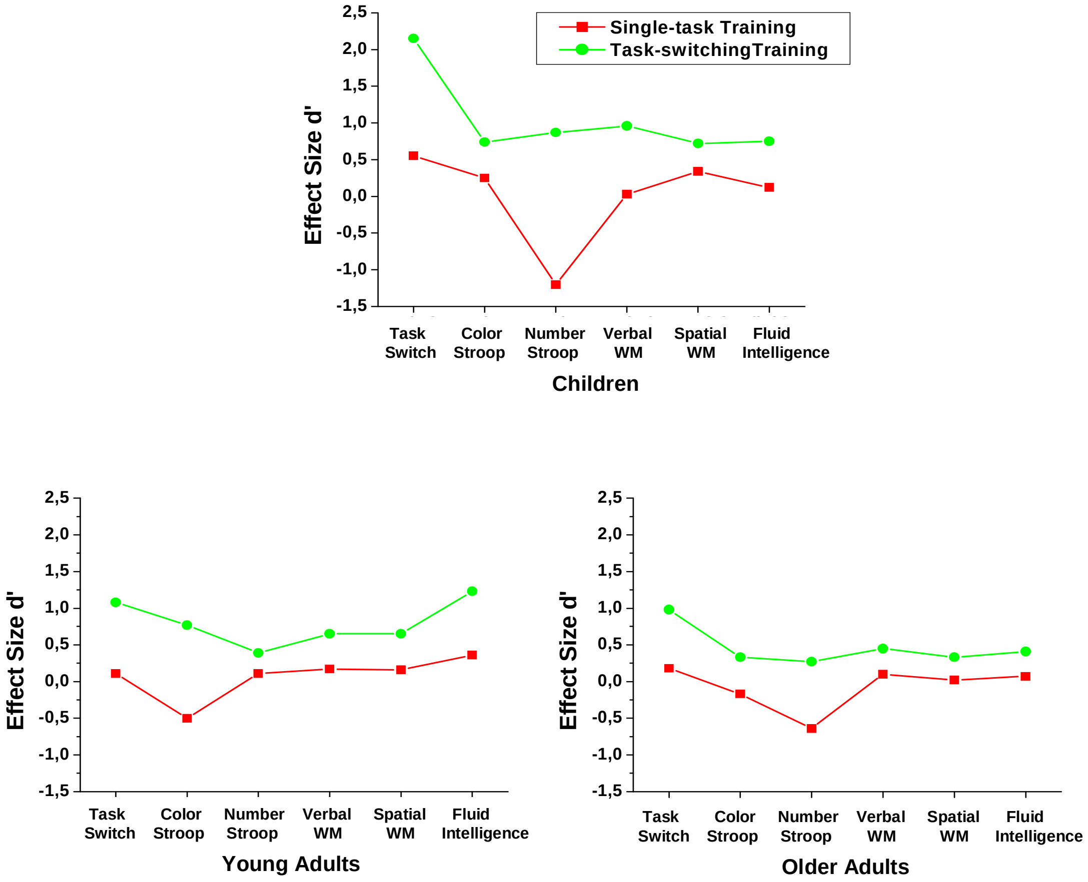

Figure 23: Effect size (d') for near and far transfer of single-task training and task-switching training as a function of age group (children, younger adults, older adults) and transfer measure.

In sum, all four training conditions (except for the variable training in adults) met Klauer's (2001) criterion that ES should be larger than .30. Moreover, ES were mostly larger

[44] Negative effect sizes were confined to the Stroop task and were due to the increase of Stroop interference effects from pretest to posttest reported above (see p. 52). This finding was clarified by the control analyses also reported in this section, indicating that the pretest-posttest improvement occurred to a larger degree in the neutral than in the incongruent condition, resulting in larger interference effects at posttest.

than one, suggesting that that the task-switching training – and even more so the switching training in combination with the verbal self-instructions – resulted in substantial training effects, at least when participants were trained with the same tasks in each training session.

ES for near as well as far transfer were in line with the previous analyses based on latencies reported above; thus, they further corroborate these results. In addition, they showed that the task-switching training (and for some tasks even the single-task training) completely satisfied Klauer's (2001) criterion for effective trainings (i.e., ES > .30).

Proportion of Transfer

Another criterion for the evaluation of training and programs is the proportion of participants actually showing training and transfer in each training condition (cf. Derwinger et al., 2003). Again, the first analysis focused on training effects. The proportion of subjects showing training benefits (i.e., a reduction of specific switch costs from the first to the last training session) was calculated for each of the four task-switching training conditions. In the switch group (group 2), 90.5% of participants showed in training-related benefits; so did 88.1% in the verbalization group (group 3), 92.5% in the feedback group (group 4), and 78% in the variability group (group 5). There were no significant differences between the training groups or the age groups (all *p*'s >. 21). Hence, all four training conditions clearly met the requirement of at least 50% participants showing training benefits.

Second, the proportion of transferring subjects was calculated for each training condition and each transfer task, so that the task-switching training could be compared with the single-task training[45]. Given that there were no age differences (p = .29), data were collapsed across age groups. Results for this analysis are provided in Table 11. And indeed,

[45] For each age group and each transfer measure, it was tested whether the four task-switching training groups (group 2-5) were characterized by a different number of transferring subjects. Given that there were no differences between these groups for any of the tasks (all p's > .13), data were collapsed across the task-switching training groups (groups 2-5).

after task-switching training, the proportion of transferring participants was always larger 60 %, and consistent with the findings on the level of effect sizes and latencies, it was also larger for near transfer to a similar switching task (i.e., general and specific switch costs) than for far transfer to other executive tasks and another task domain. Furthermore, the comparison to the single-task training group revealed more transferring subjects for both near and far transfer after task-switching training. Even though this difference failed to reach significance for visuospatial WM and fluid intelligence, results point into the same direction.

Table 11: Proportion of Participants showing Near and Far Transfer Effects (%) after Single-Task Training and after Task-Switching Training as a Function of Age Group (Children, Younger Adults, Older Adults) and Transfer Measure

Measure	Single-task training (%)	Task-switching training (%)	χ^2	*df*	*p*
General switch costs	69.0	93.5	19.77	1	> .001
Specific switch costs	64.3	87.5	12.75	1	> .001
Color Stroop interference	42.9	62.5	5.34	1	> .05
Number Stroop interference	35.7	63.1	10.32	1	.001
Verbal WM	42.9	62.5	5.34	1	> .05
Visuospatial WM	54.8	64.9	1.47	1	.225
Fluid intelligence	61.9	74.4	2.56	1	.107

Note. *n* (single-task training) = 42; *n* = (task-switching training) = 168.

Thus, results with respect to the proportion of participants showing training benefits as well as near and far transfer benefits were also consistent with the prior analyses reported above, indicating that the large majority of participants showed training-related improvements in performance and that the proportion of transfer was always larger after task-switching training than after single-task training.

Prediction of Training and Transfer Effects

Finally, it also was of interest to examine which participants showed the largest training and transfer benefits and whether these benefits can be predicted. On the one hand, one may assume that subjects initially performing on a relatively low level benefit the most (compensatory effect). On the other hand, it would also be reasonable to expect most benefits in subjects initially performing on a relatively high level (“Matthew”-effect, see p. 69). According to Klauer (2001), one way to examine this question is to analyze the status – benefit correlations, that is, the correlation between pre-training performance and training benefits as well as between pretest performance and transfer benefits. For compensatory effects, this correlation should be negative, and for “Matthew”-effects it would be positive.

Therefore, in order to inspect training benefits for each of the task-switching training groups, specific switch costs in training session 1 (status) were correlated with the training benefits (i.e., the reduction of specific switch costs from training session 1 to 4). Correlations for all training conditions were substantial (between -.66*** and -.83***, see Table 12) and most importantly, negative. That is, better performance in the beginning of training was associated with less training benefits and vice versa, suggesting that the training had compensatory rather than “Matthew”-effects in all age groups.

Accordingly, in order to assess transfer effects, pretest performance for near and far transfer measures (general switch costs, specific switch costs, Color Stroop interference, Number Stroop interference, verbal WM, visuospatial WM, and fluid intelligence) was correlated with the transfer benefits (i.e., the pretest-posttest difference) for these tasks. Consistent with the analysis of the training effects, substantial negative correlations between status and benefits were found for each of the transfer measures (between -.19* and -.72***, see Table 13). That is, the poorer participants performed at pretest, the larger were the transfer benefits – again, a finding clearly pointing to compensatory effects of the training program[46].

However, after simply inspecting the status-benefit correlations for training and transfer effects, a second set of analyses was performed for two reasons: First, although the correlations point to a negative relation between status and benefits, they do not really allow the prediction of training and transfer benefits based on status. Second, no conclusions can be drawn regarding the influence of other experimental variables with respect to the status-benefit relationship (e.g., effects of age). Therefore, in the next set of analyses a hierarchical regression approach was used to further corroborate these findings. The first analysis again focused on the prediction of training benefits. Using the training benefits as the dependent variable, specific switch costs in training session 1 were first entered into the regression procedure. To investigate age differences, age[47] was entered as second independent variable into the regression. This analysis allowed determining whether age added a significant amount of unique variance above that contributed by specific switch costs at the beginning of training. Results of the hierarchical regression analysis are shown in Table 12.

And indeed, specific switch costs at the beginning of training (status) turned out to be a reliable predictor for training benefits – that is, subjects performing poor at the beginning of training showed the largest training benefits. This relationship was strongest in the groups trained in task-switching and verbal self-instructions by means of the same training tasks (groups 3 and 4), and somewhat smaller in the groups only trained in task switching (group 2) or with variable tasks (group 5), respectively (Figure 24). However, age did not add unique variance for any of the training groups.

[46] It should be noted that in this type of analysis, the pretest-error enters the status–benefit correlation twice, so that the true correlations may be less negative (Bereiter, 1967).
[47] For the regression analysis, the age group variable (children, younger adults, older adults) used in the previous analyses was replaced with the participants' exact age.

Table 12: Regression Analysis Predicting Training Benefits

	R	R^2	F for R	β	t for β
Switch	.68***	.47	35.63***	-.68***	-5.97***
+ verbalization	.81***	.65	75.03***	-.81***	-8.67***
++ feedback	.83***	.69	83.22***	-.83***	-9.12***
++ variability	.66***	.44	30.70***	-.66***	-5.54***
Overall	.71***	.50	163.71***	-.71***	-12.80***

Note. *** p < .001; N (overall) = 168

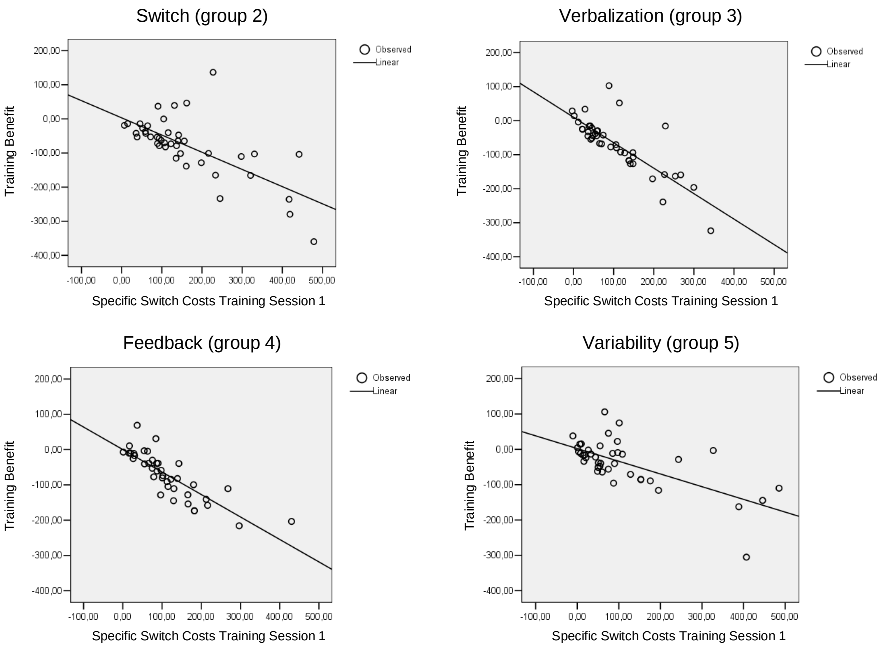

Figure 24: Linear curve fits for the prediction of training benefits based on specific switch costs at the beginning of training (session 1).

In a next step, a similar set of analyses was performed for transfer benefits regarding each of the transfer measures. That is, using the transfer benefits as the dependent variable, pretest performance was first entered into the regression procedure, followed by age. Moreover, in order to examine whether transfer benefits also depend on the actual amount of training benefits, these training benefits were also entered into the regression procedure. Results are summarized in Table 13.

Table 13: Regression Analysis Predicting Transfer Benefits

	R	R^2	*F* for *R*	β	*t* for β
1. General switch costs	.72***	.52	175.50***	-.72***	-13.25***
2. Specific switch costs	.66***	.44	127.98***	-.66***	-11.31***
3. Color Stroop	.68***	.46	142.95***	-.68***	-11.96***
4. Number Stroop	.69***	.47	148.04***	-.69***	-12.17***
5. Verbal WM	.34***	.12	22.21***	-.34***	-4.71***
6. Visuospatial WM	.19*	.04	6.30*	-.19*	-2.51*
7. Fluid Intelligence	.38***	.14	28.24***	-.38***	-5.31***

Note. *** $p < .001$; *$p < .05$; *N* (overall) = 168.

And indeed, pretest performance (status) turned out to be a reliable predictor for transfer benefits – that is, subjects performing poor at pretest showed the largest transfer benefits. This relationship was strongest for the near transfer to a similar switching task and for the far transfer to the Stroop task (the slopes of the respective regression functions are illustrated in Figure 25, bottom), and although noticeably less pronounced, it was still significant for far transfer to working memory and fluid intelligence. However, it should be noted that neither age nor the amount of training benefits added unique variance. That is, regardless of the participant's age and the amount of their training-related benefits, poor pretest performance was the best predictor for large transfer benefits and vice versa, lending further support for the interpretation that the training applied in this study was an effective means to compensate executive control deficits across a wide range of ages.

Summary. This section was dedicated to the evaluation of the training program applied in this study. Analysis of the effect sizes showed remarkably large effect sizes for the training-related benefits as well as for near transfer of task-switching training, and somewhat smaller ES that were similar across far transfer measures. However, ES after task-switching training were always considerably larger than .30, and always larger than after single-task training. In addition, the proportion of participants with training and transfer benefits easily exceeded 50%, and the proportion of transferring participants was clearly larger after task-switching training than after single-task training. Thus, these analyses have further supported the finding that task-switching training meets the criteria for effective trainings postulated in the literature (e.g., Klauer, 2001) and that it results in substantial near and far transfer effects.

In addition, analysis of the training and the transfer data consistently suggested that participants from all age groups that were characterized by relatively poor performance at pretest - or at the beginning of training, respectively - were also those who showed the most pronounced training and transfer effects. Thus, with respect to the initial question, is seems safe to say that the results reported here rather point to compensatory effects of the training than to “Matthew”-effects.

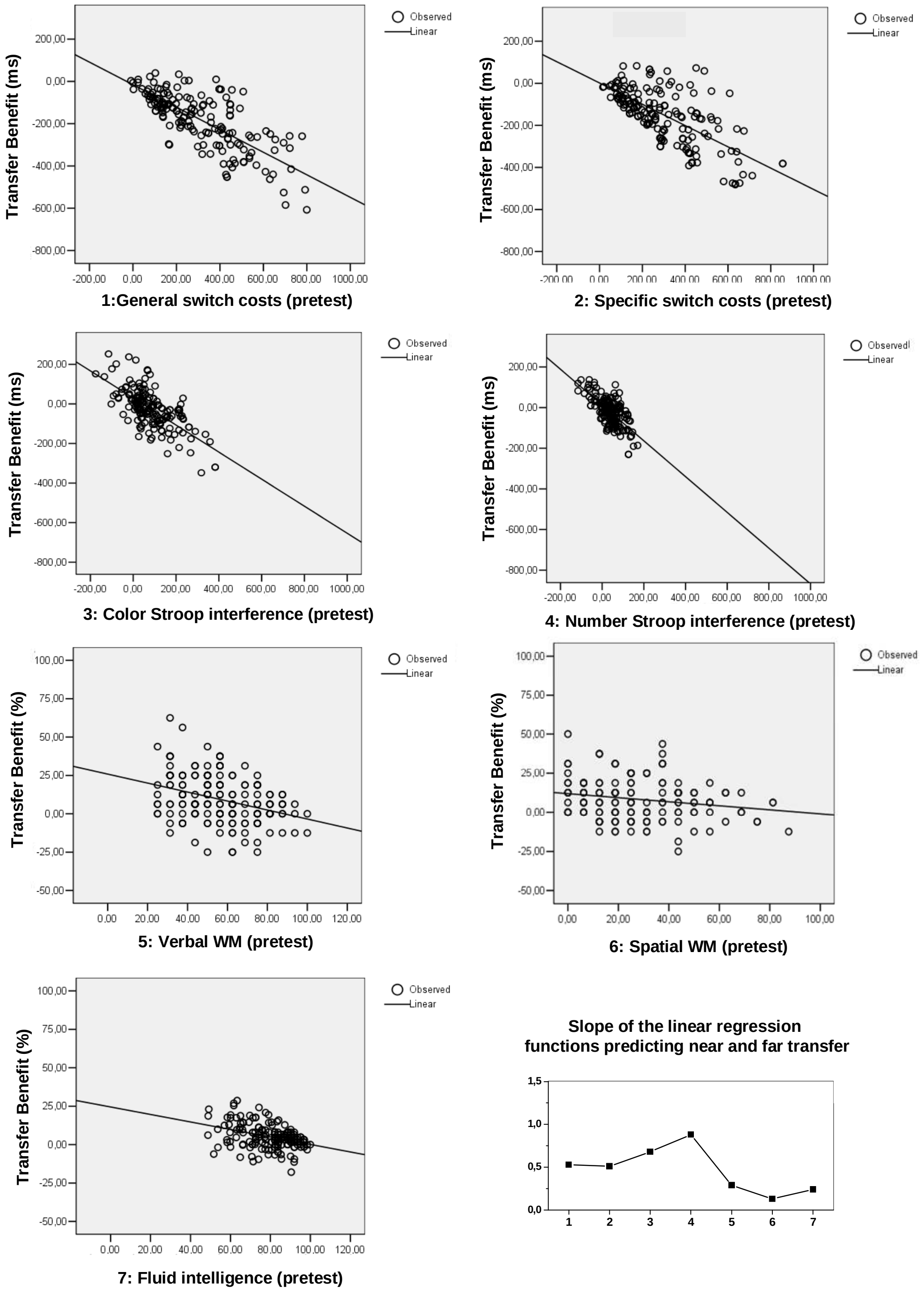

Figure 25: Linear curve fits for the prediction of transfer benefits based on pretest performance for each of the transfer measures.

6. Discussion

This last chapter is divided into four parts. In the first section, the main results are briefly summarized. The second part provides an extensive discussion of the present findings in the light of the relevant literature. First, the results for the four types of task-switching training applied in this study are briefly discussed, followed by the most important findings, namely the results for near transfer and far transfer, structured along the research predictions and the presentation of results. In the third part, the relevance of the present findings for further research and for the application of cognitive training programs is discussed. Finally, in part four, limitations of the study as well as a general conclusion and outlook are provided.

Summary of Main Results

The aim of this study was to investigate age differences in the near and far transfer of task-switching training as well as the modulation of transfer by the type of training. Children, younger adults, and older adults were investigated by means of a pretest – training – posttest design, including four sessions of intensive training. Transfer was defined as performance improvement at posttest relative to baseline performance at pretest. In order to investigate near and far transfer, pretest and posttest sessions included measurements of task-switching that were structurally similar to the training tasks, as well as a battery of cognitive tasks with a dissimilar structure, that is, other executive control tasks, measures of fluid intelligence, and control measures not supposed to rely on executive control. During training, participants were assigned to one of five training conditions. One group was only trained in single-task performance, so that executive control demands during training should be low. Another group was only trained in task switching, so that executive control training should be intense. Comparing the performance of these two groups allowed assessing the 'mere' transfer of task-switching training. The remaining three training groups were included to investigate whether the amount of transfer can be modulated in different age groups. Therefore, these groups additionally performed verbal self-instructions during training. In one of the groups, verbalizations were combined with feedback indicating the value of the verbalization strategy, and in another group they were combined with variable training (i.e., different training tasks in each training session).

Analysis of the training data revealed that specific switch costs were generally reduced as a function of training in all age groups. Also, specific switch costs were reduced when verbal self-instructions were performed, but there was no interaction with the amount of training-related benefits. However, the reduction of specific switch costs from the first to the last training session was less pronounced in all age groups when training tasks were variable.

Importantly, results indeed showed near transfer of task-switching training to a similar switching task (i.e., a reduction of general and specific switch costs from pretest to posttest) after task-switching training, but not after single-task training. With respect to general switch costs, this transfer was most pronounced for children and older adults[48]. Although it was not modulated by verbal self-instructions and feedback, variable training supported transfer on the level of general switch costs in younger and older adults, but hindered it in children. The type of training did not modulate transfer effects on the level of specific switch costs.

In addition to this near transfer, there was also reliable far transfer to another executive control task, namely the Stroop task. That is, Stroop interference effects were reduced from pretest to posttest after task-switching training, but not after single-task training. The same

[48] It should be noted that this age effect was significant based on mean RT and log-transformed RT, although the regression analysis indicated that the quadratic age trend (i.e., larger transfer in children and older adults that in young adults) did not add unique variance. However, implications of this age-related difference will be discussed anyhow.

pattern of results was found for far transfer to verbal and visuospatial working memory tasks as well as to fluid intelligence: Performance improvements from pretest to posttest were larger after task-switching training than after single-task training. Thus, there was far transfer to other executive tasks (Stroop, WM) and to another task domain (fluid intelligence), but not to control measures (perceptual speed, verbal speed, and knowledge). None of these far transfer effects were modulated by age or by the type of task-switching training. Further support for these near and far transfer effects came from the effect sizes that were always considerably high after task-switching training, and in any case larger than after single-task training. In line with previous findings (see Klauer, 2001), effects sizes after task-switching training were larger for near than for far transfer, but constantly high across far transfer tasks.

Finally, the focus was on differential aspects of the training and transfer effects. Specifically, the question was whether training and transfer benefits can be predicted. And indeed, regression analysis showed a negative linear relationship between pretest performance and training and transfer benefits across all training and age groups, that is, poor pretest performance was associated with large training and transfer benefits and vice versa.

Task-Switching Training: Effects of Age, Verbal Processes, Feedback, and Variability

Given that the main focus of the present study was on the transfer of task-switching training, training effects will only be discussed briefly. The first finding that all age groups and all training groups were able to reduce specific switch costs as a function of training (see Figure 13) is consistent with previous results regarding younger and older adults, showing that both age groups reduced the specific costs to a similar extent (Bherer et al., 2005; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). Moreover, the results with respect to children extend prior evidence by showing that not only general switch costs (Cepeda et al., 2001; Eber & Kray, in prep.), but also specific switch costs can be reduced after intensive training. These findings are supported by the corresponding effect sizes, ranging between .85 and .98 for the group that was only trained in task switching (group 2). However, the fact that reliable specific switch costs were still found after extensive training (i.e., four sessions with a total of 1768 trials) suggests that specific switch costs are a relatively robust phenomenon, at least in the type of switching task applied in this study, that is, an alternating runs paradigm without external task cues. Nevertheless, the training benefits found in all three age groups indicate that even in children and older adults, cognitive plasticity seems to be considerable, arguing against the often reported observation of reduced training benefits for older compared to younger adults (e.g., Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995; but see Kramer & Willis, 2002).

Interestingly, in some conditions children and younger adults showed a general decrease of latencies as a function of training, but at the same time an increase in error rates, pointing to a speed-accuracy trade-off. This trend was not found in older adults, suggesting that there were age differences in training-related strategies and a more conservative response tendency in older adults (cf. De Jong, 2001). However, given that this trade-off was only found on the level of latencies and error rates, but not with respect to switch costs, it does not affect the interpretation of the present results.

When it comes to the modulation of specific switch costs and training-related benefits therein by the type of training, results showed a reduction of specific switch costs under verbal self-instructions compared to task-switching training without verbalizations (see Figure 13). This finding extends prior evidence reporting a reduction of general switch costs when verbal self-instructions were performed during task preparation (cf. Kray et al., in press), suggesting that verbal processes not only support the maintenance and selection of task goals, but also the ability to flexibly switch between them. One may assume that language is particularly needed when new task sets have to be implemented and task goals have to be strengthened, and that they are less needed when tasks are highly practiced or automatized. If this was true, the verbalization benefits should decrease or even disappear after intensive practice. However, the reduction of specific switch costs under verbal self-instructions was robust against practice, that is, it was found to a similar degree in the beginning as well as at the end of training ($\triangle\eta^2$ = .004), suggesting that verbal processes are still an effective means to improve the ability to flexibly switch between tasks (in the sense of a “self-cueing device”, cf. Emerson & Miyake, 2003), even when the tasks are well practiced. This aspect seems particularly important for the application of verbal self-instruction techniques, for instance, in cognitive-behavioral therapy (for a review, see Gosch et al., 2006).

However, although performing verbal self-instructions during task switching resulted in reduced specific switch costs, the verbalization did not modulate training-related benefits; that is, the reduction of specific switch costs from the beginning to the end of training was not larger than in the group trained without verbalizations. Nevertheless, it should be noted that effects sizes increased considerably when verbalizations were performed during training (from *d’* = .85 - .95 to *d’* = 1.21 – 1.88), resulting from a marked decrease of within-group variability (see Table 15) (cf. Klauer, 2001). This reduction is in line with previous findings (Karbach,

2005) and supports Luria's (1960) claim that language can serve as effective means to stabilize motor actions and thereby as compensatory tool.

Finally, the focus was on the influence of feedback and variability on specific switch costs and training-related benefits therein. Consistent with prior studies showing a modulation of transfer rather than training effects associated with feedback indicating the value of a practiced strategy (i.e., the verbalization strategy) (Kenndey & Miller, 1976; Ringel & Springer, 1980), additional feedback did not modulate specific switch costs or their reduction as a function of training. Consistently, training effect sizes ranged on a level similar to the verbalization group that was not provided feedback (*d'* = 1.09 – 1.73).

In contrast, variable training tasks had pronounced effects on performance: Although participants in the variable training groups showed an overall reduction of specific switch costs at the end of training, this reduction was smaller than in the groups trained with the same tasks in each session (see Figure 13). This result is in line with the predictions and a number of prior findings, suggesting that variable training slows down skill acquisition during training (e.g., Sanders et al., 2002; for reviews, see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Consistently, the effects sizes decreased, especially for children and older adults (*d'* = .17 – .58). Thus, when the underlying processes practiced during training, such as the ability to flexibly switch between tasks or to inhibit task-irrelevant information, have to be applied to new tasks in each training session, performance seems to be impaired at first. However, although task difficulty does not seem to modulate switch costs (Allport et al., 1994; Mayr & Kliegl, 2000), one should keep in mind that the amount of training-related improvements for the variability-training group may be confounded with differences in task difficulty between the four different switching tasks applied in this study.

Interesting from a developmental perspective is the fact that there neither were age differences in the amount of training related benefits (i.e., the decrease of specific switch costs as a function of training), nor in the influence of the verbalizations on specific switch costs.

Though this finding may be surprising at the first glance, it is probably related to the fact that specific switch costs are usually less affected by age (e.g., Cepeda et al., 2001; Crone et al., 2004; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Mayr, 2001; Verhaeghen & Cerella, 2002). That is, if there are less age differences to begin with, there is also less potential to modulate them by training or different training strategies.

In sum, it can be concluded that cognitive plasticity regarding executive control, or more specifically, the ability to flexibly switch between tasks, seems to be considerable across a wide range of ages. Although some studies reported limited cognitive plasticity in older adults compared to younger adults (e.g., Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995), the present findings are consistent with recent reviews indicating that the majority of cognitive training studies was successful in enhancing older adults' cognitive performance[49] (see Kramer & Willis, 2002; Jones et al., 2006). However, the results of the present study also indicate that the effectiveness of cognitive interventions depends on the type of training, for instance, with respect to changing task demands. This aspect seems particularly important not only for the design of cognitive training programs, but also for the interpretation of their outcomes.

[49] This plasticity seems to be limited in very old age, that is, in individuals older than 75 years (Singer et al., 2003). However, this age group was not included in the present study.

Near Transfer of Task-Switching Training

Before transfer data were analyzed, pretest performance was inspected in order to make sure that the pattern of age-related differences in task-switching abilities was consistent with previous findings. Consistent with the predictions, the analysis of the pretest data showed that age differences were more pronounced on the level of general switch costs than on the level of specific switch costs (cf. Cepeda et al., 2001; Crone et al., 2004; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Mayr, 2001; for a meta-analysis, see Verhaeghen & Cerella, 2002) (see Figure 14). Thus, this finding supports the view that children and older adults are characterized by larger age-related deficits in the ability to maintain and select task sets than in the ability to switch between them, indicating that the development of both abilities follows different lifespan trajectories, possibly associated with age-related structural and functional changes in the PFC (for reviews, see Casey et al., 2005; Hedden & Gabrieli, 2004; West, 1996). On a more general level, these results support the view that executive control indeed consists of several separable control components (cf. Fisk & Sharp, 2004; Huizinga et al., 2006; Kray & Lindenberger, 2000; Miyake et al., 2000).

However, the main focus of the present study was on age differences in the transfer of task-switching training. Importantly, there was evidence for substantial transfer of task-switching training to a structurally similar new switching task in children, younger, and older adults. That is, the reduction of general as well as specific switch costs from pretest to posttest was larger after task-switching training than after single-task training (see Figure 15). When it comes to younger and older adults, transfer on the level of general (cf. Bherer et al., 2005; Minear, 2004; Minear et al., 2002) and specific (cf. Bherer et al., 2005) switch costs is consistent with prior results. Moreover, this study extends these findings to childhood by providing first evidence for near transfer of task-switching training in children. Particularly interesting from a developmental perspective is the result that the near transfer on the level of general switch costs was most pronounced in children and older adults. Thus, especially the age groups usually characterized by marked deficits in the ability to maintain and select task goals (e.g., Cepeda et al., 2001; Kray et al., in press; Kray et al., 2004; Reimers & Maylor, 2005) were able to transfer training-related benefits to a new task situation, pointing to compensatory effects associated with the training. This finding has important implications for the application of training programs in the clinical and educational context (see p. 198). In contrast, transfer on the level of specific switch costs occurred to a similar degree in all age groups, a finding probably related to the fact that there were no age differences in specific switch costs at pretest, at least when age differences in baseline performance were accounted for (cf. Cepeda et al., 2001; Crone et al., 2004; Karbach & Kray, 2007; Kray, 2006; Kray et al., in press; Kray et al., 2004; Kray & Lindenberger, 2000; Reimers & Maylor, 2005; Mayr, 2001; Verhaeghen & Cerella, 2002). Thus, there was less potential to modulate them by training or different training strategies.

From a theoretical point of view, the larger reduction of general and specific switch costs from pretest to posttest after task-switching training (d' = .90 - 2.15; see Figure 22) than after single-task training (d' = .11 - .60; see Figure 22) is of particular importance. Different models have been proposed to explain the processes underlying training-related improvements in the performance of complex tasks (cf. Jersild, 1927; Logan, 1988; Rogers & Monsell, 1995). Most of these models have assumed that training improvements mainly result from an automatization of single ‘component tasks’ included in the more complex task, such as the automatization of the single tasks involved in task switching. If this was true, transfer of training-related benefits should also be found after single-task training. In contrast, the results of the present study suggest that the trainability and transferability of task-switching abilities is not merely mediated by automatization of single-task components (cf. Kramer, Larish, et al., 1999), but that generalizable task-switching skills were acquired during training and subsequently transferred.

Furthermore, the present study provided first evidence for age differences regarding the influence of the training type on the amount of near transfer. Aside form the single-task training and the 'pure' task-switching training, the remaining three training groups additionally performed verbal self-instructions during training. On top of that, one of the training groups received explicit feedback indicating the value of the verbalization strategy, and another group was trained with variable tasks in each session.

Given that a previous study showed the substantial reduction of general switch costs under verbal self-instructions, particularly in children and older adults (Kray et al., in press), the question was whether these performance improvements could be transferred to a new, similar switching task. Given that no prior task-switching studies have investigated the transfer of verbal self-instruction training, this question was relatively exploratory. In contrast to the initial expectation, verbal self-instructions did not promote the transfer of task-switching training, neither on the level of general nor on the level of specific switch costs (see Figure 15). In search of an explanation for this lack of verbal self-instruction transfer, there seem to be at least two possible scenarios. First, one may assume that the group trained in task switching without verbal self-instructions used an internal verbal strategy similar to the overt self-instructions anyway, so that there was no difference in the amount of transfer between these groups. If this was true, applying articulatory suppressions (i.e., task-irrelevant verbalizations) during task-switching training (cf. Baddeley et al., 2001; Emerson & Miyake, 2003; Kray et al., in press; Kray et al., 2004; Miyake et al., 2004; Saeki & Saito, 2004) should reduce the amount of transfer compared to a group without verbalization. Second, is also seems possible that the degree of similarity between training and transfer situation is crucial for the transfer of verbal self-instruction benefits (cf. Klauer, 2001; Singley & Anderson, 1989). Specifically, if training and transfer tasks were more similar for the verbal self-instruction group, that is, if participants were allowed to verbalize at posttest (and not only during training), then transfer may occur. In order to test this latter hypothesis, an additional experiment was performed (Karbach & Kray, in prep.). Thirty-eight older participants (mean age = 68.2 years of age) were investigated in a pretest – training – posttest design. At pretest and posttest, participants performed an internally cued switching paradigm including two tasks A and B that were similar to those applied in the present study[50]. In the training phase, all participants received task-switching training (including tasks C and D, also similar to those applied in the present study) and verbal self-instruction training. Importantly, half of the participants were instructed to continue using the verbalization strategy at posttest, while the other half was not allowed to verbalize. This second group corresponds to the group receiving task-switching and verbal self-instruction training in the present study. Results from this so far unpublished study showed that participants which continued verbalizing at posttest showed a larger reduction of general switch costs (337 ms to 103 ms) and specific switch costs (347 ms to 189 ms) than the group that was not allowed to verbalize at posttest (general switch costs: 270 ms to 155 ms; specific switch costs: 251 ms to 181 ms). Thus, when both the training and transfer situation allow the application of the verbal strategy, verbal self-instruction benefits can be transferred to a new, similar switching task, at least in older adults. This finding is in line with results from Healy, Wohldmann, Parker, and Bourne (2005) showing that participants performing a secondary verbal task during training in a prospective paradigm performed worse during transfer when the secondary task was not required during transfer. The authors suggested that the training task and the verbal task are integrated into a single, more complex task during practice and that transfer only occurs when the cognitive operations acquired during training can be used in the same way during transfer.

[50] The paradigm used in the subsequent study was identical to the one used in the present study, the only difference being that letters, numbers, and symbols instead of pictures served as stimuli.

However, the present study included another manipulation supposed to increase the likelihood that the verbal self-instruction training could be transferred to a new switching task after training. Assuming that especially children are more likely to transfer verbal strategies to new task situations when they are provided feedback indicating the value of the verbalization strategy (cf. Kennedy & Miller, 1976; Ringel & Springer, 1980), the initial expectation was that transfer would be increased in the feedback group, at least for children. In contrast, no effects of feedback on the amount of transfer were found in any age group (see Figure 15). This lack of transfer is most likely related to the way feedback was provided in the present study. While the experimenter verbally emphasized the usefulness of the verbalizations at three distinct times per training session (after the first and second third as well as at the end of each training session), the feedback provided in other training studies was more intense. For instance, in two previous studies investigating memory training in preschool children (Kennedy & Miller, 1976; Ringel & Springer, 1980), feedback was provided once at the end of a short training phase, thereby explicitly referring to the previous training trials. Even more intense was the continuous, individualized, and adaptive feedback provided by Bherer and colleagues (2005; see also Kramer et al., 1995; Kramer, Larish, et al., 1999): Feedback indicators were presented continuously on a histogram in the top left portion of the screen, including one bar for each task. The bars indicated the mean RT for each task in the previous five trials; they appeared in red and changed to yellow and then green to indicate progressively faster performance. However, this kind of feedback is not entirely comparable to the one provided in the present study or in the experiments reported above (Kennedy & Miller, 1976; Ringel & Springer, 1980), because its emphasis was exclusively on participants' task performance, but not on the value of a given strategy. In addition, the type of feedback applied in the Bherer et al. (2005) study presented simultaneously with the task-switching stimuli seemed too complicated for children and was therefore not applied in the present study. In order to provide more intense and explicit feedback suitable for children, future studies may, for instance, rely on continuous auditory feedback indicating whether a given response was correct or not, and provide feedback on the subject's mean performance level.

Importantly, the group trained with different switching tasks in each training session showed differential transfer effects on the level of general switch costs. Specifically, the requirement to adapt to new task demands in each training session supported the acquisition of a generalizable switching skill in adults, but hindered it in children (see Figure 15). Regarding younger and older adults, this finding is consistent with the literature (cf. Kramer et al., 1995), and suggests that variable training can promote transfer by preparing individuals for the changing processing demands required at posttest (see Rosenbaum et al., 2001; Schmidt & Bjork, 1992). Considering the results of the training phase discussed above (see p. 181), the present data also lend support for the conceptual view that training conditions decreasing the speed of skill acquisition during training can support its long-term goals (i.e., the acquisition of a generalizable skill; cf. Schmidt & Bjork, 1992). However, when it comes to children, it seems that the increased cognitive load associated with variable training tasks did not leave enough processing capacity to implement the abilities improved during training and to develop cognitive representations of the task structure (cf. van Merriënboer, Kester, & Paas, 2006). In fact, the cognitive load theory (CLT) (Brünken, Plass, & Leutner, 2003; Sweller, 1999; Sweller, van Merriënboer, & Paas, 1998; Wallen, Plaas & Brünken, 2005) has been extensively investigated in the context of multimedia learning within the field of educational psychology. Although applied in a different context, this theory nicely fits the results of the present study: CLT assumes three different sources of working memory load, related to the complexity of the material (intrinsic load), the instructional design (extraneous load), and the amount of mental effort learners invest into learning the materials (germane load). It is assumed that the total cognitive capacity is limited and that the three different types of cognitive load are additive with respect to their capacity requirement. Thus, when the intrinsic load is increased (e.g., because the training tasks are variable and a new set of rules has to be implemented in each training session), participants' cognitive capacity can be exceeded, resulting in decreased levels of performance. Given that the total working memory capacity is more limited in children than in adults (for reviews, see Hitch, 2006; Park & Payer, 2006), the increased cognitive load associated with the variable training is more likely to exceed children's cognitive capacities. Hence, the implementation of the trained abilities and the representation of the task structure are impaired, especially on the level of general switch costs which include a substantial working memory component (i.e., the ability to maintain two task sets).

In sum, it can be concluded that the present study provided several important new findings with respect to near transfer of task-switching training. The results indicated that near transfer occurs on the level of general as well as specific switch costs, suggesting that a generalizable ability to maintain and select task sets as well as to switch them can be acquired across a wide range of ages. Moreover, the type of training can support the occurrence of these transfer benefits. Most important for the design of training programs seems the fact that the 'optimal' type of training, that is, the training resulting in the largest near transfer effects, varies as a function of age. Specifically, children benefited to a larger degree when they practiced the same tasks intensively, while adults benefited most when they had to adapt to new task demands in each training session. Implications of the present findings for the educational and clinical contest are discussed below (see p. 198).

Far Transfer of Task-Switching Training

The most striking results of the present study concern the far transfer of task-switching training; they are discussed separately for each transfer domain in the following section. In order to investigate far transfer to another 'executive' task, a color and a number version of the Stroop task were applied. In line with previous findings, interference effects were larger in the color version than in the number version (Salthouse & Meinz, 1995). Although interference effects were not larger in children than in adults, older adults were more susceptible to interference than younger adults (cf. Li & Bosman, 1996; West & Alain, 2000). But most importantly, and consistent with the initial prediction, interference effects were reduced from pretest to posttest after task-switching training in all age groups and for both task versions (see Figure 17). Thus, intensive task-switching training transferred to inhibitory control in the Stroop task, thereby providing first evidence for the far transfer of task-switching training to another 'executive' task in children, younger, and older adults. Results for the single-task training were less clear: Interference effects in this training group actually increased from pretest to posttest (except for the children in the color version). Although the single-task training was not expected to result in improved interference control, a marked decrease was also not expected. The subsequent control analyses performed to clarify this unexpected result indicated that the larger interference effects at posttest were due to participants' smaller pretest – posttest improvements in incongruent compared to neutral trials, resulting in larger interference effects at posttest. That is, the increased interference effects were due to a larger improvement in the baseline condition (i.e., neutral trials), and not to impairments in high-interference conditions (i.e., incongruent trials). A second unexpected finding was that children also showed a reduction of interference after single-task training in the Color Stroop version, indicating that this training also resulted in far transfer. Although surprising at the first glance, this finding is probably related to the specific training paradigm applied in the present study.

Despite the fact that the single-task training group only performed task-homogeneous blocks during training, participants worked with the exact same stimuli that were applied to the task-switching training groups. In order to induce high demands on executive control, these stimuli were ambiguous, that is, they represented features of both tasks relevant during training (for details, see p. 112, Method). For instance, subjects saw a picture of two cars, representing the feature “car” that was relevant for the “transportation task” (car or plane?), as well as the feature “two” that was relevant for the “number” task (one or two?). Thus, even when only one of the tasks had to be performed during task-homogeneous blocks in the single-task training condition, two interfering stimulus features were presented and the currently irrelevant one had to be ignored. Given that children are more susceptible to interference at the response level than adults (e.g., Bunge et al., 2002; Comalli et al., 1962; Karbach & Kray, sub.), they probably needed a certain amount of interference control even in the single-task training condition. Thus, if children’s interference control was trained to a certain degree even in the single-task training group, transfer to interference control in the Stroop task is not completely surprising. However, in this case one may expect similar effects (i.e., far transfer after single-task training) in the number version of the Stroop task. The fact that they were only found in the color version may be explained by the general difference in the magnitude of interference effects between both task versions: Given that interference effects were larger in the color version than in the number version (see Figure 17), it seems that the inhibitory control abilities improved during training particularly come into play in situations characterized by high demands on interference control (i.e., the color version) – however, this interpretation is clearly speculative and further research is needed to test this idea.

Aside from the Stroop task, two other ‘executive’ tasks were investigated, namely verbal and visuospatial working memory. Given that the results for both task domains were very similar, they will be discussed together. Pretest data for both aspects of WM were consistent with previous findings, showing quadratic age functions for verbal as well as visuospatial WM abilities, that is, a larger WM span for younger adults than for older adults and children (for reviews, see Hitch, 2006; Park & Payer, 2006). Most importantly, however, were the transfer effects: The performance improvement from pretest to posttest was larger after task-switching training than after single-task training, that is, there was far transfer of task-switching training to verbal as well as visuospatial WM abilities in children, younger, and older adults (see Figure 18 and Figure 19). In contrast to the initial expectations, verbal self-instruction training was not transferable to WM tasks also relying on verbal rehearsal processes. This lack of far transfer probably occurred for similar reasons as the one regarding near transfer of verbal self-instruction training (see p. 185). Specifically, one may assume that the far transfer of verbal self-instruction training was more likely to occur when participants were allowed to apply the overt verbalizations at posttest. However, further research is needed to test this hypothesis.

Finally, far transfer to another task domain, namely fluid intelligence, was examined. Consistent with far transfer to other ‘executive’ tasks, performance improvements were larger after task-switching training than after single-task training (see Figure 20), indicating that the task-switching training also transferred to measures of fluid intelligence. Although similar results have been reported for children after other types of executive control training (Rueda et al., 2005) and after working memory training (Klingberg et al., 2002b; Klingberg et al., 2005), this effect may be the most surprising one, particularly because intelligence is assumed to be a quite stable attribute (e.g., Arbuckle, Maag, Puskar, & Chaikelson, 1998; Deary, Whiteman, Starr, Whalley, & Fox, 2004). Thus, does task-switching training improve intelligence? In order to answer this question, it is important to keep in mind which abilities were trained and transferred in this study. The results discussed so far provide evidence for the transfer of executive control abilities, such as the selection of relevant task goals, the maintenance of task-relevant information, and the inhibition of task-irrelevant information. However, the literature suggests that executive control and intellectual abilities are indeed closely linked (e.g., Duncan, 1993, 1995; see also Duncan et al., 2000). For instance, prior research has shown that working memory is strongly related to fluid intelligence (Engle et al., 1999), and that visuospatial working memory correlates highly with performance on the Raven's task (Fry & Hale, 1996); both these findings have been replicated in the present study (see Figure 16 and Table 19). This association on the behavioral level is also found on the neuroanatomical level, that is, overlapping parts of the PFC and the parietal lobe are used when working memory and fluid intelligence tasks are performed (Gray, Chabris, & Braver, 2003). Also, visuospatial WM and response inhibition have neuroanatomical commonalities, that is, identical areas in the superior PFC and in the parietal cortex are associated with the development of visuospatial WM abilities (Klingberg, Forssberg, & Westerberg, 2002a) and performance of the Stroop task (Adleman et al., 2002). Thus, overlapping neural activity and the close link between executive control and intellectual abilities on the behavioral level may explain how training that transferred to performance in the Stroop task and to visuospatial WM abilities also transferred to fluid intelligence.

The results for far transfer reported in this section are further supported by the respective effects sizes (see Figure 23). Consistent with previous findings (cf. Klauer, 2001; Salomon & Perkins, 1989), effect sizes were smaller for far transfer to other executive tasks and fluid intelligence than for near transfer. However, after task-switching training they were still relatively large even for far transfer, with most values > .70 for children, > .60 for adults, and > .40 for older adults, and were quite consistent across the far transfer tasks. This latter finding is partly inconsistent with the power-generality trade-off postulated by Salomon and Perkins (1989) that would have predicted smaller effect sizes for transfer to fluid intelligence than for transfer to other executive tasks. The effect sizes for single-task training were generally small or even negative[51], and substantially smaller than for task-switching training under all experimental conditions.

Finally, there are two aspects of the present findings that may have been surprising: Far transfer was neither modulated by age nor by the type of task-switching training. Given that there was no prior evidence with respect to these aspects, the initial research predictions regarding the modulation of far transfer by means of training type and age were relatively unspecific. Based on the present results, one may assume that the different types of task-switching training were equally efficient, and that the training was equally beneficial for children, younger, and older adults. As nice at that sounds, this conclusion should be drawn cautiously. As discussed in the last paragraph, and also in line with previous theoretical assumptions (cf. Klauer, 2001; Salomon & Perkins, 1989), effects sizes were generally smaller for far transfer than for near far transfer in this study. However, the smaller effects are, the harder they are to verify in small samples. Put differently, in studies with small sample sizes, only relatively large far transfer effects can be found (for a meta-analysis, see Lipsey & Wilson, 1993). In the present study, these theoretical assumptions are important for two reasons. First, they indicate that the far transfer effects found in the present experiment can indeed be considered substantial. Second, and more importantly, they explain why it may have been hard to find a modulation of far transfer by age or training type: In order for the age differences (or differences between the training conditions, respectively) to reach statistical significance, the sample had to be relatively large. Take, as an example, the age difference in the amount of far transfer to verbal working memory: In the analysis reported above (see p. 157), the main effect for age did not reach significance within the sample of 210 participants ($p = .11$). However, power analysis[52] indicated that N = 649 would have been required to obtain

[51] Negative effect sizes were confined to the Stroop task and due to an increase in interference effects from pretest to posttest previously discussed in this section.
[52] Power analysis was based on the following parameters: α error probability = .05, power (1 - β error probability) = .90.

significant age differences in this analysis, that is, a sample thrice a large as the one included in the present study.

In sum, the far transfer results discussed in this section clearly show that in contrast to single-task training, task-switching training resulted in improved performance in an interference control task, in verbal and spatial WM tasks, and even in fluid intelligence tasks. While many training programs in previous studies resulted in large improvements on the training task itself, transfer to other tasks was very limited, suggesting that transfer was quite domain and process specific (e.g., Ball et al., 2002; Jennings et al., 2005). In contrast, the present study shows broad transfer that was stable, even for far transfer, to tasks quite remote from the training tasks, thereby providing first evidence that far transfer of task-switching training can indeed be achieved across a wide range of ages.

Evaluation of the Transfer Effects and Their Relevance for the Application of Cognitive Training Programs

In order to evaluate the effects of the task-switching training applied in the present study, three types of control analyses were performed (cf. Klauer, 2001). Analyzing the effects sizes (discussed in the previous two sections) and calculating the proportion of participants that showed training and transfer benefits indicated that the task-switching training easily satisfied previously applied criteria for effective cognitive interventions: Effects sizes were noticeably larger than .30 for all training conditions and across all age groups and transfer tasks (cf. Klauer, 2001), and the proportion of participants characterized by training and transfer benefits was always larger than 50 % (cf. Derwinger et al., 2003). However, most interesting was the third set of analyses, focusing on differential aspects of the training.

Although many training studies have been successful at improving performance on the group level, individual differences with respect to the degree of improvement are relatively large (see Bissig & Lustig, 2007). Therefore, the differential aspects of training and transfer were of great interest in the present study. Specifically, the question was whether individual training and transfer effects can be predicted. Prior evidence is ambiguous (cf. Ackerman, 1987; Bissig & Lustig, 2007; Klauer, 2001), resulting in two general theoretical positions: The first one assumes that training has compensatory effects in the sense that initially low-performing participants benefit more than high-performing participants. The second position is referred to as “Matthew”-effect, assuming that better performers benefit more from training, because they are better able to implement and generalize the trained abilities.

Results of the present study showed that training benefits were best predicted by participants’ performance at the beginning of training, and that participants initially performing on a lower level were the ones who benefited most. With respect to transfer benefits, results were very similar: Regardless of participants age and the extent of their training benefits, transfer benefits were predicted by pretest performances for each of the transfer measures, also indicating that the worse participants performed before training, the larger the transfer benefits. These results are clearly in favor of theories postulating compensatory effects associated with cognitive interventions. Although this is inconsistent with a number of studies showing that training-related benefits were smallest for those individuals who needed them most (e.g., Baltes & Kliegl, 1992; Verhaeghen et al., 1992; Yesavage et al., 1990), there is also considerable evidence pointing to larger training benefits in individuals with lower initial performance levels, such as children and older adults (e.g., Cepeda et al., 2001; Edwards et al., 2005; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). Also noteworthy seems the fact that studies pointing to “Matthew”-effects seem to be mostly from the field of memory strategy training (e.g., Baltes & Kliegl, 1992; Verhaeghen et al., 1992; Yesavage et al., 1990), while compensatory effects were found after executive control training (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray & Lindenberger, 2000; Minear et al., 2002). However, more research is needed to explore whether this difference is associated with the type and the domain of training. Nonetheless, the finding that training and transfer benefits clearly result in a compensation of performance deficits in low-performing individuals has tremendous implications for the application of cognitive interventions. Given that most training programs aim at the promotion of deficits in specific cognitive abilities or, on a more general level, at supporting individuals with special needs, it seems particularly important to identify the types of training suitable for this purpose.

Consistently, the analysis of near and far transfer effects in the present study has yielded a number of findings that are particularly relevant for the application of cognitive training programs in the educational, clinical, and scientific context. Some of these aspects are more related to near transfer effects, while others are based on far transfer of task-switching training. Considering (1) the fact that near transfer was most pronounced for children and for older adults, (2) the wide range of transfer, and (3) the finding that low-performing participants showed larger training and transfer benefits than high-performing ones, suggests that the application of the present training may be especially promising with respect to individuals characterized by executive control deficits, such as ADHD, mild cognitive impairment or traumatic brain injury (TBI).

With respect to ADHD, studies from the Klingberg lab have already shown that working memory training has the potential to yield near transfer to other working memory tasks, but also far transfer to executive control tasks (e.g., the Stroop task) and fluid intelligence (Klingberg et al., 2005; Klingberg et al., 2002b). Interestingly, this training also reduced behavioral symptoms associated with ADHD, such as motor hyperactivity. Thus, transfer of training was not confined to cognitive abilities, but also improved behavioral aspects that are critical in a number of situations, among them social interaction, emotional status, and academic accomplishment (Abikoff et al., 1994; Hechtman et al., 1994). Given that the task-switching training applied to healthy individuals in this study transferred to a number of abilities usually impaired in ADHD, such as task maintenance and selection, inhibitory control, and working memory capacity (Barkley, 1997; Castellanos & Tannock, 2002; Rapport, Chung, Shore, Denney, & Isaacs, 2000), these findings certainly have important implications for the design of training programs for children suffering from ADHD. In addition, assuming that training interventions with respect to ADHD groups most often include children, it also seems important to consider the finding that variable training conditions can obviously reduce the training and transfer benefits.

A variety of cognitive rehabilitation interventions for executive functioning have also been applied to TBI patients. The programs usually aim at the improvement of activities of daily living (ADL), and the abilities trained in most of these interventions are problem solving, working memory, behavioral and emotional regulation as well as planning and inhibition (for a review, see Cicerone, Levin, Malec, Stuss, & Whyte, 2006). However, evaluating these programs has yielded mixed findings, that is, a considerable number of these interventions failed to produce far transfer to other domains and ADL measures. Given that the task-switching training applied in this study resulted in relatively broad transfer to other cognitive abilities, these findings may also be of value for the design of interventions in the clinical context. However, given that the present study did not investigate patients, more research is needed to examine effects of task-switching training in clinical populations with executive deficits.

Limitations of the Present Study and Directions for Future Research

Although the present study has provided a number of important new findings, there also are some caveats that should be kept in mind when the results are interpreted. The first two points concern the sample investigated in this study. First, in order to realize a lifespan perspective, three age groups were chosen, representing childhood, younger adulthood, and older age. However, a sample including children below the age of 8 as well as a continuous age distribution (similar to Cepeda et al., 2001, and Reimers & Maylor, 2005) would have been more appropriate to analyze lifespan changes. Second, although the total sample size was large (N = 210), a larger number of participants per cell (n = 14) would have been desirable. However, both these points are usually hard to realize in training studies, because these experiments require lots of time and resources. Also, given that the design of the present study allowed collapsing data across some of the experimental conditions for most of the analyses, it was most often possible to avoid the problem of the small cell sizes.

However, there is one analysis in which the small cell sizes may have been particularly problematic: After pretest, participants in each age group were matched to one of the five training groups based on their pretest performance in task switching (general switch costs), speed of responding (single task RT), perceptual speed (Digit-Symbol Substitution score), and fluid intelligence (Raven score). The purpose of this matching procedure was to make sure that there were no baseline differences between the training groups that could make the interpretation of training and transfer effects difficult. In order to test whether the matching procedure was successful, control ANOVAs with the two between-subjects factors Age Group (children, younger adults, older adults) and Training Group (single, switch, verbalization, feedback, variability) were performed. Though these analyses neither showed main effects for training group nor interactions between age group and training group, a closer inspection of the mean performance (see Table 6) suggests that some post-hoc comparisons regarding the training groups may have been significant, but that the statistical power was not high enough to detect these group differences in the overall ANOVA. For a subsequent analysis of training and transfer effects exclusively based on mean latencies, this could have been problematic. However, given that all analyses reported in this study controlled for baseline differences[53], these potential training group differences are also accounted for.

Also with respect to the training data, one may criticize the fact that the training group was a between-subjects variable in the present study. Therefore, it may be argued that the differences found between the training groups, such as the reduction of specific switch costs under verbal self-instructions, may not be entirely attributable to the variations in the type of training, but to general differences between then training groups. However, the main goal of the present study was to investigate transfer effects, so that the manipulation of training group as a within-subjects variable was not possible. Also, given that the training groups were matched based on their pretest performance and neither differed with respect to general and specific switch costs, baseline speed of responding, perceptual speed nor fluid intelligence, pre-training group differences as determinants of differential training group effects seem unlikely.

A potentially critical point for the interpretation of the near transfer modulation by means of training variability is the fact that the variable training was combined with verbal self-instruction training. Although a comparison of training groups two and three indicated that verbal self-instructions did not influence the amount of transfer, it may be argued that the increased transfer after variable training found in adults is the result of an interaction between the variable training and the verbalizations performed during training. However, in order to ultimately disprove this point, a variable training condition without verbal self-instructions would have been necessary.

[53] With respect to RT, data were log-transformed. For the remaining tasks, analyses were based on transfer relative to baseline performance at pretest. This procedure as well as the advantages of the log-transformation is illustrated in detail in the Method section (see p. 52).

Furthermore, although there were no age differences in the amount of transfer for any of the far transfer measures, this finding has to be interpreted cautiously with respect to fluid intelligence. A closer inspection of the data clearly shows ceiling effects, especially for younger adults, performing around 90 % correct at pretest and up to 94 % correct at posttest. Thus, the fluid intelligence measures applied in this study (Figural Reasoning, Letter Series, Raven's Standard Progressive Matrices) were definitely not challenging enough for this age group. Though this finding reflects a problem that is often encountered in studies applying the same tasks across a wide range of ages, it should be noted that this ceiling effect may have masked potential age differences in the far transfer of task-switching training to fluid intelligence. Specifically, younger adults may have shown even more transfer if there had been room for a larger performance improvement from pretest to posttest.

Another issue concerns the nature of the training tasks. Given that the switching tasks applied during training required several distinct executive control abilities, such as the maintenance of task-relevant information, the selection of task goals, and the inhibition of currently irrelevant information, it is not possible to determine which of these trained abilities – or their interactions, for that matter – resulted in the marked near and far transfer effects found in the present study. In order to investigate this question, training tasks requiring just one of these abilities would have been necessary.

Finally, one aspect considered very important for the evaluation of training programs, namely the inspection of its long-term effects (cf. Belmont & Butterfield, 1977; Hasselhorn, 1987; Klauer, 2001), is completely missing in the present study. However, it should be noted that a one-year follow-up study is currently run in our lab. That is, participants are reexamined by means of a shortened version of the task battery applied at pretest and posttest, including task switching and one indicator for each of the far transfer domains (Stroop task, verbal WM, visuospatial WM, fluid intelligence) one year after they completed the posttest assessment. Preliminary data indicate that the near transfer benefits and even most of the far transfer effects in the task-switching training group can be maintained over the course of one year in all age groups.

Aside from the limitations of the present study, the results certainly point towards interesting questions for future research. Some of these questions arise directly from the design of the study and are mostly related to experimental research, whereas other issues concern a broader context more related to the application of training programs.

As discussed in the theoretical part (see p. 39), the task-switching paradigm is only one of the many possibilities to investigate executive functions. Therefore, it may be of interest to examine whether the transfer effects found in the present study are specific to the exact paradigm, or whether similar transfer effects can be obtained after intensive training involving other experimental paradigms, such as dual-task performance, or for instance, the Stroop task. Given that both of these paradigms impose executive control demands also involved in task switching, such as the selection of relevant task goals, the maintenance of task-relevant and the inhibition of task-irrelevant information, it seems reasonable to expect similar transfer after training involving these tasks.

Especially in the light of the relatively broad far transfer effects found in the present study, and also in terms of the potential relevance for application purposes, investigating far transfer to everyday functions would be very desirable. Edwards and colleagues (2005), for instance, have examined the influence of speed-of-processing training in older adults (63 – 87 years of age) on everyday competence by means of the “Timed Instrumental Activities of Daily Living” (Timed IADL). This test battery includes the measurement of five timed tasks simulating everyday instrumental activities, such as finding phone numbers, counting out correct change, or reading the directions on a medical container. Showing transfer of training that exceeds transfer to other laboratory tasks and directly improves ADL performance would demonstrate the ecological validity of the training.

Furthermore, given that most studies have exclusively investigated behavioral indicators for training-induced plasticity in different age groups, one important point is to assess neural correlates of cognitive plasticity. From a developmental point of view this is particularly interesting, because several behavioral studies found larger training benefits in executive control abilities in children and older adults, so that age differences in executive functioning were reduced (e.g., Cepeda et al., 2001; Kramer, Hahn, et al., 1999; Kray et al., in press; Kray & Lindenberger, 2000). The question is, whether these age-related differences are also present with respect to neural correlates of training-related changes. To date, empirical evidence regarding neural plasticity is scarce, especially in children and older adults (for a review, see Jones et al., 2006). Using an event-related potential (ERP) approach, Rueda and colleagues (2005) reported that after executive control training, 6-year-old children showed significant differences in the N2 time-window similar to those observed for adults. With respect to older adults, Erickson and colleagues (2007b) found in an fMRI study that older (but not younger) adults showed increased activity in the left ventro-lateral PFC (near Broca's area) after dual-task training, suggesting a shift to verbal strategies for the management of dual-task performance after training. Thus, there is at least some evidence indicating that training-related changes on the behavioral level are paralleled by training-related changes on the neural level.

Conclusion

All in all, the present study provided the first evidence for the near transfer of task-switching training to a similar switching task and the far transfer to other ‘executive’ tasks (Stroop task, verbal and visuospatial working memory) as well as to fluid intelligence across a wide range of ages. This finding is inconsistent with previous claims that the transferability of cognitive training is limited (e.g., Detterman, 1993; Derwinger et al., 2003; Roth-van der Werf et al., 2002; for a review, see Barnett & Ceci, 2002), and extends prior findings by consistently showing that near and far transfer of executive control training can be achieved in different age groups (cf. Bherer et al., 2005; Dowsett & Livesey, 2000; Fisher & Happé, 2005; Klingberg et al., 2005; Klingberg et al., 2002b; Kramer et al., 1995; Kramer, Larish, et al., 1999; Minear, 2004; Minear et al., 2002; Rueda et al., 2005). Thereby the present results also demonstrate that cognitive plasticity is considerable even in children and older adults (for reviews, see Jones et al., 2006; Kramer & Willis, 2002), arguing against previously reported observations of reduced training benefits for older compared to younger adults (e.g., Baltes & Kliegl, 1992; Lindenberger & Baltes, 1995).

The fact that transfer was not found after single-task training suggests that training-related benefits and their subsequent transfer were not merely due to an automatization of single-task components (e.g., Logan, 1988), but that generalizable higher-level executive control skills were acquired during training (cf. Kramer, Larish, et al., 1999). Considering these findings, one may wonder what kinds of processes were actually transferred after task-switching training. The evidence provided by the present study indicates that subjects transferred more than the mere ability to switch between tasks. However, the task-switching version applied in this study required a number of different executive control processes. First, demands on goal maintenance were high because subjects received no external task cues. Second, stimuli were highly ambiguous; that is, they always represented features relevant to both tasks, and the currently irrelevant feature had to be suppressed. Consequently, interference control was permanently required. Finally, because subjects had to perform two rather than only one task during task-switching training, task-set selection demands were high. Thus, assuming all these executive processes were trained, it seems less surprising that our task-switching training showed broad transfer to other executive and cognitive task domains. Nevertheless, it seems that this type of training is suitable for promoting not only one, but several executive control abilities. In combination with the finding that the training resulted in compensatory effects with respect to deficits in executive functioning (i.e., in children and older adults, and more generally, in low-performers), it is probably useful for a number of clinical and educational applications. It should also be noted that compared with other studies investigating the transfer of training (cf. Klauer, 2001), the effects sizes were relatively large for near transfer, particularly for children, and consistently remained on a high level even across far transfer tasks, lending further support for the substantial transfer found in this study.

Thus, coming back to the initial questions raised in the introduction, the results of the present study have certainly provided important answers. How effective is cognitive training? What exactly makes a given training useful? The present study showed that cognitive training can indeed be very effective, at least when the appropriate processes are trained. This aspect is best illustrated by comparing the results of the single-task training, which imposed low demands on executive control, and the task-switching training, raising high executive control demands: Although there was no difference with respect to the intensity and the duration of the training, the outcome was amazingly different. Thus, in order to form expectations regarding the usefulness of a given training, it seems critical to inspect the processing demands imposed by the training tasks and to make sure that they are relevant for the cognitive abilities the training is supposed to improve.

Which cognitive abilities can be improved? Results of the present study indicate that, at least with the type of training applied in this study, a wide range of cognitive abilities can be improved in different age groups. However, given that many previous studies failed to demonstrate this wide range of far transfer, the type of training seems to be critical. The present findings suggest that, at least for the transfer of executive control abilities, training tasks relying on several executive control abilities (e.g., goal maintenance, task-set selection, interference control) are most effective.

Finally, the question was which individuals benefit most from which type of training. The data reported in this thesis clearly indicate that the largest training and transfer benefits can be expected in low-performing individuals. Thus, those who needed the training most also benefited most, indicating that cognitive training, at least the type applied in this study, can be an effective means to compensate executive control deficits across a wide range of ages.

7. References

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8. Appendix

Table 14: Mean RT (ms) and Error Rates (%) as a Function of Age Group (Children, Younger Adults, Older Adults) and Session (Training 1, 2, 3, 4,) for the Single-Task Training Group (Group 1)

	Training session							
	Training 1		Training 2		Training 3		Training 4	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
	Mean RT (ms)							
Children	791	193	779	226	767	254	792	260
Younger adults	461	81	439	73	427	73	414	62
Older adults	548	91	534	90	506	85	512	89
	Error rates (%)							
Children	4.64	2.90	8.96	7.65	9.54	7.83	8.43	5.06
Younger adults	2.63	2.03	3.11	2.10	3.66	2.09	3.61	2.58
Older adults	2.62	2.10	1.90	2.35	2.14	3.44	2.31	3.52

Table 15: Mean RT (ms) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Switch, Verbalization, Feedback, Variability), Session (Training 1, 2, 3, 4), and Trial Type (Nonswitch, Switch) for the Task-Switching Training Groups (Groups 2 - 5)

	Training 1				Training 2				Training 3				Training 4			
	Nonswitch		Switch		Nonswitch		Switch		Nonswitch		Switch		Nonswitch		Switch	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children																
Switch	1096	289	1325	375	1034	316	1216	408	1015	340	1169	429	938	285	1064	371
+ verbalization	1019	170	1202	189	868	136	968	177	807	158	895	220	732	208	808	247
+ + feedback	954	226	1113	298	876	193	996	227	873	206	961	254	845	218	913	230
+ + variability	956	246	1154	410	1040	295	1264	423	1024	264	1209	392	753	193	863	284
Younger adults																
Switch	447	79	520	113	414	71	458	92	412	69	441	89	391	46	415	62
+ verbalization	495	95	561	132	437	57	461	84	414	60	423	67	387	50	399	61
+ + feedback	509	112	566	135	450	101	482	115	427	94	456	112	395	76	406	75
+ + variability	455	115	496	141	470	86	523	106	502	80	539	100	391	69	400	80
Older adults																
Switch	740	175	915	267	667	148	810	222	666	165	775	218	645	161	741	200
+ verbalization	589	123	661	165	535	106	570	115	497	78	526	91	486	95	510	109
+ + feedback	704	161	836	201	668	169	748	177	615	171	680	176	575	145	622	146
+ + variability	681	272	780	335	805	338	967	433	833	293	1027	440	586	191	689	277

Table 16: Error Rates (%) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Switch, Verbalization, Feedback, Variability), Session (Training 1, 2, 3, 4), and Trial Type (Nonswitch, Switch) for the Task-Switching Training Groups (Groups 2 - 5)

	Training 1				Training 2				Training 3				Training 4			
	Nonswitch		Switch		Nonswitch		Switch		Nonswitch		Switch		Nonswitch		Switch	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children																
Switch	6.41	7.43	7.95	8.16	7.29	6.56	8.67	5.22	8.98	7.63	10.99	6.98	8.81	8.44	10.40	8.49
+ verbalization	6.02	3.03	8.33	2.44	7.95	3.71	11.33	5.21	7.71	4.43	12.05	4.39	10.83	7.17	13.51	6.30
+ + feedback	7.54	5.95	9.82	6.09	7.95	4.01	9.41	5.46	10.77	3.77	11.92	4.02	9.17	4.12	13.01	5.53
+ + variability	5.25	2.96	6.60	2.61	5.84	1.86	9.38	3.23	6.98	2.52	10.34	3.75	7.71	4.47	11.49	5.88
Younger adults																
Switch	4.81	3.07	6.96	3.86	4.91	3.28	5.69	3.51	5.14	3.83	6.99	4.35	6.29	4.34	6.51	4.07
+ verbalization	3.31	1.51	5.10	2.53	3.95	2.53	4.87	2.34	4.55	2.77	7.55	4.28	6.03	4.38	6.32	3.32
+ + feedback	5.32	3.56	7.45	3.68	5.43	4.23	6.40	5.01	5.80	4.36	6.85	3.93	7.40	6.29	9.11	5.09
+ + variability	4.35	2.56	5.77	2.44	7.22	5.14	8.41	4.82	8.49	5.25	8.75	4.42	4.69	3.04	6.85	5.35
Older adults																
Switch	4.03	2.74	5.69	4.19	2.58	1.33	4.03	2.02	2.12	1.69	3.24	2.17	1.64	1.52	3.16	2.23
+ verbalization	4.91	4.63	6.83	5.78	3.65	3.22	4.10	3.02	2.72	2.38	3.53	3.04	2.86	2.27	3.05	2.65
+ + feedback	3.93	3.09	5.44	4.04	2.36	1.92	3.53	2.68	2.40	2.42	3.13	2.87	2.28	2.62	3.37	2.52
+ + variability	3.26	1.68	6.39	3.52	5.27	2.70	9.05	5.52	5.94	4.49	9.72	6.82	2.68	2.00	3.50	1.83

Table 17: Task Switching Mean RT (ms) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Single, Nonswitch, Switch)

	Pretest						Posttest					
	Single		Nonswitch		Switch		Single		Nonswitch		Switch	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children												
Single	1000	183	1172	227	1553	304	875	110	1005	205	1285	260
Switch	1040	194	1241	253	1657	297	915	257	934	277	10081	359
+ verbalization	973	147	1175	241	1570	353	818	161	887	166	1050	259
+ + feedback	979	194	1226	261	1537	318	826	246	899	211	1081	305
+ + variability	996	297	1161	322	1544	500	757	162	905	239	1129	326
Younger adults												
Single	570	118	632	206	849	377	479	100	542	219	712	395
Switch	546	66	596	103	795	188	453	59	464	62	565	180
+ verbalization	524	105	593	127	803	225	438	69	452	76	536	167
+ + feedback	567	41	639	190	851	340	431	66	446	84	518	138
+ + variability	510	91	603	165	789	237	428	68	433	76	491	128
Older adults												
Single	758	175	931	283	1275	523	690	184	860	321	1125	428
Switch	818	262	1029	352	1333	430	763	188	845	258	1040	329
+ verbalization	705	120	916	203	1223	340	607	87	702	131	855	216
+ + feedback	836	256	1025	293	1425	430	738	261	817	272	1049	385
+ + variability	765	214	994	402	1324	495	672	136	728	212	895	325

Table 18: Task Switching Error Rates (%) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Single, Nonswitch, Switch)

	Pretest						Posttest					
	Single		Nonswitch		Switch		Single		Nonswitch		Switch	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
						Children						
Single	5.62	3.24	8.87	5.55	12.37	7.65	6.20	5.08	9.04	6.04	11.08	6.10
Switch	7.53	7.17	6.77	6.30	11.57	9.91	6.26	4.54	9.24	8.52	12.68	9.27
+ verbalization	5.62	5.13	7.93	4.63	12.12	6.67	5.53	3.79	10.80	6.28	13.11	6.11
+ + feedback	6.09	4.14	9.46	5.87	13.32	8.64	13.31	14.82	13.60	12.20	17.31	15.53
+ + variability	5.29	3.40	6.48	3.77	10.70	6.64	9.34	7.93	13.98	8.52	16.25	7.79
						Younger adults						
Single	2.85	2.20	4.32	2.35	4.73	3.15	3.41	2.50	4.25	2.78	5.53	4.12
Switch	5.32	3.07	5.14	2.14	7.90	3.92	7.22	4.88	7.83	6.17	10.13	5.55
+ verbalization	3.81	2.33	4.56	4.26	6.19	4.82	5.85	2.80	6.20	3.76	8.33	5.23
+ + feedback	3.60	3.32	5.44	5.19	8.13	5.23	9.22	7.10	10.80	10.29	11.57	7.75
+ + variability	3.35	2.28	3.50	2.76	6.72	5.02	6.98	4.27	6.03	4.37	7.49	4.58
						Older adults						
Single	3.87	3.05	5.42	2.67	8.01	2.65	4.51	5.78	3.94	3.99	4.82	3.22
Switch	6.24	4.93	10.08	9.64	11.23	8.11	4.14	3.41	5.85	3.96	7.39	4.37
+ verbalization	3.63	3.66	8.73	5.27	10.43	8.17	3.01	3.17	5.14	4.82	7.67	4.47
+ + feedback	2.88	2.10	5.26	3.89	7.20	5.82	3.75	3.39	6.34	4.38	10.56	6.19
+ + variability	5.82	3.97	7.10	4.59	9.80	4.70	4.59	3.18	4.84	5.00	7.77	4.53

Table 19: Correlations Between the Psychometric Tests in the Cognitive Battery

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. CSI	1															
2. NSI	-.10	1														
3. CS	-.01	.04	1													
4. RS	.08	.00	.51**	1												
5. 2B	-.01	.05	.34**	.36**	1											
6. NS	-.12	-.04	.48**	.62**	.40**	1										
7. SS	-.10	-.02	.36**	.46**	.35**	.57**	1									
8. LS	-.10	-.01	.40**	.48**	.38**	.57**	.46**	1								
9. FR	-.13	-.12	.38**	.29**	.25**	.47**	.38**	.45**	1							
10. RA	-.14*	-.06	.44**	.52**	.44**	.63**	.52**	.56**	.52**	1						
11. DS	-.01	-.06	.43**	.54**	.42**	.57**	.49**	.54**	.36**	.49**	1					
12. DL	.05	-.04	.40**	.53**	.39**	.54**	.44**	.49**	.30**	.46**	.92**	1				
13. LA	.00	-.04	-.29**	-.40**	-.45**	-.41**	-.36**	-.42**	-.23**	-.34**	-.57**	-.56**	1			
14. DA	.03	-.06	-.28**	-.38**	-.48**	-.40**	-.33**	-.40**	-.21**	-.34**	-.57**	-.53**	.91**	1		
15. WA	.04	-.07	-.33**	-.43**	-.47**	-.44**	-.34**	-.44**	-.19**	-.35**	-.62**	-.60**	.87**	.92**	1	
16. SW	.25**	-.13	.25**	.42**	.14	.28**	.19**	.45**	.13	.21**	.57**	.61**	-.36**	-.33**	-.38**	1

Note. CSI = Color Stroop interference, NSI = Number Stroop interference, CS = Counting Span, RS = Reading Span, 2B = 2-back Task, NS = Navigation Span, SS = Symmetry Span, LS = Letter Series, FR = Figural Reasoning, RA = Raven's Standard Progressive Matrices, DS = Digit-Symbol Substitution Test, DL = Digit-Letter Substitution Test, LA = Letter Articulation Rate, DA = Digit Articulation, WA = Word Articulation Rate, SW = Spot-a-Word Test. ** p <.01 (two-tailed), * p <.05 (two-tailed). N = 210. Correlations marked in red refer to indicators for one factor.

Table 20: Color Stroop Task Mean RT (ms) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Neutral, Incongruent)

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
				Children				
Single	898	119	991	131	967	215	1011	148
Switch	1028	157	1025	154	949	138	979	175
+ verbalization	956	87	1068	151	899	137	956	165
+ + feedback	995	138	1039	135	883	113	889	104
+ + variability	929	224	988	208	852	148	988	164
				Younger adults				
Single	675	118	703	148	596	94	658	132
Switch	626	112	687	120	563	81	596	102
+ verbalization	655	127	721	150	581	97	605	128
+ + feedback	632	125	704	156	556	83	620	123
+ + variability	598	129	684	173	517	73	535	82
				Older adults				
Single	864	193	964	280	804	200	927	303
Switch	938	169	1107	253	902	182	1029	219
+ verbalization	866	163	972	185	793	130	891	136
+ + feedback	929	219	1052	241	864	189	970	224
+ + variability	803	175	905	237	728	153	796	161

Table 21: Color Stroop Task Error Rates (%) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Neutral, Incongruent)

Training group	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children								
Single	3.59	5.86	7.60	6.28	2.48	3.33	6.44	4.78
Switch	4.39	4.09	5.35	5.71	3.97	5.98	6.02	5.24
+ verbalization	5.22	7.90	8.74	9.23	8.15	7.56	7.24	4.31
+ + feedback	6.45	6.90	10.93	8.77	7.87	5.71	10.98	8.77
+ + variability	7.11	6.04	8.22	7.88	10.08	5.27	10.40	8.00
Younger adults								
Single	3.35	3.77	5.39	4.74	3.57	3.65	4.69	4.20
Switch	2.90	4.33	6.92	5.64	4.92	3.82	5.58	4.93
+ verbalization	1.80	1.62	2.69	2.41	5.58	5.08	5.37	6.06
+ + feedback	2.68	3.21	5.87	6.69	7.14	8.44	7.86	7.19
+ + variability	2.46	2.51	4.24	3.60	7.14	6.42	6.70	5.73
Older adults								
Single	2.69	3.44	5.63	5.57	1.58	2.38	5.09	5.00
Switch	1.58	2.05	5.73	7.19	1.82	2.38	4.55	5.95
+ verbalization	3.63	4.89	6.41	5.64	2.23	2.86	3.18	3.77
+ + feedback	2.95	3.22	4.29	3.49	2.48	2.51	3.65	4.42
+ + variability	1.59	2.44	6.88	9.52	4.24	4.84	3.79	4.45

Table 22: Number Stroop Task Mean RT (ms) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Neutral, Incongruent)

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
				Children				
Single	912	103	961	111	885	135	986	159
Switch	956	175	1011	155	914	136	934	160
+ verbalization	965	112	995	98	882	86	903	86
+ + feedback	966	67	1013	90	875	111	872	110
+ + variability	977	155	1021	166	898	158	878	173
				Younger adults				
Single	586	82	623	76	549	69	584	89
Switch	539	63	582	89	521	64	548	81
+ verbalization	600	114	638	122	528	95	567	118
+ + feedback	576	96	613	82	505	57	534	75
+ + variability	541	79	587	81	501	69	522	97
				Older adults				
Single	779	165	800	171	705	114	746	140
Switch	790	71	813	103	756	98	771	99
+ verbalization	721	90	747	103	673	91	688	89
+ + feedback	790	95	816	73	746	110	764	124
+ + variability	669	95	703	106	631	86	654	86

Table 23: Number Stroop Task Error Rates (%) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), Session (Pretest, Posttest), and Trial Type (Neutral, Incongruent)

	Pretest				Posttest			
	Neutral		Incongruent		Neutral		Incongruent	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
				Children				
Single	6.28	5.60	8.65	7.49	4.05	4.96	6.13	6.43
Switch	6.40	6.84	7.51	3.60	3.62	3.73	8.17	6.35
+ verbalization	5.15	5.37	11.69	8.61	6.94	2.78	11.15	5.71
+ + feedback	7.86	8.63	14.09	9.94	6.25	5.20	11.67	6.69
+ + variability	9.13	4.85	12.60	8.27	7.17	5.94	10.76	7.60
				Younger adults				
Single	2.90	4.33	4.46	3.62	3.79	5.77	7.81	7.23
Switch	2.01	1.98	8.26	5.56	5.58	4.10	8.48	6.98
+ verbalization	2.68	2.97	6.47	5.54	3.79	3.71	7.81	6.69
+ + feedback	1.56	2.03	7.81	5.16	4.91	5.71	11.83	11.58
+ + variability	2.23	4.14	6.03	5.12	4.91	4.70	10.27	7.50
				Older adults				
Single	0.67	1.33	4.53	4.49	2.02	2.63	3.36	4.98
Switch	1.80	2.05	4.52	4.25	2.24	2.86	3.80	3.71
+ verbalization	1.56	2.37	3.35	4.82	2.01	2.33	2.23	1.47
+ + feedback	1.34	2.66	5.38	5.28	4.69	4.86	4.33	5.55
+ + variability	2.48	4.35	6.03	7.89	1.56	2.67	4.91	5.58

Table 24: Mean Performance (% correct) for Verbal WM, Visuospatial WM, and Fluid Intelligence as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), and Session (Pretest, Posttest)

	Verbal WM				Visuospatial WM				Fluid intelligence			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children												
Single	47.3	14.4	47.8	24.0	20.1	10.7	23.7	12.8	75.2	12.0	76.8	16.0
Switch	43.3	15.6	56.3	23.8	16.1	13.4	26.3	17.9	74.3	11.4	81.4	7.3
+ verbalization	47.8	14.8	58.0	16.3	17.9	8.4	28.1	16.0	73.2	8.9	78.9	11.8
+ + feedback	41.1	8.7	55.4	13.8	13.4	10.6	22.3	16.0	71.5	11.0	79.7	9.8
+ + variability	46.4	9.4	53.6	11.7	19.2	13.1	27.2	16.4	72.3	11.6	78.9	10.3
Younger adults												
Single	66.1	12.7	68.3	16.3	44.2	14.0	46.4	17.1	92.6	5.0	93.6	4.1
Switch	73.7	11.5	81.3	12.3	43.8	20.9	55.8	17.9	88.1	7.1	93.1	7.2
+ verbalization	69.2	20.4	79.0	17.9	51.3	16.7	55.8	21.9	90.4	4.4	92.9	6.4
+ + feedback	65.2	17.8	73.7	12.5	38.9	20.7	51.8	17.1	90.2	7.2	94.5	4.7
+ + variability	71.9	15.3	83.5	16.0	42.9	14.7	56.7	12.6	90.9	7.2	94.3	5.1
Older adults												
Single	56.3	16.8	58.0	15.8	25.9	18.0	26.3	21.4	82.2	12.0	79.5	17.2
Switch	52.7	16.4	59.4	17.1	14.3	13.7	21.4	15.1	77.1	12.5	74.3	14.1
+ verbalization	55.8	18.4	64.7	21.1	25.4	20.1	29.9	17.7	79.9	11.9	81.1	13.3
+ + feedback	54.9	17.5	62.5	21.2	21.0	14.4	26.8	16.3	79.4	12.7	81.3	12.5
+ + variability	56.7	13.3	62.9	18.3	25.4	13.8	27.7	17.4	81.4	11.4	83.7	8.3

Table 25: Mean Performance for the Control Measures (Perceptual Speed, Verbal Speed, Knowledge) as a Function of Age Group (Children, Younger Adults, Older Adults), Training Group (Single, Switch, Verbalization, Feedback, Variability), and Session (Pretest, Posttest)

	Perceptual speed (items correct)				Verbal speed (ms)				Knowledge (items correct)			
	Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
Training group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Children												
Single	35.9	8.6	38.7	9.8	3958	1246	3719	1235	10.1	3.2	10.0	3.9
Switch	36.4	8.8	37.8	7.6	3763	793	3465	438	10.9	4.2	11.2	4.7
+ verbalization	34.9	6.9	37.5	7.9	3392	439	3218	425	10.6	3.6	11.7	3.0
+ + feedback	32.5	7.9	34.6	4.2	3508	693	3561	686	10.3	2.8	11.1	3.5
+ + variability	35.3	7.6	37.8	11.0	3199	534	3207	836	10.4	3.2	11.3	2.8
Younger adults												
Single	69.1	8.8	73.5	9.7	2502	327	2366	264	23.8	4.3	24.1	3.9
Switch	70.6	9.9	74.4	9.3	2420	411	2311	355	23.9	3.1	24.8	2.9
+ verbalization	66.4	11.1	72.2	11.6	2542	277	2250	353	22.4	2.7	23.4	3.2
+ + feedback	67.6	10.2	73.5	9.5	2568	316	2497	323	23.2	3.9	24.0	3.3
+ + variability	70.9	11.6	76.1	11.6	2260	255	2204	244	23.7	5.5	23.9	3.9
Older adults												
Single	52.3	12.3	53.8	12.0	3522	889	3298	717	27.9	4.0	27.9	4.4
Switch	52.4	10.3	55.0	12.2	3042	446	3250	580	27.9	3.6	28.0	3.8
+ verbalization	54.7	10.8	57.1	10.8	2950	378	2980	248	27.8	2.8	28.5	3.1
+ + feedback	50.8	11.6	53.5	11.2	3136	359	3090	420	26.8	3.8	27.7	3.6
+ + variability	54.6	11.0	56.8	10.7	3069	525	3054	471	28.4	4.0	29.6	2.4

9. Abbreviations

ADHD	Attention-deficit and hyperactivity disorder
ADL	activities of daily living
ANOVA	analysis of variance
CFA	confirmatory factor analysis
CTL	cognitive load theory
DCCS	dimensional change card sort
ES	effect size
fMRI	functional magnetic resonance imaging
M	Mean
ms	milliseconds
PFC	prefrontal cortex
PRP	psychological refractory period
RFI	response fixation-cross interval
RT	reaction time
SAS	supervisory attentional system
SD	Standard Deviation
SOA	stimulus onset asynchrony
SPM	Standard Progressive Matrices
S-R	stimulus-response
TBI	traumatic brain injury
WCST	Wisconsin Card Sorting Test
WM	working memory

10. Annotation

Some of the data reported in this thesis are also included in the following manuscripts:

Karbach, J. & Kray, J. (in press). How useful is task-switching training? Age differences in the near and far transfer of task switching training. *To appear in: Developmental Science.*

Karbach, J., Mang, S., & Kray, J. (under revision). Transfer of verbal self-instruction training in older age: Evidence from task switching.

Karbach, J., Straß, D., & Kray, J. (under revision). Age differences in the long-term transfer of task-switching training: Evidence from a one-year follow-up study.

Kray, J., Karbach, J., & Kersken, C. (in preparation). Lifespan Changes in the Stroop Task: Asymmetrical age-related differences in facilitation and interference effects.

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