Ludwig– Maximilians– Universität München

# Cognitive Reserve

# and its Association with Cognitive Abilities and the Big Five:

# An Examination of young and older Adults.

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# Zusammenfassung

Unsere Lebenserwartung ist heutzutage höher als je zuvor. Vor dem Hintergrund einer alternden Gesellschaft wird häufig eine Zunahme von altersbedingtem kognitivem Abbau befürchtet. Gleichzeitig werden die Anforderungen des Arbeitsmarktes an ältere Arbeitnehmer bzgl. geistiger Aktivität und flexiblen Lernmöglichkeiten vermutlich weiter steigen. Für unsere Gesellschaft ist demnach die Frage von großer Bedeutung, ob das kognitive Funktionsniveau von älteren Menschen aufrechterhalten oder sogar verbessert werden kann. Auch aus Sicht des Einzelnen erscheint ein möglichst effektives kognitives Funktionsniveau in hohem Alter wünschenswert, da es mit einer höheren Lebensqualität verbunden sein sollte. Die vorliegende Studie, die das Lernpotential junger und älterer Menschen untersucht, widmet sich somit einem Thema von großer praktischer Relevanz.

Kognitive Trainingsstudien haben ein beachtliches Lernpotential von älteren Menschen in Bezug auf verschiedene kognitive Fähigkeiten zeigen können, z. B. im Bereich der fluiden Intelligenz (Baltes, Dittmann-Kohli, & Kliegl, 1986; Baltes, Sowarka, & Kliegl, 1989) oder des episodischen Gedächtnisses (Verhaeghen, Marcoen, & Goossens, 1992). Dieses latente Lernpotential in kognitiv herausfordernden Aufgaben wird von Baltes und Kollegen „kognitive Plastizität“ genannt (Baltes & Lindenberger, 1988), während Stern (2002) die Bezeichnung „kognitive Reserve“ eingeführt hat. In Anlehnung an Stern soll im Folgenden der Begriff „kognitive Reserve“ beibehalten werden. Das Konzept und die verschiedenen Begrifflichkeiten werden in der Einleitung dieser Studie näher erläutert. Darüberhinaus wird ein Überblick über bisherige Studien zum Thema „kognitive Reserve“ dargestellt. In den letzten Jahren wurden vermehrt positive Ergebnisse berichtet, sowohl bzgl. der Stabilität von kognitiven Trainingsgewinnen, als auch bzgl. des Transfers auf nicht direkt trainierte Fähigkeiten. Diese unterstreichen die

Nützlichkeit weiterer Forschungsbemühungen auf diesem Gebiet. Die bereits durchgeführten Trainingsstudien unterscheiden sich jedoch sehr in ihrer Operationalisierung. Zudem existieren widersprüchliche Befunde, z. B. in Bezug auf das Ausmaß der kognitiven Reserve in hohem Alter. Auch wird teilweise beachtliche inter-individuelle Variabilität für Trainingsgewinne älterer Menschen berichtet.

Die vorliegende Arbeit hat das Ziel zu einer Präzisierung des Konzeptes der kognitiven Reserve beizutragen. Deshalb sollen drei Fragestellungen untersucht werden, die in der bisherigen Forschung zu kognitiver Reserve entweder noch nicht geprüft oder unzureichend beantwortet wurden. Als erstes soll der Frage nachgegangen werden, ob das Ausmaß der kognitiven Reserve bei älteren Menschen im Vergleich zu jungen Erwachsenen reduziert ist. Die zweite Forschungsfrage betrifft den Zusammenhang von Reserveleistungen in zwei unterschiedlichen Aufgaben: Ist die kognitive Reserve eher aufgabenspezifisch oder gibt es Hinweise auf ein generelles Reservenetzwerk, das für Lernen in unterschiedlichen Aufgaben aktiviert wird? Schließlich möchte diese Studie die Frage klären, ob die kognitive Reserve von jungen und älteren Erwachsenen mit Hilfe ihrer kognitiven Architektur (grundlegenden kognitiven Fähigkeiten) und ihrer Persönlichkeitsmerkmale vorhergesagt werden kann. Da diese Aspekte entweder bisher nicht direkt untersucht wurden (Frage 2) oder in den Vorgängerstudien zu widersprüchlichen Ergebnissen geführt haben (Frage 1, 3), wurden keine spezifischen Hypothesen in Bezug auf die drei Forschungsfragen formuliert. Im Folgenden werden die zur Prüfung der Forschungsfragen eingesetzten Testverfahren und untersuchten Stichproben beschrieben.

Um die kognitive Reserve zu messen, wurde das so genannte „Testing the Limits"-Paradigma (Kliegl, Smith, & Baltes, 1989) angewandt. Dieses methodische Vorgehen zielt darauf ab, die Leistungssteigerung in einer kognitiven Aufgabe durch Training

oder Testwiederholung zu messen, anstatt lediglich das Ausgangsniveau zu erheben. Die Annahme dahinter ist, dass sich die kognitive Reserve einer Person am ehesten nahe ihrer Leistungsgrenzen zeigen sollte. In der vorliegenden Studie wurde das Paradigma über einfache Testwiederholung operationalisiert. Der Zahlensymboltest (ZST) und ein visuelles Suchparadigma wurden von einer Stichprobe junger Erwachsener und einer Stichprobe älterer Erwachsener jeweils zehnmal in Folge bearbeitet. Der ZST wird hauptsächlich als Messinstrument für perzeptuelle Geschwindigkeit charakterisiert. Jedoch haben mehrere Studien gezeigt, dass andere Komponenten wie motorische Geschwindigkeit und Gedächtnisleistungen in die Aufgabenstellung einfließen. In der Einleitung dieser Arbeit wird der ZST ausführlich beschrieben und verschiedene Studien zitiert, die u. a. eine deutliche Leistungsabnahme mit fortschreitendem Alter dokumentieren. Der zweite Reservetest, ein serielles visuelles Suchparadigma, stellt v. a. hohe Anforderungen an die visuelle Aufmerksamkeit, erfordert aber auch exekutive Fähigkeiten. Befunde von Vergleichsstudien Jung - Alt in visuellen Suchaufgaben werden ebenfalls in der Einleitung erläutert. Es zeigt sich eine Tendenz, dass ältere Menschen v. a. in anspruchsvollen visuellen Suchaufgaben mit einer hohen Ähnlichkeit von Zielreiz und Distraktor und hoher Reizdichte verlangsamt sind. Das hier verwendete visuelle Paradigma zeichnet sich durch eben diese Merkmale aus. Analog zum ZST sollte es sich demnach um ein alterssensitives Instrument handeln. Die kognitive Architektur wurde durch einen Aufmerksamkeitstest, einen Gedächtnistest und einen Test für schlussfolgerndes Denken als Indikator für fluide Intelligenz ermittelt. Die Persönlichkeitsmerkmale (Big Five) wurden mittels eines Fragebogens gemessen. Probanden waren 140 Studenten im Alter von 20 bis 30 Jahren und 140 Seniorenstudenten im Alter von 57 bis 75 Jahren. Als Ausschlusskriterien galten

körperliche Erkrankungen, psychische Störungen und Medikation, welche die Reaktionsfähigkeit beeinträchtigen könnten, sowie unkorrigierte Sehstörungen. Weiterhin wurden die Probanden zu depressiver Symptomatik befragt und Teilnehmer mit moderater oder schwerer Symptomatik von der Analyse ausgeschlossen. Die Daten wurden hauptsächlich mit Hilfe von latenten Wachstumskurvenmodellen ausgewertet. Das Grundprinzip dieser Methodik liegt darin, dass die individuelle Leistung zu jedem Messzeitpunkt auf ein wahres Ausgangsniveau (Intercept), eine Steigung (hier Maß für die kognitive Reserve) und einen Fehler zurückgeführt wird (intra-individuelles Modell). In einem nächsten Schritt können dann systematische inter-individuelle Unterschiede in Ausgangsniveau und Steigung durch bestimmte Variablen vorhergesagt werden (inter-individuelles Modell). Um manifeste Variablen der Gruppen zu vergleichen, wurden t-Tests verwendet. Im Folgenden wird ein Überblick über die wichtigsten Ergebnisse dieser Studie dargestellt.

Zunächst wurden Unterschiede zwischen den beiden Altersgruppen analysiert. Erwartungsgemäß schnitten die jungen Erwachsenen in den Tests zur Ermittlung der kognitiven Architektur (Aufmerksamkeit, Gedächtnis, fluide Intelligenz) besser ab, als die älteren Erwachsenen. Ebenfalls zeigten sie im Durchschnitt ein besseres Ausgangsniveau in beiden Reservetests (ZST, visuelle Suche). Die Auswertung des Persönlichkeitsfragebogens ergab, dass die jungen Erwachsenen signifikant höhere Werte auf den Skalen Extraversion und Neurotizismus erzielten, als die älteren Erwachsenen. Überraschenderweise waren die Jungen im Durchschnitt weder signifikant offener, noch signifikant weniger verträglich oder gewissenhaft, als die Älteren. In Bezug auf die beiden Reservemessungen ergab sich ein uneinheitliches Bild: Während die jungen Erwachsenen bei der zehnfachen Wiederholung des ZSTs durchschnittlich eine höhere Leistungssteigerung erreichten, als die älteren

Erwachsenen (Anstieg um 22 gegenüber 16 Symbolen), zeigten beide Altersgruppen eine vergleichbare Leistungssteigerung bei der Wiederholung der visuellen Suchaufgabe (Reaktionszeiteinsparung: Junge 187 ms, Ältere 181 ms). Diese Ergebnisse wurden durch den Befund ergänzt, dass Alter ein signifikanter Prädiktor der Ausgangsniveaus in beiden Tests und der Verbesserung im ZST war, jedoch nicht bedeutsam zur Vorhersage der Verbesserung in der visuellen Suchaufgabe beitrug. In einem zweiten Schritt wurden Zusammenhänge zwischen den Ausgangsniveaus und den Steigerungsraten im ZST und in der visuellen Suche analysiert. Erwartungsgemäß waren die Ausgangslagen in beiden Tests korreliert. Dieser Zusammenhang war für die jungen Erwachsenen jedoch eher schwach. Die Leistungssteigerungen in beiden Tests korrelierten eher gering für Jung und Alt. Für die visuelle Suchaufgabe ergab sich bei jungen und älteren Erwachsenen ein moderater bis starker Zusammenhang zwischen Ausgangsniveau und Leistungssteigerung, der auf einen Deckeneffekt schließen lässt. Als letztes wurden für beide Altersgruppen inter-individuelle Unterschiede in Ausgangslagen und Steigerungsraten mit Hilfe der kognitiven Architekturvariablen (Aufmerksamkeit, Gedächtnis, fluide Intelligenz) und Big Five vorhergesagt. Hierbei wurden zunächst die vollen Effekte der Prädiktoren analysiert, indem jeder Prädiktor einzeln in das latente Wachstumskurvenmodell mit ZST und visueller Suche aufgenommen wurde. Für Jung und Alt zeigte sich Aufmerksamkeit als wichtigster Prädiktor der Ausgangslage im ZST. Gedächtnis trug ebenfalls signifikant zur Vorhersage bei. Fluide Intelligenz war lediglich für die älteren Erwachsenen ein signifikanter Prädiktor. Das Ausgangsniveau in der visuellen Suchaufgabe konnte nahezu ausschließlich durch Aufmerksamkeit vorhergesagt werden. Nur für die älteren Erwachsenen trug auch die Gedächtnisleistung signifikant zur Vorhersage bei. Nach der Analyse der vollen Effekte wurden alle kognitiven Architekturvariablen gleichzeitig als

Prädiktoren eingesetzt. In diesem Modell, das für überlappende Prädiktorvarianzen kontrolliert, trug nur noch Aufmerksamkeit bedeutsam zur Vorhersage der Ausgangslagen von Jung und Alt in beiden Tests bei. Das Hauptinteresse dieser Studie galt jedoch der Vorhersage der Leistungssteigerung, dem Maß für kognitive Reserve. Im Gegensatz zu den Ausgangslagen war die Leistungssteigerung im ZST und in der visuellen Suche weitgehend unabhängig von der kognitiven Architektur. Es ergaben sich lediglich marginale Effekte für die älteren Erwachsenen bzgl. der Leistungssteigerung im ZST, die allerdings nicht mehr bedeutsam waren, wenn alle kognitiven Architekturvariablen gleichzeitig als Prädiktoren fungierten. Nach der Analyse der kognitiven Prädiktoren wurde ein zweites Modell mit den Big Five als Prädiktoren erstellt. In diesem Modell ergaben sich zwei statistisch bedeutsame Effekte. Überraschend trug die Skala Verträglichkeit zur Vorhersage der Ausgangslage der jungen Erwachsenen im ZST bei. Zudem war Extraversion ein wichtiger Prädiktor der Leistungssteigerung der älteren Erwachsenen in der visuellen Suche.

Diese Ergebnisse werden im Diskussionsteil der vorliegenden Arbeit ausführlich besprochen und in die existierende Forschung eingeordnet. Zusammenfassend lässt sich folgendes Fazit in Bezug auf die eingangs formulierten Forschungsfragen ziehen: Die kognitive Reserve scheint im Alter nicht generell reduziert zu sein, sondern in Abhängigkeit von der trainierten kognitiven Fähigkeit zu variieren. Diese Schlussfolgerung ergibt sich aus dem Befund, dass die Leistungssteigerung im ZST für die Jungen höher ausfiel, sich jedoch nur geringe Gruppenunterschiede bzgl. der Leistungssteigerung in der visuellen Suche zeigten. Zweitens spricht der geringe Zusammenhang zwischen den Steigerungsraten von Jung und Alt im ZST und in der visuellen Suche eher für eine aufgaben- oder fähigkeitsspezifische Reserve, als für eine generelle kognitive Reserve, die für unterschiedliche Aufgaben aktiviert wird.

Schließlich implizieren die Ergebnisse dieser Studie, dass die kognitive Reserve von gesunden, gebildeten Erwachsenen weitgehend unabhängig von deren kognitiver Architektur und (mit einer Ausnahme) Persönlichkeit ist. Für die Vorhersage der Leistungssteigerungen haben sich andere Prädiktor-Kriterium-Beziehungen ergeben, als für die Vorhersage der Ausgangsniveaus. Dies spricht dafür, dass die Leistungssteigerung (Maß für die kognitive Reserve) etwas anderes abbildet, als lediglich den kognitiven Status einer Person. Welche Faktoren letztlich die kognitive Reserve einer Person beeinflussen, bleibt eine wichtige Frage für die zukünftige Forschung.

Einschränkend muss festgehalten werden, dass die beiden Altersgruppen nicht direkt vergleichbar waren, z. B. hinsichtlich der Bildungsjahre und des Geschlechterverhältnisses in der Stichprobe. Zudem handelte es sich bei den Probanden in der jungen Stichprobe ausschließlich um Studenten und bei den Probanden in der älteren Stichprobe in der Mehrheit um Universitätsabsolventen, was die Generalisierbarkeit der Ergebnisse eingeschränkt. In niedrigeren Bildungsschichten mag sich ein Einfluss der kognitiven Architektur auf die Reserve zeigen. Schließlich sollten die Ergebnisse für die visuelle Suche mit Vorsicht interpretiert werden: Unter anderem legt die eher niedrige Retest-Reliabilität nahe, dass das gewählte Suchparadigma nicht optimal zur Messung der kognitiven Reserve geeignet war. Trotz dieser Einschränkungen hat die vorliegende Studie einen wichtigen Schritt in Richtung einer weiteren Präzisierung des Konzeptes der kognitiven Reserve unternommen. Es bleibt zu hoffen, dass Forscher auf diesem Gebiet zukünftig hieran anknüpfen werden, um letztlich eine umfassende, fundierte Theorie der kognitiven Reserve zu formulieren und damit eine theoretische Einbettung der zahlreichen Befunde zu ermöglichen.

## Abstract

The present study explored the concept of cognitive reserve by using a testing-the-limits paradigm (Kliegl et al., 1989). 140 young (*M* = 22.8 years, range = 20-30) and 140 older (*M* = 67.3 years, range = 57-75) adults were provided with extensive retest practice in the Digit Symbol Substitution Test (DSST) and a visual search task. Cognitive abilities (fluid reasoning, memory, attention) and personality dimensions (Big Five) served as predictors of retest improvement (i.e., cognitive reserve). Latent Growth Curve analyses demonstrated greater DSST improvement for the young group, but similar visual search improvement for both age groups, indicating age-independent cognitive reserve in visual search. Improvement rates for both tasks were weakly correlated, speaking rather for task-specific learning than for a general cognitive reserve. Cognitive reserve was rather independent from cognitive abilities and, with one exception, also from personality dimensions. Implications for cognitive reserve in general and DSST and visual search retest learning in particular are discussed.

*Keywords:* cognitive reserve, retest learning, age, DSST, visual search, cognitive abilities, personality

# Chapter 1: Introduction

# 1. Introduction

People are living longer and are in better physical health than ever before. One of the concerns, associated with an aging population, is a higher incidence of age-related cognitive decline. At the same time, demands for older adults with highly effective cognitive functioning and flexible learning skills are growing within the working environment. Consequently, the question whether there is anything that can be done to maintain or improve cognitive functioning in old age, is of importance for our society and its individuals (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Thompson & Foth, 2005). Maintaining or improving cognitive functioning with the help of cognitive training programs would be profitable for society, because in the long run costs could be saved. From the individual's point of view, effective cognitive functioning is probably associated with higher quality of life in old age (Hertzog, et al., 2008). Cognitive training studies have demonstrated older adults' potential for improving different cognitive functions, e.g., fluid intelligence (Baltes, et al., 1986; 1989) and episodic memory (see Verhaeghen, et al., 1992 for a meta-analysis). This learning potential has been labeled "cognitive reserve" (Stern, 2002) or "plasticity" (Baltes & Lindenberger, 1988). Recently, positive findings have been reported, regarding stability of learning gain in old age (Ball, et al., 2002; Dahlin, Nyberg, Bäckman, & Neely, 2008; Willis, et al., 2006) and sometimes even transfer to other cognitive skills (Basak, Boot, Voss, & Kramer, 2008) or everyday functioning (Edwards, et al., 2002; Willis, et al., 2006). Such results support the usefulness of further research efforts on cognitive reserve in the aging mind. Given the limited number of cognitive training studies conducted up to this date, different methodologies employed, and conflicting results observed, it remains speculative if cognitive reserve of older adults is reduced, compared to young adults. In addition, it is an open question if the range of cognitive reserve varies among different cognitive ability domains. Moreover, though cognitive training for older people generally seems to be effective, there is great variability in responding (Langbaum, Rebok, Bandeen-Roche, & Carlson, 2009), indicating that not all older adults benefit from training in the same way. Inter-individual differences in cognitive reserve have not been completely understood. The present study further explores these open questions regarding the concept of cognitive reserve by examining the cognitive reserve of young and older adults in a substitution coding and a visual search task. Cognitive reserve was measured by a testing-the-limits paradigm (Kliegl, et al., 1989), providing extensive retest practice. Inter-individual differences in cognitive reserve of young and older adults were predicted by cognitive variables and non-cognitive traits (Big Five). Additionally, the rate of cognitive reserve for young and old adults and the association between cognitive reserves in substitution coding and visual search will be reported.

## 1.1. The Concept of Cognitive Reserve

For decades a rather pessimistic view of aging has been predominant in research on cognitive functioning. The aging mind has been characterized by gradual but broad cognitive decline across the life-span. Since the 1980s, a reversal of this trend has begun. Positive results regarding functional reorganization, compensation and effective interventions give rise to a more optimistic view of neurocognitive status in later life (Reuter-Lorenz, 2002; Reuter-Lorenz & Lustig, 2005). Research on effective interventions, demonstrating cognitive plasticity in the aging mind, is a current topic in psychological science (Kramer & Willis, 2002). Cognitive plasticity (learning potential) (Baltes & Lindenberger, 1988) is a behavioral construct measured by performance changes in pretest/training/posttest designs, usually operationalized by short cognitive training programs (Fernández-Ballesteros, Zamarrón, Calero, & Tárraga, 2007). The terms cognitive plasticity and cognitive reserve are often used interchangeably.

According to Stern (2002), cognitive reserve is the ability to optimize or maximize one's performance, when dealing with cognitive challenges. The present study assumes that cognitive reserve and plasticity basically represent the same construct. Therefore, this study consistently uses the term cognitive reserve, even when discussing studies on cognitive plasticity. Both terms have also been linked to neural plasticity (Mercado, 2008; Stern, 2009), e.g., measured by changes in functional brain activity in the course of training. The association between functional and neuronal level of reserve will be an important topic for future research but, to this date, is rather theoretical. So this study concentrates on the functional level. A well-established method for measuring cognitive reserve on the functional level is the testing-the-limits approach (Kliegl, et al., 1989): Instead of only measuring the person's initial performance, it focuses on the improvement in a cognitive task—either in the course of training or simple retesting. The underlying assumption is that an individual's cognitive reserve should most likely manifest itself near performance limits. Therefore, this methodological approach is aimed at discovering the limits of an individual's learning gain (Baltes, 1987). Higher cognitive reserve should be associated with greater improvement in challenging cognitive tasks. This way, researchers should be able to better discriminate between individuals with low and high latent learning potential rather than by just measuring the initial cognitive status, an assumption that has also been proposed by theories on dynamic testing (Grigorenko & Sternberg, 1998) or learning tests (Guthke & Stein, 1996). The testing-the-limits approach has been applied to different cognitive domains, including memory (Kliegl, et al., 1989), dual-task performance (Bherer, et al., 2006; 2008), reasoning, attention and speed (Yang, Krampe, & Baltes, 2006). Operationalizations range from intensive training including strategy use and individualized feedback (Bherer, et al., 2006; Kliegl, et al., 1989) to self-guided learning with minimal intervention (Baltes et al., 1989). The present study used a simple retest paradigm to assess basic forms of cognitive reserve that have been demonstrated to exist even in old age (Yang et al., 2006).

### 1.2. Cognitive Reserve and Age

Several studies have demonstrated cognitive reserve in the elderly (see Thompson & Foth, 2005 for a review). In the beginning of research on this topic, studies have concentrated on fluid intelligence (Baltes et al., 1986; 1989) and episodic memory (see Verhaeghen et al., 1992 for a meta-analysis). Recently, the focus has shifted to other cognitive abilities like working memory (Buschkuehl, et al., 2008; Li, et al., 2008), executive functions (Basak et al., 2008; Dahlin et al., 2008) or dual-task performance (Bherer, et al., 2006; 2008; Doumas, Rapp, & Krampe, 2009). The literature widely agrees that older adults can improve their performance through systematic training or in the course of extensive retest practice. However, results about adult age differences in rate of cognitive reserve differ. Some studies reported similar improvement on cognitive tasks in young and older adults or even greater cognitive reserve for older individuals (Bherer, et al., 2006; 2008; Ho & Scialfa, 2002; Scialfa, Jenkins, Hamaluk, & Skaloud, 2000). On the contrary, studies in the episodic memory domain showed reduced training benefits for older adults. For example, Kliegl, Smith, and Baltes (1990) observed a magnification of initial age differences after extensive laboratory training with a mnemonic technique. Singer, Lindenberger, and Baltes (2003) demonstrated that such limitations in modifiability of episodic memory functions appear to be pronounced in very old age. These results suggest decreased cognitive reserve in the aging mind, at least for the episodic memory domain. On the other hand, by using a simple retest paradigm, Yang et al. (2006) demonstrated some reserve for improving on basic cognitive functions (reasoning, attention, speed) even for oldest participants in their eighth decade of life. It must be kept in mind that learning a mnemonic technique, like the one used in the Kliegl et al. (1990) and Singer et al. (2003) study, requires the acquisition of new, complex cognitive skills. Thus, the amount of training benefit seems to depend not only on age, but on other factors such as the cognitive task practiced and the training paradigm used. Given the limited number of cognitive training studies conducted up to this date, different methodologies employed, and conflicting results observed, many open questions remain, e.g.: Is cognitive reserve of older adults really reduced, compared to young adults? And, does the range of cognitive reserve vary among different cognitive domains? Further empirical studies are needed to answer these questions. The present study contributes to this topic by examining cognitive reserve of a young and an older group in two different tasks: the Digit Symbol Substitution Test (DSST) and a visual search task.

### *1.2.1. DSST and Age*

According to Hoyer, Stawski, Wasylyshyn, and Verhaeghen (2004), the DSST, which has been used as the first cognitive reserve measure in this study, is a valuable tool for aging research. In their meta-analysis of 141 studies, age accounted for 86% of DSST score variance in a regression model using age, education, and estimated year of measurement as predictors. The study by Willoughby (1929) was one of the first to suggest that performance on Digit Symbol substitution tasks reaches an early peak (age 18), but decreases severely during adulthood. Since then, the age-sensitive nature of substitution coding tasks, e.g., the DSST, has been demonstrated many times (e.g., Salthouse, 1992), although the behavioral and biological processes underlying these age effects are not well understood (Laux & Lane, 1985; Piccinin & Rabbitt, 1999; Salthouse, 2000). Explanations vary from age differences in perceptual speed and working memory (Salthouse, 1992) to a psychomotor slowing in older adults (Stephens, 2006). Rogers and Gilbert (1997) mentioned that the examination of age effects on substitution coding tasks has typically focused on initial task performance instead of providing practice on the task. Results of age effects on DSST learning are inconsistent. Erber (1976) was one of the first researchers to investigate practice effects on a modified Digit Symbol task. Young and old participants practiced on ten 30-second trials of this task. Both age groups showed similar, significant improvement (approximately six items across the ten trials), but the performance level of the young group was higher throughout. Piccinin and Rabbitt (1999) provided an overview of studies, conducted on substitution coding training, and concluded that, generally, these studies have found improvement in the performance of young and old adults, but a tendency for young adults to benefit more from practice. In their study, age (ranging from 49 to 95 years) predicted initial level in a substitution coding task, but not improvement during the four practice trials. Yang et al. (2006) compared a group of young-olds (70 to 79 years) to a group of oldest-olds (80 to 91 years) regarding their retest practice in the DSST. They reported that overall level of performance and retest improvement were higher for the young-olds, although the oldest-olds showed considerable retest improvement. All in all, the literature indicates that younger adults generally perform better on substitution coding tasks than older adults. Increasing age also, by tendency, seems to reduce learning gains in these tasks, although some studies reported age-independent learning rates.

### *1.2.2. Visual Search and Age*

As a second measure of cognitive reserve, a visual search paradigm was used. Visual search can be described as “the processes by which we localize, detect, and identify salient objects, often in visually cluttered environments” (Anandam & Scialfa, 1999). In laboratory studies, visual search tasks mainly consist of detecting a visual target stimulus among distractor stimuli in a given set of stimuli (set size). Visual search involves both parallel and serial processes (e.g., Treisman & Gelade, 1980). In parallel search, attentional and executive resources are low, whereas in serial search, attentional demands are high and executive abilities are required. Parallel search has been associated with tasks, where the target differs from other stimuli by a single visual feature (feature search), e.g., a red target among green distractors. On the contrary, if the target differs from the distractors by a combination of distractor features (conjunction search), search requires serial, item-by-item processing, which leads to an increase of reaction time with an increasing number of stimuli. This interpretation of feature and conjunction search as parallel and serial search has been supported by the feature integration theory (Treisman & Gelade, 1980). Since then, subsequent studies have found contradictory results. In short, feature search tasks can be difficult, due to target–distractor similarity or distractor heterogeneity, and conjunction search can be easy, due to dissimilarity of targets and distractors (Duncan & Humphreys, 1989; Scialfa, Esau, & Joffe, 1998). These findings led to revisions of the feature integration theory (Treisman & Gormican, 1988) and new explanatory models (Duncan & Humphreys, 1989). These models assume that instead of the strict distinction between parallel, preattentive and serial, attention-demanding search, the same fundamental processes underlie both feature and conjunction search. The feature search task of the present study was rather demanding because of high target-distractor similarity and a large set size of 15 stimuli (for details see method section). Thus, it most likely required serial processing.

Growing literature has examined age-related differences in visual search (e.g., Humphrey & Kramer, 1997). Results from these studies indicate that young and older adults perform with similar efficiency when the search task is easy. However, age differences emerge when the task is made more difficult by increasing target-distractor similarity (Scialfa et al., 1998) or using conjunction search (Plude & Doussard-Roosevelt, 1989). Similar to the DSST, processes behind age differences in difficult visual search tasks have not been completely understood. Explanations of age differences usually either focus on the general slowing hypothesis (Cerella & Hale, 1994), assuming each component involved in visual search being slowed equivalently with aging, or on a deficit in selective attention of older adults (Plude & Doussard-Roosevelt, 1989). The latter assumption is in line with a theory by Hasher and Zacks (1988) on age and higher-order cognition, postulating that a deficit in distraction control, or in the ability to inhibit irrelevant information, plays an important role for age-related cognitive decline. However, according to Scialfa et al. (1998), restricting explanations of age-related visual search deficits to a single mechanism could be too simplistic, because many age-dependent cognitive abilities (e.g., oculomotor involvement, working memory, attentional shifts) are likely to contribute to differences in visual search. Hommel, Li, and Li (2004) studied gains and losses in visual search across the life span. Older adults showed particular problems on target-absent trials and with increasing number of distractors. The authors concluded that search performance of older adults is not only impaired due to neurocognitive decline, but because of a more careful, maybe compensatory search style. Consistent with these findings, in the study by Scialfa et al. (1998), older adults' problems in feature and conjunction search emerged in three conditions: high target-distractor similarity, a large number of distractors and target-absent trials. The analysis of the present study concentrated on target-present trials. Yet, as mentioned above, the visual search task used in this study is characterized by rather high target-distractor similarity and a relatively large number of distractors. Thus, it should be rather demanding for older adults.

Contrary to the DSST, practice in visual search tasks has been extensively studied. Practice improves search efficiency in younger adults (Shiffrin & Schneider, 1977), which has been interpreted as automatization of the processes involved (Czerwinski, Lightfoot, & Shiffrin, 1992). Results regarding adult age differences in visual search practice differ. Rogers, Fisk and their colleagues conducted several studies examining practice benefits for young and older adults in visual or semantic category search performance (Fisk & Rogers, 1991; Fisk, Rogers, & Giambra, 1990; Rogers & Fisk, 1991; Rogers, Fisk, & Hertzog, 1994). Generally, they observed age deficits in learning and in disruption that should follow a reversal of targets and distractors, if search has become automatized. The authors concluded that older adults do not develop an automatic attention response to trained targets. However, Rogers and her colleagues often used the semantic category search task, which differs from typical visual search paradigms in that it involves a much larger memory component (see Anandam & Scialfa, 1999; Scialfa et al., 2000 for a detailed discussion of differences between semantic category search and visual search). Recently, Scialfa and colleagues demonstrated comparable training benefits for young and older adults in different visual search tasks. Anandam and Scialfa (1999) conducted a training experiment with 18 young and 18 old participants who were asked to search for an orientation-defined target among a homogeneous set of distractors (feature search). They completed seven practice sessions, followed by one session of target-distractor reversal. Results showed equivalent learning rates and equivalent disruption after reversal for young and old adults. Studies by Scialfa et al. (2000) and Ho and Scialfa (2002) suggested that older adults also benefit from practice in conjunction search tasks. With the exception of a more conservative (i.e., accurate) search style in target-absent trials (Ho & Scialfa, 2002), old adults developed proficient and flexible search skills to the same degree as their younger counterparts. These studies suggest equal cognitive reserve for young and older adults in visual search.

### 1.3. Cognitive Reserve and Cognitive Abilities

In addition to age, many variables have been related to cognitive reserve, including depression (Bäckman, Hill, & Forsell, 1996), anxiety (Yang, Reed, Russo, & Wilkinson, 2009), verbal ability (Yesavage, Sheikh, Tanke, & Hill, 1988), education (Hill, Wahlin, Winblad, & Bäckman, 1995), mental status (Calero & Navarro, 2004; Hill, Yesavage, Sheikh, & Friedman, 1989; Yesavage, Sheikh, Friedman, & Tanke, 1990) and certain personality characteristics (see next section for a detailed discussion). In this study, concentrating on a normal range of cognitive functioning, it was explored whether differences in individual standings in *cognitive architecture* account for variability in cognitive reserve of young and older adults. By using the term *cognitive architecture* the present study refers to an individual's basic cognitive abilities, namely fluid intelligence, memory and attention.

Cognitive reserve has been extensively studied in the memory domain. Some of these studies also focused on the association between different cognitive abilities and benefit in a memory (mainly mnemonic) training. Studies by Kliegl et al. (1990) and Singer et al. (2003) revealed measures of perceptual speed as important predictors of cognitive reserve in memory tasks. In the study by Kliegl et al. (1990), in which pretraining scores were related to task-specific performance factors like cued recall, the posttraining outcome identified digit symbol substitution as the most powerful indicator. This is consistent with Singer et al. (2003), who demonstrated that perceptual speed was stronger related to individual differences in episodic memory after training than before training, while the predictive value of verbal knowledge and socio-biographical variables decreased. Such findings led to the conclusion that training likely induces the use of more general intellectual resources and reduces the impact of task-specific or personal background variables. This is in line with the stage model of complex skill acquisition by Ackerman (1988; Ackerman & Cianciolo, 2000), who proposed that performance in the course of practice should be highly associated with perceptual speed abilities (before it reaches the stage of automatization). On the contrary, Verhaeghen and Marcoen (1996) found that memory plasticity after instruction in the method of loci was not only influenced by mental speed, but also by more task-specific factors like associative memory and number of list rehearsals. In a recent study by Langbaum et al. (2009), latent class analysis for identifying different response patterns to memory training was used and potential predictors of these response patterns were examined. They observed three distinct response patterns, suggesting that participants gravitated toward specific mnemonic techniques. Besides age and education, baseline memory and speed of processing abilities were the most important predictors of these response patterns. The authors concluded that maybe a combination of baseline demographic characteristics, baseline cognitive functioning and task-specific factors determines the success of memory training.

To summarize, there is a great deal of evidence that relationships between ability measures change with practice in a task (e.g., Ackerman, 1988, Piccinin & Rabbitt, 1999). However, there is still fundamental disagreement about whether postpractice individual differences in performance are predictable by measures of general or other abilities. Rogers et al. (1994) recommended that, if one wants to know how to best predict practice effects, knowledge about the learning requirements of particular tasks is needed. They pointed out the possibility that abilities, predicting individual differences in performance after training, may differ across tasks, even if all of the tasks contain components that can become automatized with practice. Thus, a short overview will be given about the cognitive reserve tests of the present study, the DSST and visual search, and their association with cognitive abilities, especially fluid reasoning, memory and selective attention.

### *1.3.1. DSST and Cognitive Abilities*

The studies described above focused on the memory domain and used perceptual speed measures, like the DSST, as predictor of cognitive reserve. But what predicts performance and cognitive reserve in the DSST itself? Laux and Lane (1985) divided a digit-symbol task into the following sub-tasks: (a) detecting and encoding the digit; (b) finding the digit in the key area; (c) encoding the symbol paired with the digit; (d) selecting the proper response; and (e) initiating and executing that response. The DSST has often been characterized as speed measure (Salthouse, 2000; Yang et al., 2006). However, it has been demonstrated that digit-symbol tasks are rather complex, measuring motor response speed, cognitive speed and memory components (e.g., Joy, Kaplan, & Fein, 2004). In a recent study by Piccinin and Rabbitt (1999), initial performance in a substitution coding task was predicted by reasoning, vocabulary, memory and cross-out speed. They concluded that all these abilities are involved in successful performance of the task.

As described above, performance-ability relationships often change with practice in the task. Yang et al. (2006) and Piccinin & Rabbitt (1999) examined the association between DSST retest learning and cognitive functioning. Yang et al. (2006) compared 34 young-olds in their seventh and 34 oldest-olds in their eighth decade of life, with half in each age group screened for high or low (actually midrange) level of cognitive functioning. The latter was measured by a theory-based test battery (two speed tests, two fluency tests) for which normative data were available. Both age groups took part in six retest sessions over a 3-week period, practicing tests of reasoning, speed (DSST) and attention. Level of cognitive functioning significantly correlated with learning gains in the reasoning domain, but learning gains in the other domains (including the DSST) were rather independent. Whereas Yang et al. (2006) measured retest effects over three weeks, Piccinin and Rabbitt (1999) investigated immediate retest learning. In their growth curve analysis involving 3.708 participants (49 to 95 years of age), retest improvement during four 2 min-trials in a substitution coding task was accounted for by memory performance to a greater extent than by age, reasoning, vocabulary or cross out speed. In fact, prediction of improvement could be drawn almost exclusively from the memory variables. However, operational overlap between the coding task and memory for code, which was assessed after the last trial, accounted for substantially larger amounts of individual variability in improvement than other memory measures. So it remains questionable, whether memory, assessed without such strong operational overlap, is an important predictor of cognitive reserve in substitution coding tasks.

### *1.3.2. Visual Search and Cognitive Abilities*

In visual search paradigms, if attention is not drawn directly to the target (pop out, parallel processing), participants have to form a mental representation of the target and compare several nontargets in the display to this representation, before the target can be found. Such visual search tasks highly demand selective visual attention. Additionally, processing speed and inhibitory efficiency are crucial components of visual search performance (Hommel et al, 2004). Even if the memory component in classic visual search tasks is not as important as, for example, in semantic category search (see Anandam & Scialfa, 1999 for a discussion), visual search requires participants to hold a single element in memory and to determine if that element is contained within a multi-element display (Fisk, Rogers, Cooper, & Gilbert, 1997). Thus, at least some proportion of variance in initial visual search performance should be explained by working memory. Fluid reasoning abilities help in dealing with a novel task by supporting the understanding of task instructions and quickly developing optimal performance strategies (Piccinin & Rabbitt, 1999). Moreover, an association of fluid intelligence to parallel and serial visual search tasks has been demonstrated (Diascro & Brody, 1993). Therefore, fluid intelligence should also be related to some extent to visual search performance, at least before practice.

As far as known, only studies using semantic category visual search explored the relations between basic cognitive abilities and learning in visual search. Rogers et al. (1994) examined relationships between abilities and performance in a category search task for young and old adults, who received extensive practice on the task. In their models, general ability and semantic memory access predicted initial performance, whereas improvement in the task was predicted by perceptual speed. Interestingly, these ability-performance relations were remarkably similar for young and older adults (consistent with e.g., Hertzog, Cooper, & Fisk, 1996). However, many studies have emphasized that different mechanisms are involved in learning of memory search versus visual search (Anandam & Scialfa, 1999, Czerwinski et al, 1992, Fisk & Rogers, 1991, Hertzog et al., 1996). Rogers et al. (1994) stated, it would not be surprising, to find differences in the ability variables that predict performance acquisition in semantic category and visual search tasks. Therefore, it remains speculative which cognitive abilities predict learning in more classical visual search tasks like the one used in the present study.

To summarize, prediction of cognitive reserve by cognitive abilities has mainly been studied in the memory domain. Research on prediction of cognitive reserve in substitution coding reported either independence from cognitive functioning (Yang et al., 2006) or influence of memory variables (Piccinin & Rabbitt, 1999). As far as known, studies on determinants of cognitive reserve in classical visual search tasks are still lacking.

## 1.4. Cognitive Reserve and Personality

The present study not only tried to predict cognitive reserve by cognitive architecture, but included personality dimensions as explanatory variables into the analysis. Many studies have concentrated on the relation between cognitive abilities and personality dimensions like the Big Five (Ackerman & Heggestad, 1997; Ackerman & Rolfhus, 1999; Ashton, Lee, Vernon, & Jang, 2000; Schaie, Willis, & Caskie, 2004). Ackerman & Heggestad (1997) provided an extensive meta-analysis of correlations between personality and intellectual abilities. Extraversion (positive relation) and Neuroticism (negative relation) were significantly, but rather weakly correlated with intellectual abilities. Openness to Experience was the only Big Five domain score showing substantial (positive) correlations with ability traits. This is in accordance with the study by Holland, Dollinger, Holland, and MacDonald (1997), who observed a moderate to strong correlation of .42 between Openness, measured by the NEO-Personality Inventory, and IQ, measured by the full Wechsler Adult Intelligence Scale-Revised. In the study by Asthon et al. (2000), an Openness/ Intellect scale, defined as the sum of four Personality Research Form scales, was substantially correlated with crystallized intelligence or knowledge (see also Ackerman & Rolfhus, 1999), but rather weakly associated with measures of fluid intelligence, especially when these measures involved numbers or abstract figures instead of meaningful visual stimuli.

When trying to understand the relation of cognitive reserve to personality variables, research on training benefit is more important than considering just the initial task performance. Before turning to the few studies on cognitive training and personality, research conducted in the field of job behavior, which explored the association of personality dimensions and job-relevant training performance, will be presented. Ackerman, Kanfer and Goff (1995) investigated possible determinants of individual differences in skill acquisition of a complex, air traffic controller simulation task. None of the Big Five domain scores correlated significantly with overall task performance or performance in the course of practice. On the contrary, in the study by Dean, Conte, and Blankenhorn (2006), several Big Five domain scores (Extraversion, Openness to Experience, Conscientiousness) significantly predicted performance on simulation-based training criteria. But in their sample of 370 Marines, no association with training performance on paper and pencil exams was found. The meta-analysis by Barrick and Mount (1991) indicated that Openness to Experience and Extraversion were positively related to job training proficiency. The predictive value of Extraversion was mainly attributed to the social interactions involved in the training program. However, Barrick and Mount (1991) emphasized the importance of Openness for the ability and motivation to learn. They reasoned that this Big Five domain assesses characteristics like curiosity and creativity which are associated with positive attitudes towards learning. So individuals, who score higher on this personality dimension, should have a higher motivation to learn in a training program, which would result in a higher probability to succeed in this training. This is in accordance with a study on academic success by Ziegler, Danay, Schölmerich, and Bühner (in print), demonstrating that self-ratings on the facets Openness to ideas and Openness to values predicted grades on a statistics exam two months later, Openness to values even after controlling for reasoning scores. Thus, an impact of Openness on job training and academic learning success has been shown. This could also refer to training success in cognitive tasks.

Gratzinger, Sheikh, Friedman, and Yesavage (1990) explored the relationship of Big Five domain scores (Openness to experience, Extraversion, Neuroticism) to the ability of older adults to benefit from a cognitive training intervention. Their subjects were 156 elderly (age ranging from 55 to 87 years), who were trained in a memory task, namely face-name recall, by teaching a mnemonic technique. As in prior studies on mnemonic training, there was an overall improvement in the outcome measure after the intervention. Moreover, subjects, who scored higher on the Openness domain score, scored significantly higher on all face-name outcome measures. Furthermore, higher scores on the Openness subscale fantasy were related to greater improvement in one training condition (imagery training). Contrary to the authors' expectations, no effect of Neuroticism and Extraversion was found. Accordingly, this study suggests there might be some association between cognitive reserve and Openness to experience, at least for older people who practice associative memory. Another study, that addressed the same question, was conducted by Yesavage (1989), who trained 128 subjects (mean age 69 years) in mnemonic techniques to improve name-face recall, and compared improved to unimproved subjects on the basis of personality traits. Contrary to the study by Gratzinger et al. (1990), he observed a significant main effect for Neuroticism, suggesting that subjects with high scores for Neuroticism showed the least improvement.

It must be kept in mind that the mnemonic training, used in these two studies, is clearly different to the DSST and visual search task examined in the present study. To name an important difference, the tasks consisted of meaningful visual stimuli (associating faces with names) instead of abstract figures. So it seems likely that such tasks are related to Openness (Ashton et al., 2000, see above). On the contrary, in the study by Ashton et al. (2000), a Digit Symbol task, similar to the DSST, correlated only .02 with the Openness/Intellect factor. Based on this one and other findings, the authors stated that the factor seems to be rather independent from the ability to process information of an abstract spatial or quantitative nature. Therefore, it is also questionable whether visual search performance should be associated with Openness to experience. Newton, Slade, Butler, and Murphy (1992) investigated, if performance in a visual search task is related to personality. They examined 123 students, who completed the Eysenck Personality Questionnaire and 50 trials of a simple visual search task. Two personality factors were related to performance on the task: Extraversion was positively related to the average speed in target-present and target-absent trials, whereas Neuroticism was negatively related to the average speed in target-absent trials. The authors attributed the association between Extraversion and speed to introverts being more accurate and, therefore, requiring more information before making a response. Because they just examined the average reaction time in the task, no straightforward conclusions can be made regarding whether or not Extraversion and Neuroticism are related to improvement in a visual search task. All in all, research on cognitive reserve and personality is scarce and results are inconsistent.

### 1.5. The Present Study

This study investigated performance (initial level) and cognitive reserve (improvement rate) of 140 young adults and 140 older adults in the DSST and a serial visual search task. To assess basic forms of cognitive reserve, a retest paradigm, consisting of 10 repetitions for both tasks, was used. The study was conducted to explore the following questions:

1. Do young and older adults benefit equally from retest training in the DSST and a visual search task, reflecting equal cognitive reserve?
2. Is cognitive reserve in substitution coding (DSST) related to cognitive reserve in visual search for young and older adults?

3. Can cognitive reserve of young and older adults be predicted by cognitive architecture and/ or personality variables?

Regarding the comparison between the two age groups, the young group was expected to outperform the older group in all cognitive architecture variables and in initial performances in both reserve tests. It was assumed that both groups would improve with retest practice, reflecting cognitive reserve. However, the average performance level of the older group was not expected to reach the average performance of the young group throughout all retest trials. Given the inconsistent findings summarized above, there were no concrete hypotheses regarding the first research question about age differences in rate of cognitive reserve.

To address the second research question, the relationship between improvement rates (i.e., cognitive reserves) in both tasks was analyzed. The DSST and the visual search task of the present study share important aspects, for example speed conditions, motor response requirements and visual attention demands. Gilmore, Royer, Gruhn, and Esson (2004) also demonstrated that visual search is one crucial component of DSST performance. Therefore, initial performances in both tasks were expected to be related. As far as known, this is the first study which directly addresses the question whether cognitive reserve in one task is related to cognitive reserve in another task, indicating some general cognitive reserve factor as opposed to task-specific cognitive reserve. Thus, no hypotheses could be derived from prior research concerning the relationship between improvement rates.

Most importantly, it was examined if inter-individual differences in cognitive reserve of both age groups can be predicted by cognitive architecture and personality variables. Cognitive architecture was assessed by a fluid intelligence measure, a memory measure and a test of selective visual attention. Personality was measured by the Big Five factors. It was assumed that all cognitive architecture variables predict differences in initial DSST and visual search performance: Fluid reasoning abilities help in dealing with a substitution coding task as a novel situation which requires understanding task instructions and quickly developing optimal performance strategies (Piccinin & Rabbitt, 1999). This could also refer to the first visual search task. The memory component of DSST performance has been demonstrated many times, for example by Ackerman & Cianciolo (2000). To perform well in the visual search task of this study, the target stimulus must be held in memory and then be compared with different stimuli. Thus, at least some proportion of initial performance variance should be explained by memory. The d2 Test, used to measure selective visual attention, shares many aspects with the DSST and the visual search task, including visual search, motor speed and memory for symbols. All in all, it seems reasonable to expect that all of these predictor variables, to some extent, are related to initial performance in both tasks.

In addition, predictor-criterion relations were expected to be different for cognitive reserve than for initial performance, because relationships between ability measures often change with practice in a task. If measuring cognitive reserve, instead of only assessing initial task performance, reveals novel variance, indicated by different predictor-criterion relations, this would also provide further support for the usefulness of the testing-the-limits approach. The specific contribution of fluid intelligence, memory and attention for predicting cognitive reserve in the DSST and in visual search, as addressed with the third research question, is a rather new research issue. This is even more the case for the prediction of cognitive reserve by personality variables. So the examination of these aspects was explorational instead of guided by specific hypotheses.

Because of rather large sample sizes, Latent Growth Curve (LGC) models could be applied to study improvement in the course of retest practice. Until now, this well-known technique for analyzing change over time has rarely been applied to short cognitive training programs. An exception is the study by Piccinin and Rabbitt (1999), who pointed to advantages over conventional methods of longitudinal analysis. A further goal of this study is to examine if these models are useful for describing the retest data and, if so, suggest the wider application of this method for analyzing the concept of cognitive reserve.

# Chapter 2: Method

# 2. Method

## 2.1. Participants

Two samples participated in this study. The first sample originally consisted of 150 students. Ten of them had to be excluded from the statistical analysis: five students were familiar with the administered tests; the other five didn´t follow the instructions appropriately. The final sample included 140 students—100 women and 40 men—aged between 20 and 30 years (*M* = 22.81, *SD* = 2.41). They were recruited at the Ludwig-Maximilians-University (LMU) and the Technical University (TU) in Munich. 44 participants majored in psychology; 45 in education; and the remaining 51 in various subjects (e.g., physics, economics). The grades of the final school exams of the complete sample ranged from 1.0 to 3.4 (*M* = 1.92, *SD* = 0.62). The second sample contained 148 older participants. Eight of them had to be excluded from further analysis: three did not mention their health problems until they were tested; two showed severe concentration problems during the test session; three were identified as outliers after inspecting scatter plots. The final second sample also consisted of 140 subjects—66 women and 74 men—who participated in a program for senior students. They were addressed in the context of lectures, organized by the Center for Senior Studies at the LMU. Thus, participation of regular cognitive activities by the older subjects was assured. Their average age was 67.27 (*SD* = 4.16) ranging from 57 to 75 years. The majority of 121 older participants had university degrees, and 19 graduated from German secondary school (degree “Abitur”). All participants were screened for health problems twice: in a telephone interview prior to an appointment and again before the beginning of the tests. Subjects having any active acute illness, having any chronic illness which might affect cognition, or taking any medications that might affect cognition were excluded. Older participants with diabetes, high blood pressure or thyroid problems were accepted into the study if they took adequate medication and were well adjusted to it. Potential subjects in both groups were excluded if they had impaired vision. Moreover, both samples were screened for depressive symptoms (Results are presented below.). Participation was voluntary and was compensated with 30 Euro. Additionally, a short oral feedback on test performance at the end of the test session was offered to the older subjects.

### 2.2. Procedure

Potential participants were called and screened according to inclusion criteria (see above). Twenty-four hours before the test, subjects were asked to abstain from alcohol and medication that might influence their ability to respond. All test sessions were administered individually and lasted about two hours. The tests were conducted by a psychologist and four student assistants who were experienced in testing and carefully trained. The test sessions took place in two different laboratories at the university. Before the test session started, an informed consent (voluntary participation) was signed by the subjects. This was followed by a socio-demographic interview that included a second screening of physical or mental health problems. Then, depressive symptoms were assessed with a structured interview (young sample) or a questionnaire (older sample). Subsequently, an attention and a memory test were applied, followed by the first test for cognitive reserve. Additionally, a computer-administered personality questionnaire and a fluid intelligence test were completed by the subjects. The test session was concluded with the second test of cognitive reserve. The order of the cognitive reserve tests was counterbalanced across all subjects. Finally, subjects filled out a second informed consent—acceptance of their data being analyzed for research questions—and got paid. If requested, older participants received a short feedback about their test performance.

## 2.3. Measures of Cognitive Reserve

Cognitive reserve was measured by the testing-the-limits approach (Kliegl et al., 1989). For this purpose, a simple retest paradigm (Yang et al., 2006) including ten retests of two different measures was chosen.

*Digit Symbol Substitution Test (DSST; German Version; Aster, Neubauer, & Horn, 2006; Wechsler, 1997).* This test measures multiple factors such as motor response speed, cognitive speed and memory components (Joy et al., 2004). Participants were asked to relate as many digits as possible to a series of corresponding symbols and note the symbols in a given time period. The same test was administered ten times in a row with approximately one-minute breaks in between. After each test, participants were asked to put down their pencil until the next test started. The processing time per test was shortened to 90 sec instead of 120 sec as recommended by the manual. This way it was tried to eliminate any ceiling effects. The number of correctly written symbols per test served as outcome measure.

*Visual Search (Software program of the working group Neuropsychology, Max-Planck-Institute for Psychiatry, Munich).* Participants began and finished the test with a paradigm of parallel and serial search, which is not part of the results presented in this study. To estimate cognitive reserve a serial search paradigm with a constant set size of 15 stimuli and a target frequency of 70% was used. Subjects were required to detect a green triangle with *upward* vertex (target) among green triangles with *downward* vertex (distractors). Each trial began with a blue fixation cross presented on a black screen—screen size 15.4"—for 500 to 1500 ms (randomly assigned); then the randomly distributed stimuli were presented and remained on the screen until a response was recorded. Participants were instructed to respond as quickly and accurately as possible with the left (target-present) or right (target-absent) mouse key. Ten repeated measures consisting of 20 trials each were used. Before the actual task, participants performed 10 practice trials to assure compliance with the instructions. Distance to the screen was approximately 40 cm during all trials. Reaction times (median for target-present and target-absent trials) and number of mistakes (false positive and false negative reactions) were recorded. The outcome measure in the statistical analysis was the median reaction time of the target-present trials for the ten measurements.

**2.4. Measures of Cognitive Architecture**

*d2 Test (Brickenkamp, 2002).* This test measures selective visual attention. It consists of 14 lines, each with 47 items; in total, there are 658 items. These are composed of the letters *p* and *d* with one to four dashes, arranged either individually or in pairs above and below the letter. Participants were asked to scan across each line to identify and cross out all *d*s with two dashes as quickly and accurately as possible. The processing time per line was limited to 20 seconds. Concentration performance was calculated by the total number of correctly crossed out items minus the number of false ones (crossed-out *d*s, with less or more than 2 dashes, or *p*s).

*Auditory Digit Span (German Version; Härting, et al., 2000; Wechsler, 1987).* The digit span forward measures short-term memory, whereas the digit span backward measures working memory (Lezak, Howieson, Loring, Hannay, & Fischer, 2004). Subjects were asked to listen to a series of digits of increasing length (constant pace: 1 digit/s). Digit sequences forward included 3 to 8 digits, and digit sequences backward included 2 to 7 digits. Each length was presented twice with different digits. After the last digit was presented, participants had to repeat the numbers in the same (forward condition) or the reverse (backward condition) order. When a participant failed to accurately reproduce both digit sequences of a certain length, the task was ended. The number of correctly recalled sequences in the forward and backward condition was used as outcome measure.

*Matrices (German Version; Aster et al., 2006; Wechsler, 1997).* This subtest measures fluid intelligence and inductive reasoning in the visual domain. It includes 26 items of increasing difficulty. Subjects were asked to identify the structural principle of a series of geometric patterns and select one of the five given patterns to complete the series. The test ended if four items in a row or four out of five items were not answered correctly. Participants were instructed to take as much time per item as needed. In addition, they were told that they have more than enough time—about 20 minutes—to complete the test. There was one point for every correct answer with a maximal raw score of 26 points. Raw scores served as outcome measure for the analysis.

### 2.5. Other Measures

*NEO-Five-Factor-Inventory (NEO-FFI; German Version; Borkenau & Ostendorf, 2008; Costa & McCrae, 1989).* This questionnaire consists of 60 items to assess the five personality factors: Neuroticism, Extraversion, Openness to experience, Agreeableness and Conscientiousness. Thus, each factor is estimated by 12 items. Participants were asked to rate themselves according to their typical behaviors or reactions on a five-point Likert scale, ranging from ‘‘strongly disagree’’ to ‘‘strongly agree’’. A computer-administered version was applied.

*Montgomery-Asberg Depression Rating Scale (MADRS; German Version; Montgomery & Åsberg, 1979; Neumann & Schulte, 1989).* This external rating was based on a clinical interview (Iannuzzo, Jaeger, Goldberg, Kafantaris, & Sublette, 2006) moving from broadly phrased questions on depressive symptoms to more detailed ones which allow a precise rating of severity. The rater decides whether the rating for the ten items—each representing a depression symptom—lies on the defined scale steps (0, 2, 4, 6) or in between (1, 3, 5). The items of the MADR-S are: apparent sadness, reported sadness, inner tension, reduced sleep, reduced appetite, concentration difficulties, lassitude, inability to feel, pessimistic thoughts and suicidal thoughts. The rating should reflect the respondent's current status or that of the last few days. The raw score ranges from 0 to 60 points. Cut-offs recommended by the manual are: 0-12 points = healed, 13-21 points = mild depression, 22-28 points = moderate depression, > 28 points = severe depression.

*Beck Depression Inventory - Second Edition (BDI-II; German Version; Beck, Steer, & Brown, 1996; Hautzinger, Kühner, & Keller, 2006).* This questionnaire includes 21 items that represent essential depression symptoms according to DSM-IV (Saß, Wittchen, Zaudig, & Houben, 1996). Four statements per item are given, reflecting stages of severity from 0 (no depression) to 3 (severe depression). Participants were required to select the statement that characterized their conditions during the last two weeks. The raw score ranges from 0 to 63 points and can be interpreted as follows: 0-13 points = no or minimal depression, 14-19 points = mild depression, 20-28 points = moderate depression, 29-63 points = severe depression.

## 2.6. Statistical Analysis

*First analysis.* The data were analyzed with SPSS 17.0. Four missing values were estimated with the aid of regression analysis or mean substitution: One older participant did not complete the concentration test. His score was estimated via regression analysis. In addition, three older participants left out one item on the NEO-FFI scale Agreeableness. Their means on the remaining 11 items were multiplied by 12 to estimate raw scores for the complete scale. Afterwards, descriptive statistics of the young and the older sample were calculated. If available, norm values were added for cognitive tests and personality scales. One-tailed t-tests were computed to determine whether the young group outperformed the older group in cognitive architecture variables and initial level of cognitive reserve tests. Big Five differences between young and older adults were also examined by one-tailed t-tests. Based on prior research, it was expected that the older group shows lower Neuroticism, Extraversion and Openness scores, but higher Agreeableness and Conscientiousness scores, compared to the young group (McCrae, Martin, & Costa, 2005; Roberts, Walton, & Viechtbauer, 2006; Terracciano, McCrae, Brant, & Costa, 2005). Additionally, effect sizes and power estimates were calculated with the software G-Power 3.0. Subsequently, reliabilities for cognitive and personality tests were calculated.

*Latent Growth Curve models*. The main part of the statistical analysis consisted of Latent Growth Curve (LGC) models. Parameters were estimated via maximum likelihood method in Amos 17.0. In the unconditional LGC model, a model of within-individual growth, the performance of each individual at each measurement point is regressed on a true initial level of performance (intercept, all regression weights fixed at 1), a slope (improvement or estimate of cognitive reserve) and an error. In a next step, a conditional LGC model can be applied to examine the extent to which systematic inter-individual differences in growth can be accounted for by other variables. This is accomplished by regressing level and slope simultaneously on predictors that are considered to be important determinants of change. The principles of this method for analyzing change over time have been described in more detail elsewhere (Bollen & Curran, 2006; Byrne & Crombie, 2003; Meredith & Tisak, 1990). To begin with, a basic LGC model was conducted separately for each reserve measure (DSST vs. visual search) and each group (young vs. old). For these four models a freely estimated curve (first and last regression weight of the slope fixed at 0 and 1), a linear and a logarithmic trend were tested and compared by a $\chi^2$ - difference test. The freely estimated growth curve achieved the best fit and was chosen for further analysis (see Results section for detail). Then, both freely estimated growth curves—DSST and visual search—were integrated into one model for each group. This model yielded means and variances of the growth factors, and the covariances between them. Additionally, the standardized solution provided correlations between the growth factors. Means of the slope factors served as estimates of average cognitive reserve in both groups. The correlation between slope factors reflected the relationship between cognitive reserves in two different tasks. Furthermore, latent variances were compared by the $F_{max}$ -Test (Howell, 2007) to examine group differences in inter-individual variability of levels and slopes. Next, correlations were tested for significant group differences. After looking at these basic models, more complex conditional LGC models were conducted. The predictive power of cognitive architecture variables and the Big Five for levels and slopes in both groups was estimated. To control for unreliability of the cognitive predictors, parcels were computed: Scores of the digit span forward and backward served as indicators of memory performance; three parcels of matrices items served as indicators of fluid intelligence; and three parcels of concentration performance per line in the d2 Test served as indicators of attention. The three matrices parcels were generated by assigning item 1 to parcel 1, item 2 to parcel 2, item 3 to parcel 3, item 4 again to parcel 1, and so on. This way it was tried to ensure that the three parcels did not differ substantially in item difficulty. The d2 Tests consists of 14 lines with only three different patterns: line 4 is identical to line 1, line 5 is identical to line 2, line 6 is identical to line 3 and so on. The three d2 Test parcels were computed by aggregating the concentration performance score for all identical lines. After computing parcels, cognitive and personality variables were entered as predictors separately into the model to estimate their full effects. Next, one model with all predictors of the cognitive architecture (attention, memory, fluid intelligence) and a second model with all Big Five variables were computed to estimate unique effects of the predictors. A multiple-group comparison could not be conducted because of negative variance estimates in Amos 17.0. Therefore, results of young and older participants could not be compared directly. Finally, the variables gender, age, depression, and order of testing were entered into the model with cognitive predictors to control for their influence on the growth factors.

*Indication of model fit.* Chi-square and difference chi-square statistics will be reported. One important assumption for Structural Equation Modeling, using maximum likelihood estimation, is a multivariate normal distribution. Results of the Mardia Test in Amos showed a violation of this assumption. This means the $\chi^2$-test is too liberal. Therefore, a Bollen-Stine bootstrap with $N = 200$ samples was conducted to correct the p-value of the $\chi^2$-tests. Additionally, a relative fit index, the Root Mean Squared Error of Approximation (*RMSEA*), will be reported. As recommended by Hu and Bentler (1999), it should be less than .06 for $N > 250$ and less than .08 for $N < 250$. Other established fit indices—such as the Standardized Root Mean Square Residual (*SRMR*) or the Comparative Fit Index (*CFI*)—will not be reported because they cannot be applied to LGC models without restrictions (Wu, West, & Taylor, 2009).

# Chapter 3: Results

# 3. Results

## 3.1. Descriptive Statistics and Mean Comparisons

Descriptive statistics and mean comparisons for both age groups are presented in Table 1. Whereas the young group mainly consisted of students, who graduated from German secondary school (13 years of education), the majority of older participants had university degrees (18 years of education) or doctor's degrees (21 years of education). A mean comparison of depression severity could not be conducted because of two different depression measures for young and older adults. Ranges for both groups indicated none or mild depression symptoms for participants in both samples. Consistent with the assumptions, the young group outperformed the older group in all cognitive architecture variables and initial levels of both reserve tests. As expected, the young group scored significantly higher on Neuroticism and Extraversion than the older group. Contrary to the expectations, the young group did not score significantly higher on Openness or lower on Agreeableness and Conscientiousness, compared to the older group.

In Table 2, the ten repeated measures of the reserve tests for young and older adults are shown: Both groups improved with retest practice, which reflected cognitive reserve. Yet, as expected, the old group never achieved the average performance level of the young group, especially in the visual search task. This refers only to the group level. On the individual level, several older participants outperformed young participants, e. g. the best older participant correctly wrote down 72 symbols in the first DSST, whereas the worst result in the young group was 42 correct symbols. DSST within-group variability increased with repeated measures for both groups. On the contrary, variability in the visual search task rather decreased and the older adults showed more inter-individual differences than the young ones.

Table 1
*Descriptive statistics and mean comparisons for education, depression, cognitive and personality variables*

| | Younger group ($N$ = 140) | | | Older group ($N$ = 140) | | | | |
|---|---|---|---|---|---|---|---|---|
| Measure | *M* | *SD* | Range | *M* | *SD* | Range | *g* | *1-β* |
| Years of eduction | 13.13 | 0.77 | 13-18 | 17.58 | 2.00 | 13-21 | -2.93*** | > .99 |
| MADRS | 3.24 | 3.14 | 0-14 | | | | | |
| BDI-II | | | | 4.61 | 4.36 | 0-18 | | |
| DSST 1 | 67.01 | 9.63 | 42-99 | 47.28 | 9.36 | 26-72 | 2.08*** | > .99 |
| PR | 26.79 [a] | | | 42.88 [a] | | | | |
| Visual Search 1 | 1416.74 | 406.94 | 738-3050 | 2205.57 | 707.16 | 948-4648 | -1.37*** | > .99 |
| d2 Test | 201.68 | 37.46 | 127-294 | 146.07 | 32.04 | 77-248 | 1.60*** | > .99 |
| PR | 62.99 | | | 56.00 [b] | | | | |
| Digit Span | 16.71 | 3.24 | 9-24 | 14.05 | 2.83 | 9-22 | .87*** | > .99 |
| PR forward [c] | 60.54 | | | 57.20 | | | | |
| PR backward [c] | 56.97 | | | 54.12 | | | | |
| Matrices | 21.81 | 2.58 | 14-26 | 16.88 | 4.45 | 6-24 | 1.36*** | > .99 |
| PR | 66.20 | | | 80.71 | | | | |
| NE | 19.49 | 7.27 | 7-43 | 15.46 | 6.58 | 1-40 | .58*** | .99 |
| T-score | 48.09 | | | 42.64 | | | | |
| EX | 30.86 | 5.43 | 6-44 | 27.11 | 6.24 | 6-44 | .64*** | > .99 |
| T-score | 56.16 | | | 50.39 | | | | |
| OE | 32.59 | 6.26 | 15-46 | 32.39 | 4.29 | 21-43 | .04 | .02 |
| T-score | 54.74 | | | 54.28 | | | | |
| AG | 33.33 | 5.90 | 13-44 | 32.26 | 5.28 | 12-43 | .19 | – [d] |
| T-score | 55.70 | | | 53.49 | | | | |
| CO | 32.63 | 6.69 | 15-46 | 33.77 | 5.40 | 22-46 | -.19 | .22 |
| T-score | 50.07 | | | 51.81 | | | | |

Note. PR = percent rank; DSST = Digit Symbol Substitution Test; NE = Neuroticism; EX = Extraversion; OE = Openness to Experience; AG = Agreeableness; CO = Conscientiousness. Significance levels are * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.
[a] Percent ranks are based on a processing time per test of 120 sec, which was shortened to 90 sec in this study.
[b] Percent ranks for the d2 Test exist for a maximum age of 60. So the percent rank for the older group could only be computed for a subsample of $n$ = 13, who were 60 years old or younger.
[c] For some raw scores in some age categories no percent ranks are given. So percent ranks were computed for subsamples: $n$ = 135 (forward, older group), $n$ = 123 (backward, younger group), $n$ = 125 (backward, older group).
[d] Power was not calculated because effect is contrary to hypothesis.

Table 2
*Descriptive statistics for reserve measures*

| | Younger group ($N$ = 140) | | | Older group ($N$ = 140) | | |
|---|---|---|---|---|---|---|
| Measure | *M* | *SD* | Range | *M* | *SD* | Range |
| DSST 1 | 67.01 | 9.63 | 42-99 | 47.28 | 9.36 | 26-72 |
| DSST 2 | 73.52 | 10.47 | 49-117 | 53.50 | 10.88 | 32-90 |
| DSST 3 | 76.68 | 10.97 | 53-113 | 55.56 | 11.53 | 30-103 |
| DSST 4 | 78.91 | 10.97 | 53-108 | 57.69 | 11.59 | 34-112 |
| DSST 5 | 81.48 | 12.17 | 54-118 | 59.44 | 11.83 | 32-106 |
| DSST 6 | 83.03 | 12.24 | 53-118 | 60.25 | 11.97 | 37-102 |
| DSST 7 | 85.07 | 12.94 | 54-119 | 61.77 | 11.95 | 33-100 |
| DSST 8 | 86.66 | 13.70 | 54-124 | 62.38 | 11.90 | 35-100 |
| DSST 9 | 88.46 | 13.01 | 56-125 | 63.60 | 12.66 | 33-108 |
| DSST 10 | 89.34 | 13.67 | 59-125 | 63.74 | 12.22 | 37-102 |
| VS 1 | 1416.74 | 406.94 | 738-3050 | 2205.57 | 707.16 | 948-4648 |
| VS 2 | 1365.24 | 439.07 | 742-3070 | 2225.62 | 712.57 | 978-4998 |
| VS 3 | 1330.01 | 401.49 | 648-3047 | 2137.09 | 603.36 | 961-4078 |
| VS 4 | 1311.83 | 364.93 | 649-2314 | 2098.90 | 616.76 | 1045-4040 |
| VS 5 | 1289.89 | 385.91 | 669-2431 | 2106.12 | 659.15 | 993-4964 |
| VS 6 | 1254.13 | 389.11 | 636-2640 | 2050.19 | 609.19 | 1030-5711 |
| VS 7 | 1252.79 | 387.46 | 588-2637 | 2153.99 | 730.16 | 908-4926 |
| VS 8 | 1223.06 | 347.09 | 628-2453 | 2092.99 | 711.35 | 986-4084 |
| VS 9 | 1235.27 | 376.46 | 548-2515 | 2061.91 | 614.05 | 864-3738 |
| VS 10 | 1258.01 | 386.75 | 624-2456 | 2029.98 | 643.87 | 818-4583 |

Note. DSST = Digit Symbol Substitution Test; VS = visual search.

Figures 1 and 2 demonstrate the average learning curves for both groups in the DSST and the visual search task. Benefits of practice reduced for both groups, which is characteristic of most learning curves (Delaney, Reder, Staszewski, & Ritter, 1998). The young and the old group showed similar learning gradients in the DSST. On the contrary, in visual search, the older group's learning curve did not follow that of the young group. Apparently, the old group experienced a disruption during the seventh trial, before they improved again, whereas the young group slowed down during the last two trials.

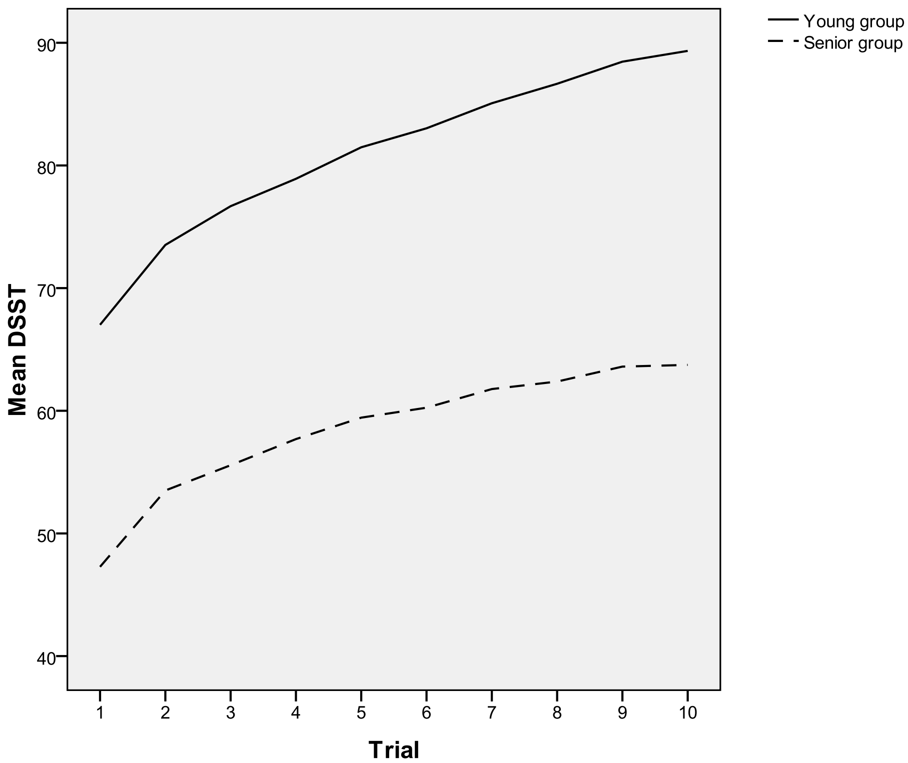


*Figure 1*. DSST Learning Curves. DSST = Digit Symbol Substitution Test.

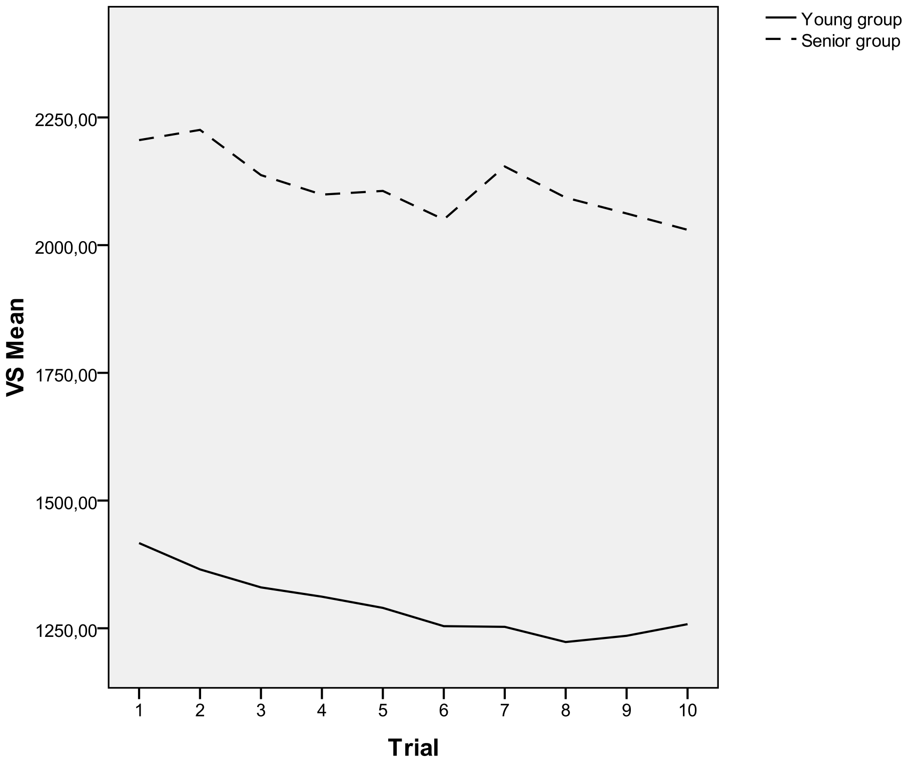


*Figure 2.* VS Learning Curves. VS = visual search.

### 3.2. Reliabilities

Table 3 illustrates the reliabilities of the administered tests. For the two reserve tests, the correlations between the first and the second measurement served as reliability estimates. Correlations between DSST 1 and 2 indicated good reliability. On the other hand, correlations between visual search task 1 and 2 were only moderate, suggesting instability of the test results. Retest reliability of both tests was higher for the older participants. For the other cognitive tests, construct reliability *H* (Hancock & Mueller, 2001) was calculated by the estimated standardized regression weights of the test parcels. Except for the digit span, all estimates reached the required value of .70 or higher. The lower construct reliability of the digit span is not surprising as two different constructs, short-term and working memory (Lezak et al., 2004), were integrated into one estimate of memory performance. The five personality scales of the NEO-FFI showed satisfactory internal consistency estimates with a Cronbachs $\alpha$ of .74 to .83 for the young group and .76 to .84 for the older group. Only the scale Openness to experience was less reliable for the older group ($\alpha$ = .48), with some corrected item-total correlations near zero.

Table 3
*Reliabilities for cognitive tests and personality scales*

| Reliability | Young | Old |
|---|---|---|
| $r_{1.2}$ DSST | .87 | .93 |
| $r_{1.2}$ VS | .42 | .64 |
| *H* d2 Test | .97 | .97 |
| *H* Digit Span | .61 | .61 |
| *H* Matrices | .70 | .87 |
| $\alpha$ NE | .83 | .84 |
| $\alpha$ EX | .74 | .81 |
| $\alpha$ OE | .76 | .48 |
| $\alpha$ AG | .79 | .76 [a] |
| $\alpha$ CO | .83 | .78 |

Note. [a] $n$ = 137.
DSST = Digit Symbol Substitution Test.
VS = visual search.
NE = Neuroticism; EX = Extraversion;
OE = Openness to Experience; AG = Agreeableness;
CO = Conscientiousness.

### 3.3. Modeling the Retest Trend

The starting point for growth curve modeling was fitting different curves to the repeated measures data of the DSST and the visual search for both groups. First, a freely estimated growth curve—first and last regression weight fixed at 0 and 1—was tested for all four models separately (DSST young, DSST old, visual search young, visual search old). Chi-square statistics (Table 4) demonstrate that these curves fitted well for the visual search task. However, there was no exact model fit for the DSST. In addition, the RMSEA for the DSST models was above .08. Modification indexes suggested correlated measurement errors in the DSST for both groups. By allowing for correlated measurement errors in the DSST, growth curve parameter estimates remained nearly the same. So the original assumptions were maintained for all models in order to simplify their interpretation. After fitting a freely estimated growth curve, a linear curve was tried, although the observed curves (Figures 1 and 2) did not show equal improvements among all measurement points. As expected, the linear curves resulted in a significantly poorer fit for the DSST, than the freely estimated ones (see again Table 4). Yet, the linear curves did not result in a significantly poorer fit for the visual search models. As the observed learning curves did not follow a straight line, a logarithmic trend was tested with regression weights fixed at $\log_{(10)} 1$ to $\log_{(10)} 10$. This induces a diminishing increment between time points with increasing values of time (Bollen & Curran, 2006). Compared to the freely estimated curve, this resulted in a significantly poorer fit for the DSST model of the young group. All other three logarithmic growth models did not show any significant decrease in model fit. Moreover, in line with the assumptions, the logarithmic growth curve provided a better match for the data of both tests and both groups than a linear trend. But because of the poor fit for the DSST model of the young group and the desire for consistent modeling of all four learning curves, the freely estimated solution was selected for all further analysis. There are at least two advantages for choosing this procedure: First, there is a great flexibility of the growth curve, ending up with an optimal shape (McArdle, 2006). And secondly, if the first and last loadings are set to 0 and 1, respectively, each estimated loading represents the cumulative proportion of total change that has occurred from the initial time to that specific time (Bollen & Curran, 2006).

Table 4
*Chi-square statistics for freely estimated, linear and logarithmic growth curves*

| Model | *df* | $\chi^2$ | *p** | RMSEA (90% CI) | $\chi^2_{diff}$ | *p*** |
|---|---|---|---|---|---|---|
| Young group | | | | | | |
| DSST | | | | | | |
| 1. Freely estimated | 51 | 144.21 | .01 | .12 (.09 - .14) | | |
| 2. Linear | 59 | 340.80 | .01 | .19 (.17 - .21) | | |
| Difference between Model 1 and 2 | | | | | 196.59 | <.001 |
| 3. Logarithmic (Log 10) | 59 | 178.26 | .01 | .12 (.10 - .14) | | |
| Difference between Model 1 and 3 | | | | | 34.05 | <.001 |
| Visual Search | | | | | | |
| 4. Freely estimated | 51 | 77.40 | .36 | .06 (.03 - .09) | | |
| 5. Linear | 59 | 89.21 | .31 | .06 (.03 - .09) | | |
| Difference between Model 4 and 5 | | | | | 11.81 | .16 |
| 6. Logarithmic (Log 10) | 59 | 78.87 | .50 | .05 (.01 -. 08) | | |
| Difference between Model 4 and 6 | | | | | 1.47 | .99 |
| Old group | | | | | | |
| DSST | | | | | | |
| 7. Freely estimated | 51 | 182.85 | .01 | .14 (.12 - .16) | | |
| 8. Linear | 59 | 558.66 | .01 | .25 (.23 - .27) | | |
| Difference between Model 7 and 8 | | | | | 375.81 | <.001 |
| 9. Logarithmic (Log 10) | 59 | 194.92 | .01 | .13 (.11 - .15) | | |
| Difference between Model 7 and 9 | | | | | 12.07 | .15 |
| Visual Search | | | | | | |
| 10. Freely estimated | 51 | 53.22 | .73 | .02 (< .01 - .06) | | |
| 11. Linear | 59 | 65.27 | .72 | .03 (< .01 - .06) | | |
| Difference between Model 10 and 11 | | | | | 12.05 | .15 |
| 12. Logarithmic (Log 10) | 59 | 63.60 | .75 | .02 (< .01 - .06) | | |
| Difference between Model 10 and 11 | | | | | 10.38 | .24 |

Note. DSST = Digit Symbol Substitution Test.
* Bollen-Stine bootstrap (*N* = 200)-corrected p-value; **p-value of the chi-square difference.

### 3.4. Unconditional Growth Curve Model

The freely estimated growth curves for the DSST and the visual search were integrated in one model (see Figure 3). The unstandardized solution of this model not only provided estimated means and variances for levels and slopes, but also made it possible to check for covariances between them. Correlations from the standardized solution, instead of covariances, will be presented below in order to simplify the interpretation.

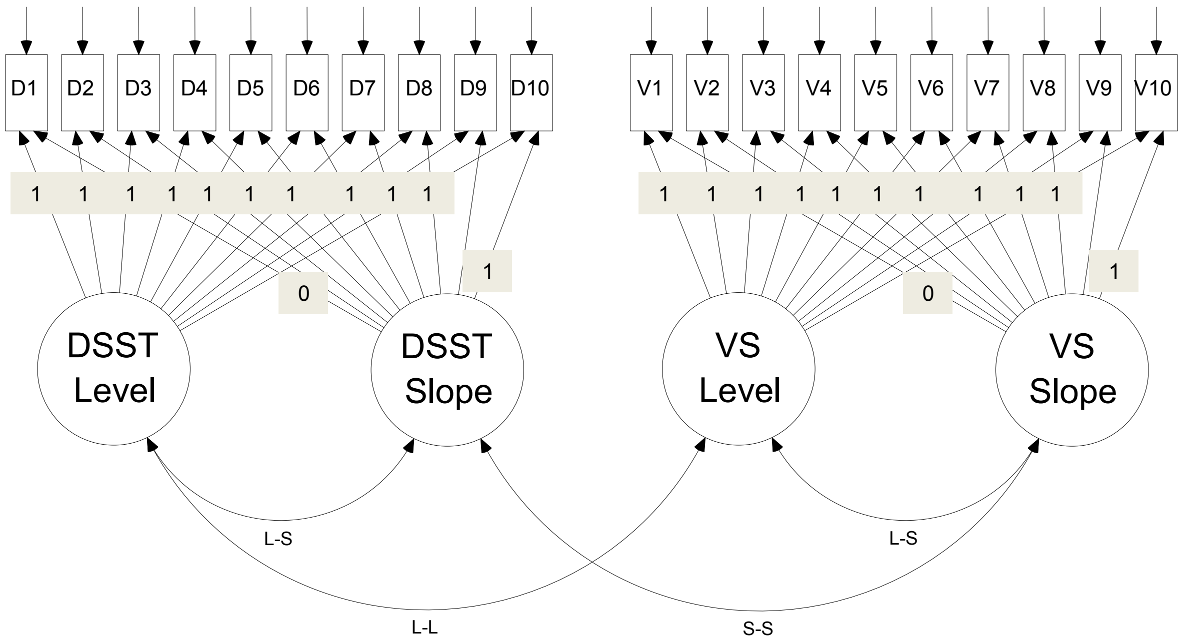


*Figure 3*. Unconditional growth model (corresponding to Table 6). Measurement errors are indicated by arrows. DSST = Digit Symbol Substitution Test; VS = visual search; D1 to D10 = ten retests of Digit Symbol Substitution Test; V1 to V10 = ten retests of visual search; numbers are fixed regression weights; L-S = level-slope; L-L = level-level; S-S = slope-slope.

Although an exact model fit was missing for young and older adults, the RMSEA suggested that the estimated growth model described the observed mean and covariance structure well (Table 5). A complete assessment not only considers the overall fit, but also examines the components of fit (Bollen & Curran, 2006). Firstly, the magnitude of the squared multiple correlations of the ten DSST and visual search practice trials were considered. Squared multiple correlations represent the variance in the observed variable, explained by the level and slope factors. For the DSST, the squared multiple correlations ranged from .83 to .90 (young) and .91 to .94 (old). This indicates that virtually all of the systematic DSST variance (see reliability estimates above) was explained by the growth factors. For visual search, the squared multiple correlations ranged from .53 to .58 (young) and .52 to .61 (old). In comparison to the DSST, more unexplained variance remained in the visual search model. Secondly, the presence of large and significant modification indexes was determined. As expected, correlated measurement errors for the DSST in both groups were again suggested. For the reasons explained above, correlated measurement errors were not integrated into the model. In summary, the results suggested an acceptable fit of the LGC model. Its growth curve parameter estimates are shown in Table 6.

Table 5
*Fit indices for growth curve models*

| Model | *df* | $\chi^2$ | *p** | RMSEA (90% CI) |
|---|---|---|---|---|
| Young group | | | | |
| Basic growth (Unconditional) | 200 | 332.12 | .03 | .07 (.06 - .08) |
| With predictors (Conditional) | | | | |
| Cognitive architecture | 365 | 527.06 | .07 | .06 (.05 - .07) |
| Big Five | 280 | 426.68 | .06 | .06 (.05 - .07) |
| Old group | | | | |
| Basic growth (Unconditional) | 200 | 329.63 | .01 | .07 (.06 - .08) |
| With predictors (Conditional) | | | | |
| Cognitive architecture | 365 | 529.46 | .05 | .06 (.05 - .07) |
| Big Five | 280 | 423.95 | .02 | .06 (.05 - .07) |

Note. * Bollen-Stine bootstrap ($N = 200$)-corrected p-value.

Table 6
*Growth curve parameter estimates for unconditional growth model*

| | Young | | Old | |
|---|---|---|---|---|
| Parameter | DSST | VS | DSST | VS |
| | Proportion of total growth | | | |
| Trial | | | | |
| 1 (fixed) | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.27 | 0.33 | 0.35 | 0.02 |
| 3 | 0.42 | 0.48 | 0.49 | 0.50 |
| 4 | 0.53 | 0.62 | 0.62 | 0.62 |
| 5 | 0.65 | 0.72 | 0.73 | 0.62 |
| 6 | 0.71 | 0.88 | 0.78 | 0.81 |
| 7 | 0.81 | 0.90 | 0.87 | 0.39 |
| 8 | 0.89 | 0.88 | 0.91 | 0.85 |
| 9 | 0.96 | 0.97 | 0.98 | 0.89 |
| 10 (fixed) | 1.00 | 1.00 | 1.00 | 1.00 |
| | Unconditional growth model | | | |
| Level | | | | |
| *M* | 67.23 | 1420.60 | 47.46 | 2219.31 |
| Variance | 86.67 | 96065.49 | 95.85 | 297406.50 |
| Slope | | | | |
| *M* | 22.03 | -187.41 | 16.42 | -180.85 |
| Variance | 89.56 | 37878.74 | 45.83 | 97188.91 |
| Error variance | 18.06 | 68622.15 | 9.33 | 194195.42 |
| L-S correlation | -.04 | -.43 | -.01 | -.55 |
| L-L correlation | -.25 | | -.45 | |
| S-S correlation | -.23 | | -.27 | |

Note. DSST = Digit Symbol Substitution Test; VS = visual search; L-S = level-slope; L-L = level-level; S-S = slope-slope.

The unstandardized regression weights for trials 2 to 8 represent the proportion of total growth that occurred up to each trial. Young and older adults showed a similar learning trend of reducing practice benefits in the DSST. The learning curve for the older participants was steeper: Whereas they had 73% of their total growth after half of the trials, the young group had 65% of their total growth at the same time point. The visual search curves deviated from the DSST curves, especially for the older group. The growth curve of the young group started similar to the DSST learning curves, but fell between the seventh and eighth trial, before it increased again. The curve of the older group followed a zigzag course with nearly no growth between the first and second trial, almost half of the growth between the second and third trial and a slowing between sixth and seventh trial before catching up again. Growth curves of both groups deviated slightly from the observed learning curves described above, as they represented the true estimated growth after accounting for measurement error.

To address the first research question about cognitive reserve of young and older adults, estimated means and variances for levels and slopes were examined. They closely mirrored the observed values (Table 2), which indicated good reliability of the change parameters (Piccinin & Rabbitt, 1999). The mean initial level of the DSST curve was 67.23 for the young group and 47.46 for the older group. This reflected the average number of correct symbols at the first time point. The mean slope was 22.03 for the young group and 16.42 for the older group. This represented the average increase in the number of correct symbols from the first to the last test. In the visual search task, the average initial level of young and older adults was 1.42 sec and 2.22 sec, respectively. The average reduction in reaction time from the first to the last task was 187 ms for the young group and 181 ms for the older group. Thus, while the young group had more cognitive reserve in the DSST, visual search reserve of young and older adults was quite similar. It is important to underline that these means characterize the group curve, but not necessarily the individual learning curves. The variances of levels and slopes for both groups (Table 6) were significant, suggesting inter-individual differences in both groups. The $F_{max}$-Test, conducted to compare variances of young and older adults, resulted in significant group differences, except for the DSST level variance ($F(139, 139) = 1.11$, $p = .28$). The young group showed more inter-individual differences in DSST slope than the older group, $F(139, 139) = 1.95$, $p < .001$, indicating greater variance in cognitive reserve in this test. On the contrary, the older group varied significantly more in their visual search levels, $F(139, 139) = 3.10$, $p < .001$, and visual search slopes, $F(139, 139) = 2.57$, $p < .001$.

To address the relationship between cognitive reserves in different tasks, correlations between latent factors were calculated (Table 6). The low level-slope correlation in the DSST speaks for the absence of a ceiling effect in both groups: Participants, who performed well in the first DSST, not necessarily improved less until the last DSST. By contrast there were moderate to strong correlations between level and slope in visual search for both groups: Very fast performers in the first visual search task, by trend, could not reduce their reaction times in the following trials as much as slowly starting participants. As expected, there existed a relationship between levels in both tests, especially for the older group: Older participants, who performed well in the first DSST, on average, performed also well in the first visual search task. However, the main interest of this study concerned the relationship of the slope factors. By tendency, subjects' learning in one test was associated with their learning in the other, but the correlation was low for young and old adults. There were no significant correlation differences between both groups (see Table 7).

Table 7
*Correlation group differences*

| *r* | Young | Old | *z* | *p* |
|---|---|---|---|---|
| Level-Slope DSST | -.04 | -.01 | 0.25 | .80 |
| Level-Slope VS | -.43 | -.55 | -1.31 | .19 |
| Level-Level | -.25 | -.45 | -1.90 | .06 |
| Slope-Slope | -.23 | -.27 | -0.35 | .73 |

Note. DSST = Digit Symbol Substitution Test; VS = visual search; all *p*-values two-tailed.

### 3.5. Conditional Growth Curve Models

As a next step, inter-individual differences in levels and slopes of both groups were regressed on different explanatory variables. First, it was explored if cognitive reserve in both groups can be predicted both fully and partially by cognitive architecture variables. Secondly, the predictive power of the Big Five variables was examined. The first conditional model with the cognitive predictor variables is presented in Figure 4.

Before estimating the unique effects, each predictor was entered separately into the model to estimate its full effect on levels and slopes. The standardized weights of levels and slopes regressed on each predictor variable are presented in Table 8. The proportion of explained variance in levels and slopes was obtained by squaring these values. As expected, attention (d2 Test) and memory (Digit Span) predicted DSST level for both groups: Attention accounted for 30% (young) and 36% (old) of the variance. Memory explained 10% (young) and 12% (old) of the variance. In the older group, 6% of the DSST level variance was explained by fluid intelligence (Matrices). Fluid intelligence did not significantly contribute to the prediction of DSST level in the young group and visual search level in both groups. The latter was explained by attention in the young group (14% explained variance), and attention and memory in the older group (18% and 14% explained variance).

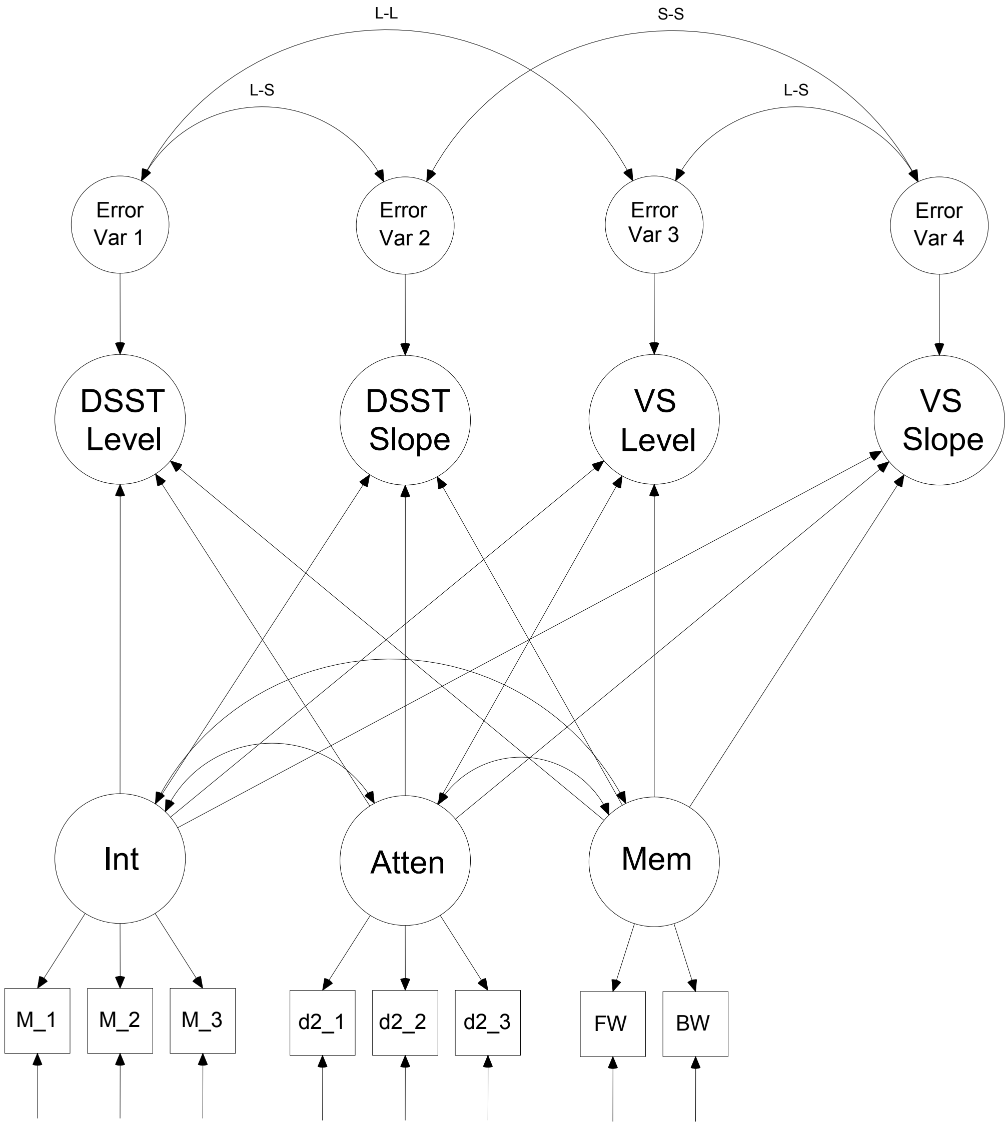


*Figure 4*. Conditional growth model with cognitive predictors[1] (corresponding to Table 9). The basic growth model for estimating levels and slopes of this model is shown in Figure 3. Measurement errors of the parcels are indicated by arrows. DSST = Digit Symbol Substitution Test; VS = visual search; Int = intelligence; Atten = attention; Mem = memory; M_1, 2, 3 = Matrices parcel 1, 2, 3; d2_1, 2, 3 = d2 Test parcel 1, 2, 3; FW = Digit Span forward; BW = Digit Span backward; L-S = level-slope; L-L = level-level; S-S = slope-slope.

[1] It would have been an alternative modeling approach to draw a directed arrow from level to slope instead of error correlations and predict the adjusted slope. It was decided to report the conventional model here. In the base-free measure of change model, attention predicts the adjusted visual search slope in the older group. In this model, the effect of attention on improvement (slope) is independent of any prior performance (Voelkle, 2007).

The direction of these effects was as expected: Good performance in one cognitive test was associated with good performance in other cognitive tests. On the contrary, slopes in both tests were not predicted by cognitive architecture variables with one exception: DSST slope of the older group was explained by memory (6%), intelligence (6%) and attention (5%). Apart from that, there were no significant effects on slope factors. DSST and visual search learning of the young group and visual search learning of the older group were independent from basic cognitive abilities.

Next, the predictive power of the five personality factors, with levels and slopes serving again as criterion, was examined. Only two significant effects were observed (Table 8). First, Agreeableness predicted DSST level in the young group (7% explained variance). Secondly, Extraversion explained 15% of the visual search slope variance in the older group; higher extraversion was related to a speeding up over the ten repeated measures. All other effects of Big Five variables on levels and slopes were marginal.

Table 8
*Standardized regression coefficients for level and slope on cognitive and personality predictors*

| | Young | | | | Old | | | |
|---|---|---|---|---|---|---|---|---|
| | DSST | | VS | | DSST | | VS | |
| Predictor | Level | Slope | Level | Slope | Level | Slope | Level | Slope |
| Matrices | .18 | .12 | -.11 | -.23 | .24** | .24* | -.18 | .01 |
| d2 Test | .55*** | .07 | -.37*** | -.15 | .60*** | .22* | -.43*** | -.08 |
| Digit Span | .32** | .16 | -.05 | -.27 | .34** | .25* | -.37** | .27 |
| NE | -.01 | .06 | -.06 | -.08 | -.01 | .14 | .02 | .15 |
| EX | -.02 | -.12 | .04 | -.02 | -.01 | -.12 | .08 | -.39* |
| OE | .06 | .01 | -.04 | .04 | .01 | .02 | .05 | -.22 |
| AG | .27*** | -.01 | .09 | -.06 | -.09 | -.03 | .01 | -.01 |
| CO | .08 | .07 | -.03 | .08 | .08 | -.05 | .01 | -.04 |

Note. DSST = Digit Symbol Substitution Test; VS = visual search; NE = Neuroticism; EX = Extraversion; OE = Openness to Experience; AG = Agreeableness; CO = Conscientiousness. * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.

After the analysis of full effects, the three correlated cognitive predictors were entered simultaneously into the model (see Figure 4). Then, the five correlated personality predictors were entered simultaneously into a second model. These two conditional models fitted better than the unconditional growth model (Table 5): There was an exact model fit for the young group and a marginally significant p-value for the old group. When comparing the results of the first conditional model with cognitive predictors (Table 9) to that of the unconditional growth model (Table 6), unstandardized parameter estimates changed: Level and slope variances decreased, compared to the unconditional growth model estimates. The difference between the conditional and unconditional variances indicated the proportion of variance explained by the predictors. As expected, this difference was larger for level than for slope variances in both groups. In the standardized solution of the conditional model, level-slope correlations were slightly larger than that from the unconditional model, but interpretation remained the same: a clear ceiling effect for both groups in the visual search task. The relationship between levels almost disappeared when controlling for linear effects of the predictors, especially in the young group. On the contrary, the rather small correlations between slopes did not diminish severely, which indicated a relationship that was not solely based on the variance shared with cognitive architecture variables. When comparing the full effects (Table 8) with the unique effects (Table 9), levels in the model with all cognitive predictors entered simultaneously were almost exclusively predicted by attention. The effects of memory and intelligence were no longer significant. Thus, their full effects were based on variance shared with attention. Together, the three cognitive predictors explained 34% (young) and 37% (old) of the DSST level variance, and 14% (young) and 24% (old) of the visual search level variance. Compared to the full effects, unique effects on slopes were mainly reduced, because of overlapping predictor variances. The significant effects on slopes disappeared. In summary, the cognitive variables predicted 3% (young) and 10% (old) of the DSST slope variance and 10% (young) and 9% (old) of the visual search slope variance. Standardized regression weights indicated that, on average, memory accounted for most of this explained variance, but these effects did not reach the significance level.

Table 9
*Growth curve parameter estimates for model with cognitive predictors*

| | | Young | | Old | |
|---|---|---|---|---|---|
| Parameter | | DSST | VS | DSST | VS |
| | | Model with predictors | | | |
| Level | | | | | |
| | Intercept | 67.22 | 1418.45 | 47.46 | 2214.99 |
| | Variance | 57.46 | 81387.42 | 59.39 | 227791.58 |
| Slope | | | | | |
| | Intercept | 22.03 | -186.96 | 16.41 | -185.91 |
| | Variance | 86.56 | 33868.64 | 41.29 | 80209.36 |
| Error variance | | 18.06 | 68658.91 | 9.33 | 194857.34 |
| L-S correlation | | -.13 | -.53 | -.14 | -.62 |
| L-L correlation | | -.001 | | -.23 | |
| S-S correlation | | -.15 | | -.22 | |
| | | Unique effects | | | |
| Matrices | | | | | |
| | Level | .01 | -.08 | .04 | -.01 |
| | Slope | .07 | -.13 | .16 | .001 |
| d2 Test | | | | | |
| | Level | .50*** | -.37*** | .54*** | -.34*** |
| | Slope | .03 | -.08 | .11 | -.18 |
| Digit Span | | | | | |
| | Level | .20 | .07 | .14 | -.24 |
| | Slope | .12 | -.21 | .15 | .32 |

Note. DSST = Digit Symbol Substitution Test; VS = visual search; L-S = level-slope; L-L = level-level; S-S = slope-slope. * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.

Results of the conditional model with personality predictors are presented in Table 10. Its estimates resembled those from the unconditional growth model (Table 6). Contrary to the model with cognitive predictors, the conditional variances of the growth factors in this model were almost identical to the unconditional variances in the basic model. This means that little variance was explained by the personality predictors. For the same reason, correlations between latent factors were hardly influenced by integrating the personality predictors into the model. Similarly to the full effects, most unique effects were close to zero. The effect of Agreeableness on DSST level (young) and Extraversion on visual search slope (old) remained significant. This resulted in an explained variance of 9% for DSST level in the young group and 16% for visual search slope in the older group. All other squared multiple correlations of levels and slopes ranged from 1% to 3%. Except for the two effects described above, performance and learning in the DSST and visual search task were independent from personality factors.

Table 10
*Growth curve parameter estimates for model with personality predictors*

| | | Young | | Old | |
|---|---|---|---|---|---|
| Parameter | | DSST | VS | DSST | VS |
| | | Model with predictors | | | |
| Level | | | | | |
| | Intercept | 67.22 | 1420.13 | 47.46 | 2203.19 |
| | Variance | 79.16 | 94250.51 | 94.22 | 280604.51 |
| Slope | | | | | |
| | Intercept | 22.04 | -184.97 | 16.42 | -169.94 |
| | Variance | 87.52 | 35239.88 | 44.44 | 73582.87 |
| Error variance | | 18.06 | 68665.49 | 9.33 | 194568.63 |
| L-S correlation | | -.05 | -.42 | -.01 | -.56 |
| L-L correlation | | -.28 | | -.45 | |
| S-S correlation | | -.23 | | -.33 | |
| | | Unique effects | | | |
| NE | | | | | |
| | Level | .01 | -.05 | -.04 | .07 |
| | Slope | .04 | -.09 | .12 | .07 |
| EX | | | | | |
| | Level | -.07 | .01 | -.01 | .10 |
| | Slope | -.11 | -.05 | -.10 | -.34* |
| OE | | | | | |
| | Level | .07 | -.05 | .03 | .02 |
| | Slope | .01 | .05 | .07 | -.12 |
| AG | | | | | |
| | Level | .29*** | .09 | -.12 | .01 |
| | Slope | -.001 | -.08 | .04 | .11 |
| CO | | | | | |
| | Level | .03 | -.06 | .09 | .01 |
| | Slope | .09 | .08 | -.01 | .02 |

Note. DSST = Digit Symbol Substitution Test; VS = visual search; L-S = level-slope; L-L = level-level; S-S = slope-slope. * = $p \leq .05$; ** = $p \leq .01$; *** = $p \leq .001$.

### 3.6. Effects of Control Variables

To control for their influences the following variables were entered separately into the model shown in Figure 4: gender (men coded 1 and women coded 2), depression, order of testing (DSST first coded 1, visual search first coded 2) and age. Gender predicted DSST level ($\beta$ = .32***) in the young group. The positive parameter estimate indicated young women outperformed young men in the first test. This must be interpreted with caution because of unequal proportion of men and women in the sample. There were no significant gender effects in the older group.

Severity of depression did not show significant effects on the growth factors in both groups. However, depression variance in both samples was limited. Testing order did not influence the growth factors in the young group, but it affected visual search level ($\beta$ = -.25**) in the older group. By tendency, old participants, who worked on visual search first, performed better in the first task (lower reaction times), than old participants, who dealt with the visual search paradigm at the end. There was also an effect of testing order on visual search slope in the older group, but not in the assumed direction ($\beta$ = .36*). Older participants, who worked on the visual search task first, presumably started closer to their personal ceiling, so they could not reduce their reaction times as much as those older participants, who took part in visual search at the end of the test session and started more slowly.

Age predicted DSST level ($\beta$ = -.17*) in the young group; younger participants scored higher in the first DSST. Moreover, age predicted DSST level ($\beta$ = -.19**) and DSST slope ($\beta$ = -.19*) in the older group; younger participants in the old group scored higher in the first DSST and improved more over the ten repeated measures.

In a second step, this model with age as predictor was analyzed for the complete data set of 280 participants, instead of separating both groups. Age significantly predicted DSST level ($\beta$ = -.43***) and visual search level ($\beta$ = .51***), but only DSST slope ($\beta$ = -.20**). This confirms the result of similar cognitive reserve in visual search for young and older adults.

# Chapter 4: Discussion

# 4. Discussion

## 4.1. Summary of Results

First, age group differences were examined. As expected, the young group outperformed the older group in all cognitive architecture variables and in initial performances in the DSST and visual search. Slope factors demonstrated that both groups improved with retest practice, reflecting cognitive reserve. However, in line with the assumptions, the older group did not reach the average performance level of the young group throughout all DSST and visual search retest trials. Additionally, age group differences in Big Five domain scores were observed. As expected, the young group showed significantly higher Neuroticism and Extraversion than the older group. Contrary to the expectations, the young group did neither score significantly higher on Openness, nor significantly lower on Agreeableness and Conscientiousness, compared to the older group. The first research question concerned age group differences in rate of cognitive reserve. The young group showed higher cognitive reserve in the DSST, reflected by an average performance gain of 22 symbols as opposed to 16 symbols of the older group. Nevertheless, DSST retest improvement of the older group was substantial, consisting of more than one standard deviation of the first test. In visual search, both age groups reduced their reaction times to almost the same extent (187 msec of the young group and 181 msec of the older group), indicating comparable cognitive reserve. To add to these descriptive results, age was entered as predictor into the cognitive architecture model for all 280 participants. In this model, age significantly predicted initial performances and DSST improvement, but not visual search improvement, supporting the descriptive findings.

To address the second research question, correlations between initial performances and between improvement rates (i.e., cognitive reserves) were analyzed.

In accordance with the expectations, initial performances in the DSST and in visual search were related, although this relationship was stronger for the older group. However, improvement rates were rather weakly correlated in both groups. The correlation between DSST and visual search improvement was not strongly affected by integrating the cognitive predictor variables into the models, but the correlation between initial performances diminished severely for both age groups. This finding indicates that, whereas the relation between initial task performances can be mainly attributed to cognitive architecture variance, the association between improvement rates, although not strong in nature, reflects something different than mere cognitive status.

To explore the third research question, inter-individual differences in initial performances and improvement rates (i.e., cognitive reserves) were predicted by cognitive architecture (attention, memory, fluid reasoning) and personality (Big Five) variables. Unexpectedly, not all cognitive architecture variables significantly contributed to prediction of initial performances. In both age groups, attention was the most important predictor of initial DSST performance, followed by memory. Fluid reasoning contributed only in the older group to prediction of initial DSST performance. Attention was also the most important cognitive predictor of initial visual search performance. Additionally, memory contributed to prediction of initial visual search performance of the older group. When integrating all cognitive predictors simultaneously into the model, only attention remained a significant predictor of initial DSST and visual search performance in both age groups. Contrary to initial performances, improvement rates were rather independent from cognitive architecture variables, except for DSST improvement of the older group. The latter was marginally explained by attention, memory and fluid reasoning, but only when considering full effects of the predictors. For the second model with the Big Five as predictor variables, two significant effects were found. Agreeableness predicted initial DSST performance of the young group and Extraversion predicted visual search improvement of the older group. To summarize, except for the Extraversion effect, variance of improvement rates (i.e., cognitive reserves) was hardly explained by the predictor variables. In visual search, improvement displayed moderate to strong correlations with initial performance, suggesting a ceiling effect in this task.

### 4.2. Age Group Differences in Initial Performances and Improvement Rates

The young group outperformed the older group in the first DSST by approximately 20 symbols. Even within each age group, age was a significant predictor of initial DSST performance. These results confirm the age-sensitive nature of the DSST that has been demonstrated many times (see Hoyer et al., 2004 for a meta-analysis). Additionally, the young group outperformed the older group in the first visual search task. This is consistent with research showing that older adults have difficulties in demanding visual search tasks with high target-distractor similarity and a large number of distractors (Hommel et al., 2004; Scialfa et al., 1998). Moreover, the older group showed reduced reserve in the DSST, but similar reserve in visual search, compared to the young group. The first result is in accordance with earlier findings, suggesting a tendency of younger adults to benefit more from practice in substitution coding tasks than older adults (see Piccinin & Rabbitt, 1999 for an overview). However, some studies reported age-independent improvement rates for substitution coding (Erber, 1976; Piccinin & Rabbitt, 1999). This indicates that age effects in these tasks are not as strong for learning as for initial performance, which is supported by the results of the present study. The finding of similar cognitive reserve in visual search for young and older adults is in line with recent research, conducted by Scialfa and colleagues. For example, Anandam and Scialfa (1999) reported equal learning rates for young and older adults during seven practice trials in a feature search task, where the target, similar to the present study, differed from the distractors only by its orientation. On the contrary, findings in semantic category visual search suggested reduced practice benefits for older adults, which often led to the conclusion that they have automatization problems, compared to their younger counterparts (Fisk et al., 1990; Fisk & Rogers, 1991; Rogers & Fisk, 1991; Rogers et al., 1994). The results of the present study support the notion by Scialfa and colleagues that older adults can improve their visual search performance to the same extent as young adults (Anandam & Scialfa, 1999; Ho & Scialfa, 2002; Scialfa et al., 2000).

Regarding the concept of cognitive reserve, results of this study only partly support the assumption of reduced cognitive reserve in the aging mind, as has been proposed by studies conducted in the memory domain (Kliegl et al., 1990; Singer et al., 2003). Instead, findings for the visual search task provide evidence for comparable training benefits of young and older adults. Thus, age differences in rate of cognitive reserve seem to depend on the cognitive abilities, trained in a specific task. This conclusion is in accordance with studies on dual-task performance (Bherer et al., 2006; 2008) that discovered even greater cognitive reserve for older adults. In addition to the cognitive ability trained, Bherer et al. (2006) emphasized the importance of the specific training protocol. They hypothesized that providing feedback and/or instruction conditions to assist older adults in developing effective strategies might be important for them to develop greater cognitive skills over the course of training. By using a simple retest paradigm, the present study demonstrated age-independent improvement in visual search, suggesting that, sometimes, older adults do not need more than a minimal intervention to benefit from training to the same extent as young adults. This is consistent with the study by Baltes et al. (1989) showing that self-guided retest and tutor-guided training can produce an equal amount of improvement. The role of the specific training protocol for cognitive reserve in old age remains an issue for future research.

### 4.3. Relationships between Initial Performances and Improvement Rates

The DSST and the visual search task of this study share important aspects, for example speed conditions and visual attention demands. Gilmore et al. (2004) demonstrated that visual search is an important aspect of DSST performance. Thus, initial performances of both tasks were expected to be related. The results of the present study were consistent with this assumption. However, the correlation between initial performances was stronger for the older group: By tendency, older participants, who scored higher in the first DSST, were faster in the first visual search task. Selective visual attention was the most important predictor of initial performances. Presumably, older participants, who had a stronger decline in selective visual attention, were limited in their initial DSST and visual search performance. The stronger association of initial performances in the older group also provides support for a general cognitive slowing hypothesis (Salthouse, 1996), indicating that older participants, who have an age-related decline of psychomotor speed (DSST), also perform more slowly on simple reaction time measures (visual search).

The main interest of the present study concerned the relationship of improvement rates (i.e., cognitive reserves). DSST improvement correlated rather weakly with visual search improvement for both age groups. Although the DSST and the visual search task of the present study share important performance components (see above), they also differ in several aspects, e.g., regarding the motor response required. A study by Stephens (2006) demonstrated that the correlation between writing time per item and DSST performance was (negatively) larger for older adults, compared to young adults, suggesting that the age-related slowing on Digit Symbol tests might be due to a psychomotor deficit. Whereas writing speed is a crucial component of DSST performance, which could have limited learning gains in the older group, in visual search, the motor response required is less complex (press left or right mouse key). Besides different motor requirements, the DSST, contrary to visual search, provides feedback about improvement of test performance: If participants keep their last test result in mind, they are able to try to outperform it in the next test. On the contrary, in visual search, they can only estimate if their performance is getting faster and/ or more accurate. The opportunity to obtain feedback could directly or indirectly (e.g., via achievement motivation) affect improvement.

In general, mechanisms for self-guided retest learning are poorly understood. Salthouse, Schroeder and Ferrer (2004) assumed that retest learning could be driven by memorizing specific items, familiarity with the testing situation, reduced anxiety, and procedural learning. Yang et al. (2009) investigated DSST retest learning in the absence of item-specific effects with older adults. Parallel versions of the DSST were developed by assigning each digit a different symbol for each new version. The results showed substantial retest learning, comparable to retest learning without controlling for item-specific effects. The authors concluded that DSST retest learning may be primarily driven by item-general effects through familiarity with the testing situation or skill-based procedural learning, like better eye – hand coordination and visual scanning. It seems possible that these mechanisms also operate to some extent in visual search retest learning. This explains that at least some association of improvement rates in both tests was observed.

However, Stern (2009) hypothesized that a more general “cognitive reserve network” would be elicited by tasks of different cognitive demands. By focusing on the neural level, Stern et al. (2008) examined whether a common neural mechanism for cognitive reserve could be demonstrated in brain imaging data acquired during the performance of two tasks with differing cognitive processing demands. Young and older subjects were scanned with fMRI while performing delayed item response tasks that used either letters or shapes. For the young adults, evidence for a latent brain pattern, activated for both tasks, was observed that might represent a general cognitive reserve on the neural level. The present study explored this topic on the functional level. The rather weak correlation of improvement rates in the DSST and in visual search for both age groups does not support the assumption of a general cognitive reserve, but rather speaks for task-specific learning. This finding is consistent with research, reporting that training improvement is rather specific to the trained task, instead of broad learning gains across abilities (Ball et al., 2002; Dahlin et al., 2008). However, results for the visual search paradigm of the present study must be interpreted with caution (see section Limitations). The reduction of reaction times in the course of practice, reflecting cognitive reserve, was rather small, compared to inter-individual variance of visual search performance in both age groups. More neuro-imaging and behavioral intervention studies are needed that address the question whether cognitive reserve is task-specific or activated for learning in different tasks.

## 4.4. Cognitive Architecture Variables as Predictors

### *4.4.1. Predicting Initial Performance*

Initial DSST performance of both age groups was mainly predicted by the d2 Test, used to measure selective visual attention. This is not surprising, because the DSST is often characterized as a measure of cognitive and motor speed (Laux & Lane; 1985; Salthouse, 1992; Stephens, 2006) and the d2 Test probably requires both.

However, besides information processing speed and psychomotor requirements, many studies emphasized the role of memory for a successful DSST performance (Joy et al., 2004; Piccinin & Rabbitt, 1999). This is consistent with the finding that memory was a predictor of initial DSST performance in both groups. Piccinin and Rabbitt (1999) argued that fluid reasoning abilities help in dealing with a substitution coding task as a novel situation, which requires understanding task instructions and quickly developing optimal performance strategies. Therefore, it was expected that fluid reasoning contributes to prediction of initial DSST performance. This was only the case for the older group. Maybe, the young group easily understood the instructions, because they were used to participate in new, challenging cognitive tasks in the context of their studies. However, fluid intelligence might have helped older adults to deal with this novel situation, and, thus, predicted at least some variance of their initial DSST performance. Contrary to the present study, in the study by Piccinin and Rabbitt (1999), fluid reasoning contributed substantially to prediction of initial coding performance. However, they conducted the fluid reasoning test under time-limited, speeded conditions, as opposed to power conditions, which could have contributed to the rather strong correlation between fluid reasoning and substitution coding in their analysis. Consistent with Piccinin and Rabbitt (1999), full effects of the cognitive predictor variables in the present study indicate that the DSST is not a pure measure of cognitive speed.

Initial visual search performance was also mainly predicted by the d2 Test. This could be expected, because both tests, although they differ in administration mode (paper and pencil vs. computer), measure selective visual attention. Fluid reasoning did not contribute to prediction in both age groups. One could speculate that participants understood task instructions and developed optimal performance strategies for visual search, while working on practice trials before the actual retest paradigm started. Memory was only a predictor of initial visual search performance in the older group, indicating that lower memory demands of visual search, compared to the DSST, were only challenging for the older adults. When integrating all cognitive predictor variables simultaneously into the model, only attention remained a significant predictor of initial DSST and visual search performance in both age groups. From this result it can be seen, that the unique effects of memory and fluid reasoning on initial performances, partialed for attention, were not substantial.

### *4.4.2. Predicting Cognitive Reserve*

The main interest of this study concerned the prediction of cognitive reserve. As expected, different predictor-criterion relations emerged for task improvement (i.e., cognitive reserve), compared to initial performance. Contrary to initial performance, cognitive reserve was rather independent from cognitive architecture variables. This finding contradicts research, demonstrating that higher mental status is related to greater cognitive reserve in memory training (Hill et al., 1989; Yesavage et al., 1990). However, these studies compared individuals with and without cognitive deficits, whereas the present study concentrated on a normal range of cognitive functioning. The finding that cognitive reserve is rather independent from basic cognitive abilities also contradicts previous findings with young and old adults, showing an increase of predictive importance of cognitive abilities from the broad fluid-ability domain, mainly perceptual speed measures, in the course of memory training (Kliegl et al., 1990; Singer et al., 2003; Verhaeghen & Marcoen, 1996). Verhaeghen and Marcoen (1996) proposed an “amplification model”, in which cognitive variables positively associated with pretest performance and negatively associated with age are positively related to cognitive reserve. Thus, they tried to explain a magnification of age differences observed after extensive memory training. However, cognitive reserve in the memory domain has been demonstrated to be severely compromised in old age (Baltes & Kliegl, 1992). Therefore, it seems reasonable that mental status, indicated by basic cognitive functions, is a powerful source of individual differences in reserve. In the present study, the older adults showed considerable retest improvement in the DSST and even similar improvement in visual search, compared to the young adults. If cognitive reserve in old age varies, depending on the cognitive ability trained, predictors of reserve may also differ across cognitive abilities.

Concerning prediction of reserve in visual search, one can only consider findings on semantic category search. In the study by Rogers et al. (1994), initial category search performance of young and older adults was predicted by general ability and semantic memory, whereas improvement after extensive practice was predicted by perceptual speed. In the present study, initial visual search performance of both age groups was mainly predicted by attention, instead of fluid intelligence or memory. Visual search improvement was rather independent from cognitive architecture variables. These results demonstrate that the visual search paradigm, used in the present study, and semantic category search tasks require different abilities for initial performance and probably also differ in learning mechanisms. This is in accordance with many researchers who have emphasized that different mechanisms are involved in learning of semantic category visual search and classic visual search (Anandam & Scialfa, 1999; Czerwinski et al., 1992; Fisk & Rogers, 1991; Hertzog et al., 1996).

Retest learning of substitution coding has already been examined before. Results of the present study are consistent with Yang et al. (2006), who demonstrated that DSST retest learning of older adults over a 3-week period was rather independent from level of cognitive functioning, measured by a test battery of intellectual abilities. On the contrary, in the study by Piccinin and Rabbitt (1999), retest improvement in a substitution coding task was predicted by memory variables. However, operational overlap between the coding task and memory for code, which was assessed after the last trial, accounted for substantially larger amounts of individual variability in improvement than the other memory measures. In fact, if one takes a closer look at their models, all predictor variables together (age, cross out speed, fluid reasoning, vocabulary and memory) accounted for 2-3% of slope (improvement rate) variance, which is consistent with the results of the present study. Only in the model including memory for code, all covariates together accounted for 12-13% of slope variance. Thus, it remains questionable if memory, assessed without such strong operational overlap, is an important predictor of cognitive reserve in substitution coding. An important difference between Piccinin and Rabbitt (1999) and the present study concerns the substitution coding task examined. Piccinin and Rabbitt (1999) used the Alphabet coding task as criterion measure. Compared to their task, the DSST has fewer pairs and greater distinctiveness of stimuli. Therefore, Piccinin and Rabbitt (1999) hypothesized that learning in the DSST occurs over the first 90 sec trial. This is consistent with the finding of the present study that memory is a predictor of initial DSST performance, but not of improvement over the ten retest trials. Thus, it remains an open question for future research whether memory does not predict substitution coding learning in general or DSST learning in particular.

Interestingly, predictor-criterion relations for initial performance and cognitive reserve in both tasks were quite similar for young and old adults. This is consistent with studies on memory performance (Verhaeghen & Marcoen, 1996), semantic category visual search (Rogers et al., 1994) and pure memory search (Hertzog et al., 1996). However, equivalent ability-performance relationships of young and old adults not always reflect identical learning mechanisms (Rogers et al., 1994). The cognitive architecture variables, used in the present study, did not predict cognitive reserve of young and older adults. If other predictor variables would have been included (e.g., associative memory or psychomotor tests), maybe differential predictor-criterion relations for young and old adults would have been observed. Therefore, one must be cautious to assume the same learning mechanisms underlying DSST and visual search performance of young and older adults.

## 4.5. Big Five Variables as Predictors

### *4.5.1. Predicting Initial Performance*

Agreeableness predicted initial DSST performance of the young group. This finding cannot easily be reconciled with the existing literature on personality and cognition that mainly reports correlations for Extraversion, Neuroticism and Openness with intellectual abilities (see Ackerman & Heggestad, 1997 for a meta-analysis). One could possibly explain the relationship of Agreeableness to initial DSST performance by an effect of task compliance. Perhaps, from the beginning of DSST retesting, agreeable participants in the young group showed more compliance with the task instructions, resulting in better initial performances. This is consistent with the result that Agreeableness predicted initial DSST performance of the young group, but not improvement in the course of practice. No other Big Five dimension was related to initial task performances of young and old adults. At first sight, this contradicts meta-analytic findings that Openness to Experience shows substantial positive correlations with intellectual abilities (Ackerman & Heggestad, 1997). However, in studies differentiating between measures of fluid and crystallized intelligence, Openness was substantially correlated with crystallized intelligence or knowledge, but rather weakly associated with measures of fluid intelligence, especially when these measures involved numbers or abstract figures instead of meaningful visual stimuli (Ackerman & Rolfhus, 1999; Ashton et al., 2000). Thus, the factor seems to be rather independent from the ability to process information of an abstract nature, which is required by the DSST and the visual search task in the present study.

*4.5.2. Predicting Cognitive Reserve*

Cognitive reserve in the DSST and in visual search was also independent from Big Five dimensions, with the exception of Extraversion, which predicted visual search improvement of the older group. The study by Newton et al. (1992) has already demonstrated a positive relationship of Extraversion to the average speed in visual search trials. The authors assumed that introverts required more information before making a response, because they were more accurate. However, their sample consisted of young adults. In the present study, Extraversion only predicted visual search improvement of the older adults. Many visual search studies observed a more careful, accurate search style for older adults, indicated by problems with certain task conditions like target-absent trials or a large number of distractors (Ho & Scialfa, 2002; Hommel et al., 2004; Scialfa et al., 1998). Strayer and Kramer (1994) examined the hypothesis that such a conservative response bias in older persons interferes with the acquisition and mastery of cognitive skill in a memory search task. Differences between younger and older subjects were modulated by speed-accuracy instruction. When younger and older subjects performed at equivalent levels of accuracy, age-related differences in learning rates were reduced. This suggests that a more conservative response bias of older adults is partially responsible for observed age-related differences in memory search learning, which probably also applies to visual search. If visual search performance of older adults is generally slowed by a careful search style, higher Extraversion may be even more important for them than for young adults to accomplish a speed-accuracy trade-off. Thus, it seems plausible that higher Extraversion was related to a speeding up in visual search performance of older adults over the ten retest trials.

Contrary to earlier research on personality and cognitive training, no effects of Openness or Neuroticism were found. In the study by Gratzinger et al. (1990), older adults, who scored higher on an Openness subscale (fantasy), were more able to benefit from one condition of a memory training intervention. However, their task consisted of meaningful visual stimuli (associating faces with names) instead of abstract figures. So it seems more likely for such tasks to be related to Openness (Ashton et al., 2000). Besides this, it should be mentioned that the scale Openness to experience did not show satisfactory internal consistency for the older group in the present study. Thus, interpretability of results seems to be restricted for this group. In the study by Yesavage (1989), older adults with high scores for Neuroticism showed the least improvement in memory training. This is in accordance with findings by Bäckman et al. (1996), indicating negative effects of depression symptoms on benefit from free recall training. However, these studies used rather complex memory training interventions. In the study by Yang et al. (2009), DSST retest learning of older adults was independent from anxiety, supporting the findings of the present study. Yet, in the present study, participants were screened for depressive symptoms. Accordingly, Neuroticism scores were below average, compared to a representative population sample. So it cannot be ruled out that, without this range restriction, Neuroticism would have a negative effect on cognitive reserve in substitution coding and visual search.

### 4.6. Limitations

First, it should be mentioned that, besides the general limitations of a cross-sectional design, the two age groups differed in years of education and proportion of men and women. Thus, it seems possible that group differences are not solely due to age effects.

Additionally, the present study investigated retest learning in the course of one test session. More retest sessions or an intensive training intervention could have resulted in other age effects on cognitive reserve. As mentioned above, the role of the specific training protocol remains a question for future research.

Findings of the present study suggest that cognitive reserve of young and older adults is quite independent from basic cognitive abilities, at least for substitution coding and visual search tasks. However, young participants were university students and the majority of older adults had university degrees. Fluid reasoning variance of the young group was restricted. This limits generalizability of results. Including individuals from lower educational levels might result in an effect of cognitive architecture variables.

In addition to that, cognitive abilities were each assessed by one test. For example, the memory components examined (short-term and working memory) might not reflect the important memory aspect of DSST learning. Alternatively, an associative memory measure could have been included, as has been recommended by Piccinin and Rabbitt (1999). Moreover, other ability measures like psychomotor tests could have been predictive of cognitive reserve, as has been proposed by Ackerman (1988) for complex skill acquisition. Furthermore, no tests of verbal abilities were included, which have been related to cognitive reserve in other studies (e.g., Yesavage et al., 1988). However, compared to other retest learning studies (e.g., with the Alphabet Coding task, Piccinin & Rabbitt, 1999), verbal ability should not be crucial for the cognitive reserve measures of the present study.

Another limitation of this study concerns the comparison of young and older adults. A multiple-group comparison could not be conducted because of negative variance estimates in Amos 17.0. Thus, group differences were not directly tested. To add to the descriptive statistics of both age groups, the cognitive architecture model with age as additional predictor was analyzed for the complete data set of 280 participants. In this model, age predicted initial performances and (to a lesser extent) DSST reserve, but not visual search reserve. However, these findings must be interpreted with caution, because no adults with the age of 31 years to 56 years were examined, which could have influenced the relationships between age and the criterion variables.

One last word of caution regards the specific visual search paradigm of the present study. Analysis of retest reliability suggested instability of test results in both age groups. As mentioned above, the reduction of reaction times in the course of practice was rather small, compared to inter-individual variance of visual search performance in both age groups. Moreover, average learning curves for both groups deviated from power functions that usually describe all learning curves (Delaney et al., 1998). These findings suggest that the specific visual search paradigm, used in the present study, is suboptimal for examining cognitive reserve. This refers not to visual search tasks in general, which has been demonstrated by prior research (Anandam & Scialfa, 1999; Ho & Scialfa, 2002).

### 4.7. Conclusions

The present study addressed important questions regarding the concept of cognitive reserve. First, the findings indicate that cognitive reserve of older adults is not generally reduced, compared to young adults, but varies, depending on the cognitive abilities trained. Secondly, the weak association between improvement rates in substitution coding and visual search rather speaks for task-specific learning than for a general cognitive reserve, activated for learning in different tasks. Finally, the results of the present study suggest that cognitive reserve of well-educated, healthy adults is independent from basic cognitive abilities (attention, memory, fluid reasoning) and, with one exception, also from personality dimensions (Big Five). Differential predictor-criterion relations for task improvement, compared to initial task performance, indicate that cognitive reserve reflects something different than mere cognitive status. However, what constitutes cognitive reserve in young and old age? This question should be further explored by future research. Maybe it is a combination of background variables (education, age), general abilities, task-specific factors and motivational aspects (Langbaum et al., 2009).

Moreover, the present study used Latent Growth Curve (LGC) models to examine improvement (i.e., cognitive reserve) in the course of retest practice. Until now, this well-known technique for analyzing change over time has rarely been applied to short cognitive training programs (Piccinin & Rabbitt, 1999). Byrne and Crombie (2003) described several important advantages of LGC modeling over more traditional approaches to the measurement of change. To name one obvious advantage, it integrates within-person (unconditional) and between-persons (conditional) models of individual growth within the same structural framework. Thus, the wider application of LGC modeling for investigating the concept of cognitive reserve is suggested.

In the last years, the focus of cognitive training studies with older adults has shifted to analyzing stability of learning gain and transfer to other cognitive abilities or everyday functioning. Although this research is important for proving the usefulness of cognitive training interventions in old age, more studies are needed that aid in defining a comprehensive theoretical framework for cognitive reserve. The present study took a first step towards this goal.

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## Ausbildung

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| 09/92 – 06/01 | Städtisches Luisengymnasium München<br>Leistungskurse: Englisch, Sozialkunde/Geschichte; Abiturnote: 1,3 |

## Berufstätigkeit

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## Weiterbildung

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## Vorträge

Zusammenhang von kognitiver Reserve mit kognitiver Architektur und Persönlichkeitsfaktoren. 10. Arbeitstagung der Fachgruppe Differentielle Psychologie, Persönlichkeitspsychologie und Psychologische Diagnostik vom 27. bis 30. September 2009 in Landau (Emmert, M., Bühner, M., Ziegler, M., Zihl, J., & Münzel, K.)

## Preise und Auszeichnungen

| | |
|---|---|
| 07/08 | Abschluss des Psychologiestudiums als eine der fünf Besten des Frühjahrstermins 2008 |
| 07/06 | Als Jahrgangsbeste im Fach Methodenlehre und Evaluation mit einem Preis für herausragende Leistungen ausgezeichnet |

München, 19. Juli 2010 gez. Maria Emmert