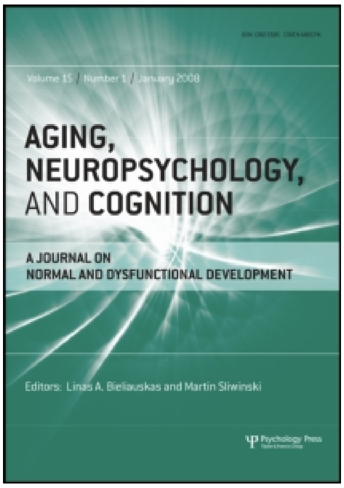


Aging, Neuropsychology, and Cognition
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713657683

Adult Age Differences in Inhibitory Processes and their Predictive Validity for Fluid Intelligence

Michael Witthöft [a]; Nicolas Sander [b]; Heinz-Martin Süß [c]; Werner W. Wittmann [d]
[a] Johannes Gutenberg-University, Mainz, Germany [b] Federal Employment Agency, Nürnberg, Germany [c] Otto-von-Guericke-University, Magdeburg, Germany [d] University of Mannheim, Mannheim, Germany

First Published:March2009

To cite this Article Witthöft, Michael, Sander, Nicolas, Süß, Heinz-Martin and Wittmann, Werner W.(2009)'Adult Age Differences in Inhibitory Processes and their Predictive Validity for Fluid Intelligence',Aging, Neuropsychology, and Cognition,16:2,133 — 163

To link to this Article: DOI: 10.1080/13825580802348554

URL: http://dx.doi.org/10.1080/13825580802348554

Aging, Neuropsychology, and Cognition, 16: 133–163, 2009
http://www.psypress.com/anc
ISSN: 1382-5585/05 print; 1744-4128 online
DOI: 10.1080/13825580802348554

Psychology Press
Taylor & Francis Group

Adult Age Differences in Inhibitory Processes and their Predictive Validity for Fluid Intelligence

MICHAEL WITTHÖFT[1], NICOLAS SANDER[2], HEINZ-MARTIN SÜß[3] AND WERNER W. WITTMANN[4]

[1]Johannes Gutenberg-University, Mainz, Germany, [2]Federal Employment Agency, Nürnberg, Germany, [3]Otto-von-Guericke-University, Magdeburg, Germany, and [4]University of Mannheim, Mannheim, Germany

ABSTRACT

According to the inhibition-deficit hypothesis age differences in working memory capacity and fluid intelligence have been attributed to a decline in inhibitory efficiency. Conceptualizing inhibition as multifaceted, 88 participants (49 younger and 39 elderly) completed two versions of the negative priming paradigm (identification and localization), and two variants of the directed forgetting paradigm (listwise and itemwise). Two tasks of the Wechsler Intelligence Test with high loadings on general fluid intelligence (Gf) served as validation criteria. Results revealed task-specific and speed-independent inhibitory deficits in the elderly (lower negative priming in both paradigms; more intrusions in the directed forgetting tasks), as well as higher levels of repetition priming. Significant correlations between measures of inhibition and the Wechsler scores were found in both age groups. Results support the view of multiple inhibitory-like capabilities that play a central role in the decline of higher-order cognitive functions in old age.

Keywords: Cognitive aging; Inhibition; Working memory; Negative priming; Directed forgetting; Modified Sternberg task.

INTRODUCTION

Over the last decades, there has been growing interest in a particular function of the human mind, namely the ability to block, ignore or deactivate irrelevant or no longer relevant information in order to maximize the cognitive resources available for the ongoing processing of currently relevant

Address correspondence to: Dr Michael Witthöft, Department of Clinical Psychology and Psychotherapy, Johannes Gutenberg-University, D-55099 Mainz, Germany. E-mail: witthoef@uni-mainz.de

information (e.g., Bjork, 1989; Dempster, 1992; Dempster & Corkill, 1999; Hasher & Zacks, 1988). In cognitive psychology, especially this latter aspect of preventing information from entering working memory or to remove no longer relevant information from the focus of attention has been rediscovered as an explanatory construct for age differences in higher order cognitive functions (e.g., Connelly, Hasher, & Zacks, 1991; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). In addition to the ability to keep elements activated in working memory or more precisely in the focus of attention according to Cowan's model (Cowan, 1995, 1999), abilities preventing distracting information from entering and removing no-longer relevant contents from parts of working memory have been considered as crucial for goal directed thinking and reasoning. As an example, Engle, Tuholski, Laughlin, and Conway (1999) attribute the empirically well-established distinction between short-term memory (STM) and working memory (WMC) theoretically to the demand of *controlled attention*, which is inherent only in WMC tasks. According to the authors, controlled attention particularly comes into effect in situations characterized by high interference and the presence of distracting stimuli.

Two different perspectives have been guiding the research on inhibitory processes: The experimental perspective has primarily focused on task characteristics, mechanisms in the sense of explanatory accounts (e.g., inhibition vs. episodic trace retrieval in case of the negative priming phenomenon; e.g., May, Kane, & Hasher, 1995; Neill, 1997), and group differences (e.g., older vs. younger adults; individuals with high vs. low working memory span, and differences between normal and clinical groups). In contrast, the differential perspective (e.g., Friedman & Miyake, 2004; Friedman et al., 2008; Miyake et al., 2000) subsumed inhibition under the concept of executive functions aiming at the examination of the communality between diverse inhibitory processes (e.g., stop-signal, negative priming), and their predictive validity with regard to higher order cognitive abilities (e.g., traditional intelligence tasks).

Theories of Cognitive Aging

The decline of *fluid* abilities (Gf) in older age has become a well-documented finding and different explanations have been proposed (e.g., decline in central resources, such as working memory capacity, speed of information processing, and controlled attention or inhibition). From these explicative candidates especially, two theoretical approaches have gained wide prominence, namely the processing-speed (e.g., Cerella, 1991; Salthouse, 1996) and the inhibition-deficit hypothesis (Hasher & Zacks, 1988; Hasher et al., 1999).

Processing-Speed Theories

According to Salthouse (1996), age differences in various cognitive tasks are attributable to differences in the speed with which single information processing steps are executed. In line with the processing-speed theory, mental speed has been found to account for 83–97% of age-related variance in measures of working memory (Salthouse, 1996). Therefore, proponents of this approach claim that after controlling for general mental slowing, only little or no incremental decrement in performance measures remain substantial and that therefore the slowing hypothesis represents the most parsimonious explicative approach to account for cognitive aging effects (e.g., Salthouse & Meinz, 1995). While strong confirming evidence regarding this position is derived from meta-analyses (Verhaeghen & Cerella, 2002), many single studies question this position with respect to its generalizability by demonstrating over-additive age decrements in certain task conditions reflecting executive abilities, i.e., task switching (Kray & Lindenberger, 2000), stop-signal performance (Christ, White, Mandernach, & Keys, 2001), and directed forgetting (Oberauer, 2001; Zacks, Radvansky, & Hasher, 1996). Some of these studies have strengthened another explicative account in aging research, namely the inhibition-deficit hypothesis that we will outline next.

Inhibition-Deficit Hypothesis

Numerous studies in the area of cognitive aging and life span research have documented an age-related decline in the efficiency of diverse inhibitory control processes (e.g., Kane, Hasher, Stoltzfus, Zacks, & Conelly, 1994; Persad, Abeles, Zacks, & Denburg, 2002). One line of evidence in favor of the inhibition hypothesis concerns the finding that task manipulations that reduce the amount of proactive interference are effective in reducing age differences in classical working memory tasks (e.g., reading span; Bowles & Salthouse, 2003; Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999). Another line of evidence comes from studies that directly compared different age groups on tasks performance in inhibitory paradigms. For example, Christ et al. (2001) found disproportionate age differences between younger and older adults in a stop-signal paradigm – a finding that could be replicated by Bedard et al. (2002). Numerous studies could document an age-related decline in the ability to suppress distracting stimuli in the negative priming paradigm (e.g., Kane et al., 1994; McDowd & Oseas-Kreger, 1991; Verhaeghen & DeMeersman, 1998). Moreover, the ability to intentionally forget no more relevant information has been found impaired in older adults (Oberauer, 2001; Zacks et al., 1996). Another study by Viskontas, Morrison, Holyoak, Hummel, and Knowlton (2004) suggests, that the ability to control interference is crucial in order to perform well in reasoning tasks of medium to high relational complexity and that a decline in inhibitory efficiency is able to explain age-related declines in reasoning ability.

Different experimental paradigms have been developed to focus on diverse aspects of inhibition (for a taxonomy and a detailed overview over types of inhibition see Nigg, 2000). Besides the 'global' inhibition hypothesis, recent articles have contributed to a differentiated and more fine-grained view of single inhibitory processes that seem to decline with chronological age. For example, Oberauer (2001) shows that elderly people have marked problems with the deactivation of elements in the activated part of long-term memory, whereas the ability to remove elements from the core component of working memory (i.e., the region of direct access according to Oberauer, 2002, 2005a, 2005b) seems immune to the aging process. Furthermore, it has been shown that there is no age-related deficit in the ability to access elements in working memory efficiently in the domain of mental arithmetic (Oberauer, Wendland, & Kliegl, 2003). Therefore, it seems likely that only some inhibitory abilities are prone to chronological aging effects, whereas others remain intact (Kramer, Humphrey, Larish, Logan, & Strayer, 1994) – a pattern of results that turns into question the view of a unitary or global construct of inhibition.

Measures of Inhibitory Control Processes

Especially two experimental paradigms, namely negative priming and directed forgetting, have gained wide popularity among researchers into aging and experimental psychology. According to a theoretical framework of executive functions, Miyake et al. (2000) propose reactive and intentional inhibitory processes. In this sense, negative priming refers more to reactive components, whereas the directed forgetting paradigm represents more cognitive intentional parts of the inhibition construct. We will briefly portray these two inhibitory paradigms that we used in this study.

The Negative-Priming (NP) Paradigm

In this paradigm pairs of trials (prime and probe trials) consisting of target and distractor elements are being presented. Typically three types of prime-probe relations occur: trials with no systematic relation between prime and probe display (control condition; CO), trials in which the ignored stimulus in the prime trial becomes the target stimulus in the probe trial (ignored repetition condition; IR), and trials in which the prime target stimulus is repeated in the probe display (attended repetition condition; AR). The term 'negative priming' refers to the slowing of responses to target stimuli in the IR compared to the CO condition. Experimental manipulations of the NP paradigm have demonstrated the robustness of the effect across content domains, perceptual modalities, presentation, and response modes (see Fox, 1995; May et al., 1995 and Tipper, 2001 for reviews). However, still no consensus exists about the underlying mechanisms of the NP phenomenon like episodic retrieval or distractor inhibition (e.g., Neill, 1997; Schmuck & Bloem, 1998; Tipper, 2001), just to name the two most prominent accounts (for a recently proposed theoretical account see Rothermund, Wentura, & De Houwer, 2005).

As outlined above, numerous studies reported an age-related lack or at least reduction of the NP effect (e.g., Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane et al., 1994; McDowd & Filion, 1995). With respect to the identity NP effect, two meta-analyses exist so far: The first (Verhaeghen & DeMeersman, 1998) found reliable NP effects in both young and old adults, whereas the younger adults showed larger NP effects. Contrary to this first meta-analysis, which at least partly supported the inhibitory deficit hypothesis (Hasher & Zacks, 1988), different single studies (e.g., Grand & Dagenbach, 2000; Schooler, Neumann, Caplan, & Roberts, 1997; Simone & McCormick, 1999) and a recent meta-analysis by Gamboz, Russo, and Fox (2002) reported equivalent identity NP in young and elderly adults.

Although most of the studies with the NP paradigm focus on the difference between the CO and the IR condition (i.e., the negative priming effect) the task contains another interesting condition – the attended repetition condition (AR). Contrasting the AR condition with the CO yields effects of stimulus repetition (i.e., repetition priming effects; RP). Different cognitive aging studies that assessed not only NP but also RP effects found equal to larger amounts of RP in elderly participants (Kramer & Strayer, 2001; identity negative priming; McDowd & Filion, 1995; location negative priming). Although RP has often been interpreted as an index of activation effects, Meiran (1996) proposed that immediate RP effects (in contrast to long-term RP) contain substantial amounts of residual activation and that the amount of immediate RP mirrors the ability to decrease this residual activation. In accordance with his activation dumping hypothesis Meiran (1996) found that smaller repetition priming effects in a lexical decision task were associated with better performance in measures of reading comprehension. We therefore suggest that immediate (i.e., prime-probe) repetition priming effects in the NP paradigm reflect processes of activation dumping with small scores indicating efficient deactivation of no longer relevant stimuli and larger values signaling poorer deactivation of residual activity of the former stimulus.

The Directed-Forgetting (DF) Paradigm

In contrast to the NP paradigm, which is classified as a rather fundamental and unintentional form of inhibitory control, the DF paradigm (Bjork, 1989) is considered to represent a more cognitive demand on inhibitory control processes (Nigg, 2000). In this paradigm, participants are presented single words or word lists and an instruction telling which of the words should be remembered and which should be forgotten (for reviews see MacLeod, 1998; Sheard & MacLeod, 2005). Several studies with varying directed forgetting methodologies (listwise vs. itemwise presentation, cueing mode, free recall or recognition as variations in the response mode) have reported age-related declines in the ability to forget or deactivate previously memorized words (Andrés, Van der Linden, & Parmentier, 2004; Dulaney, Marks, & Link, 2004; Oberauer, 2001; Zacks et al., 1996). Given the higher complexity of the DF compared to the NP paradigm, at least two inhibitory processes have been postulated to be involved in successful task performance, namely stopping of rehearsal of to-forget words after forget-cue presentation and the inhibition of forget-item retrieval during recognition or recall (Zacks et al., 1996, p. 144). Comparing the number of aging studies that used either the NP or the DF paradigm, reveals that the latter has been used more rarely and contrary to the NP paradigm no meta analysis has been conducted on aging and DF so far. However, recent data have demonstrated age equivalent performance under certain task conditions (Gamboz & Russo, 2002). This started again a debate on age differences versus age equivalence, analogous to the NP effect.

Predictive Validity of Inhibitory Paradigms

The question of predictive validity of inhibitory processes represent a comparatively neglected area in inhibition and aging research (Dempster & Corkill, 1999). Exceptions represent the work of Salthouse and Meinz (1995), Kramer et al. (1994), and Miyake et al. (2000). Salthouse and Meinz could demonstrate that Stroop interference effects account for small but significant proportions of variance in a reading span task. However, generalization of results is limited by the operationalization of inhibition by only a Stroop like task. In a cognitive aging study with an identity NP task and a measure of working memory capacity, Grant and Dagenbach (2000) found no mediating effect of NP on age-related decreases in working memory capacity. Additionally, Koshino, Boese, and Ferraro (2000) reported consistent medium sized correlations only with regard to the positive (repetition) priming effect with a digit span and a mental rotation task in a sample of young adults. In this study no consistent pattern of predictive validity was found for the NP effect. To our knowledge, there is no study that has so far explicitly assessed the predictive validity of directed forgetting tasks in a cognitive aging context.

Aims and Hypotheses of the Present Study

The present study was designed to mainly address three questions: Firstly, we will broadly examine the inhibition-deficit hypotheses of cognitive aging (Hasher & Zacks, 1988) by analyzing differences across age groups based on heterogeneous operationalizations of the inhibition concept. Accordingly, two versions of the modified Sternberg task, a specific form of the DF paradigm (Oberauer, 2001, 2005a, 2005b) served as an intentional inhibition task. Two variants of the NP paradigm (identification and localization; Conway, 1999) were used to focus on basic, reactive and unintentional inhibitory processes. Besides the differences between both paradigms, active inhibition is considered at least as one of the dominating processes inherent in the two task families. According to the inhibition-deficit hypothesis we expected diminished NP and enhanced RP effects for the elderly participants in the identification and localization task, and stronger intrusion effects for no longer relevant items in the two DF tasks (listwise and itemwise) compared to the younger participants. Secondly, we evaluate the question of common variance of the two inhibitory paradigms. Since both paradigms assess inhibitory processes we expect significant proportions of shared variance between the four single tasks. Thirdly, the mostly neglected issue of predictive validity will be addressed for a sub-sample of the younger and older adults by providing correlational analyses of inhibitory functions with external criteria such as general mental speed and general fluid intelligence (Gf). We hypothesize that inhibitory processes as measured by the two paradigms NP and DF should be (a) relatively independent of mental speed and (b) incrementally predictive of Gf after statistically controlling for mental speed. To our knowledge this is the first aging study that combines two of the most prominent inhibitory paradigms (DF and NP) and simultaneously addresses the question of predictive validity of these measures.

METHODS

Participants

Forty-nine younger adults (28 females and 21 males; *M* age = 24.4 years; *SD* = 3.6; range = 19–33 years) and 39 elderly adults (25 females and 14 males; *M* age = 71.1 years, *SD* = 5.8; range = 61–84 years) participated in the study. The elderly participants responded to an article in a local newspaper in which they were offered an individual feedback after their performance and the participation in an ‘information session’ on cognitive aging. Inclusion criteria for the elderly participants were age equal or above 60 years and the absence of severe neurological diseases and color blindness (assessed through self-reports of participants). The younger adults were represented by students of the universities of Mannheim and Heidelberg and received credit point equivalents for their participation. The young adults reported more years of formal education than the elderly (younger: *M* = 16.2 years; *SD* = 3.0; elderly: *M* = 13.0 years; *SD* = 3.5; $t(86) = 4.6$, $p < .01$; $d = 0.98$). In spite of the significant difference in the length of formal education, the elderly can be considered as well educated, documented below by higher values in a measure of verbal intelligence (MWT-B) compared to the younger participants. Self-reports concerning the subjective state of physical ($t(86) = 1.0$, $p = .34$) and mental ($t(86) = 0.8$, $p = .43$) health did not differ significantly between younger and older adults. Self-reports on stress and frustration after the experiment did not differ significantly between age groups either (stress level after task completion: $t(86) = 1.4$, $p = .16$; frustration level: $t(86) = 1.6$; $p = .10$). The paper–pencil-based intelligence measures (MWT-B and HAWIE-R) were collected in a second testing session approximately 1 week after the first testing session. At this second testing session, 37 of the 39 elderly participants and 32 of the 49 younger participants could be recruited again. Therefore, correlation results between measures of inhibition and intelligence refer to a reduced sample. Because the dropout in the younger sample appears quite substantial, we tested for performance differences between people that participated in both compared to only the first testing session. No significant performance differences were found in the inhibition (NP and DF) and the mental speed tasks. We therefore consider a systematic dropout as unlikely.

Experimental Measures

Negative Priming (NP)

Two variants of the NP paradigm, a localization and an identification task, were used. Both tasks closely follow the operationalization of Conway (1999). After the completion of 40 practice trials participants worked through 120 randomized pairs of prime and probe trials comprising the following three experimental conditions: 40 trials with no systematic relation between prime and probe display (control condition), 40 trials in which the ignored stimulus in the prime trial became the target stimulus in the probe trial (ignored repetition condition; negative priming), and 40 trials in which the prime target stimulus was repeated in the probe display (attended repetition condition; repetition priming[1]). A shorter interstimulus interval (ISI) of 500 ms between two related trials (prime and probe) and a longer ISI of 2000 ms between a probe and a prime trial was chosen to maximize the negative priming effect (Fox, 1995).

The Localization Task

In this task, four equal signs (two above the center and two below the center) arranged in a trapezoid shape appeared on the computer screen indicating the four possible locations at which target and distractor stimuli could appear. The keys S, C, M, and L of a standard computer keyboard were chosen for ergonomic reasons as the corresponding response set was mirroring the shape of the screen locations. The letter ‘O’ was introduced as the target stimulus to which participants should respond to as fast as possible

[1]In many studies the terms *positive priming* and *repetition priming* are used interchangeably. In order to avoid misunderstandings we will refer to repetition priming as the experimental condition in which the same target stimulus is repeated in the prime and probe display and consequently the same answer is required two times in a row (attended repetition condition). In contrast the term *positive priming* will just indicate the direction of the difference score that means facilitation of responses compared to the baseline condition.

by pressing the corresponding key. Contrary, the letter ‘X’ was designated as distractor which people were told to ignore. The stimulus size for O and X was about 2 cm in height and 2.5 cm in width.

The Identification Task

In the identification task pairs of letters (each letter was 4.5 cm in height and 2.5–3.5 cm in width) appeared in the middle of the computer screen next to each other with a distance of 1 cm. The target letter was printed in green and the distractor letter in red color. The keyboard keys S, C, M, and L were chosen as the response set for ergonomic reasons. These were labeled with the target letters B, K, L, and S.

Directed Forgetting (DF)

The operationalization of the DF tasks followed closely the methods proposed by Zacks et al. (1996) and Oberauer (2001). Accordingly, two versions were constructed one with a listwise presentation and a listwise cueing procedure and the other with an itemwise presentation and a word-by-word cueing method.

DF Listwise Version (Modified Sternberg Task)

In the listwise version two word lists appeared simultaneously in two columns on the left and the right side of the computer screen. Each list consisted of a column of 1 to 4 words (each word 2 cm in height and varying width). The words were chosen from a pool of 400 common German nouns with high usage frequency (Hasselhorn, Jaspers &, Hernando, 1990). The word length was restricted to 7 letters. Beneath each list either a red or a green square appeared as a cue. The presentation duration of each word list depended on the list length, i.e., the number of words. The presentation duration was one second per word, i.e., a display consisting of a two-word and a four-word list lasted for 6 s. After the offset of the two lists and a pause of 500 ms, either a red or a green square appeared for 500 ms in the middle of the screen, indicating which list should be remembered. The participants were instructed to ‘forget’ the other list immediately. After a pause of 500 ms a single word appeared as a cue in the middle of the screen belonging to either the to-be-remembered (TBR), or to the to-be-forgotten (TBF) or to neither of both lists. People were instructed to respond to words from the TBR list by pressing the ‘Yes’ key and to TBF or new words by pressing a key labeled with ‘No’. The task consisted of 20 practice trials and 80 test trials. If problems in the understanding of the task became obvious after the practice trials, the experimenter restarted the program to give the participant the chance to work again through the practice trials. The 80 pseudo randomized test trials (same sequence for all participants) comprised three experimental conditions: within 40 trials a word from the list that should be remembered was presented requiring a yes-response (TBR condition); within 20 trials a word from the forget list was presented (TBF condition) requiring a no-response, and within the 20 remaining trials completely new words were presented (true negative condition; TN). The latter condition required a no-response. After each 10 pairs of trials, participants were provided with feedback about the percentage of correct responses.

Df Itemwise Task (Modified Sternberg Task)

The itemwise version was constructed similarly to the listwise version and utilized the same item material. Again, participants were presented two lists of words: one that they should remember (TBR) and one that they should forget as fast as possible (TBF). In contrast to the listwise task words were presented sequentially one at a time. The cue that associated the words with any of the two lists followed immediately after the presentation of each single word (itemwise cueing). The information linking the two colors (green and red) to the TBR and TBF list was presented at the beginning of each trial. The presentation of a word lasted for one second. The colored cue appeared for 800 ms after an ISI of 500 ms. The next word was presented with a RSI of 500 ms. The end of the list was indicated by a display containing four question marks displayed for 500 ms. Eventually, a probe word was presented to which participants should respond to by pressing either a ‘Yes’ or ‘No’ response key. As in the listwise version this task consisted of 80 pseudo randomized test trials (common sequence for all participants) with the three experimental conditions: 40 TBR words, 20 TBF words and 20 TN words.

Paper–Pencil Measures

Multiple Choice Vocabulary Intelligence Test (MWT-B)

The MWT-B (Lehrl, 1999) was chosen to assess the actual level of (verbal) intellectual abilities of the younger and elderly adults. The MWT-B is a routine test often used in clinical research to assess the pre-morbid intellectual level and can be considered as unaffected by normal cognitive aging effects. It is conceptually more closely related to crystallized intelligence rather than fluid intelligence.

General Mental Speed (BIS-B)

Within the Berlin Model of Intelligence Structure (BIS, Jäger, 1984) mental speed (BIS-B) is defined as the ability to perform tasks with simple cognitive demands and low difficulty levels quickly and accurately (Jäger, Süß, & Beauducel, 1997; Süß & Beauducel, 2004; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Three tasks for measuring BIS-B in different content domains were selected, namely a figural task (OE; marking letters of a certain typeface), a verbal task (KW; classifying words), and a numerical task (RZ; imputation of operators in simple equations). In more complex theoretical frameworks of mental speed, the kind of 'speed' measured by the BIS-B tasks is considered as 'clerical speed' (Danthiir, Roberts, Schulze, & Wilhelm, 2005). However, for reasons of parsimony we speak of mental speed in the following.

Fluid Intelligence (Gf)

Two tasks of the HAWIE-R (Tewes, 1994), the German version of the Wechsler Adult Intelligence Scale (WAIS-R; Wechsler, 1981), with high loadings on general fluid intelligence Gf (Rudinger & Rietz, 1995; Süß & Schweickert, 2001) were administered. The two subtests were the *block design task* that involves putting sets of blocks together to match special patterns shown on cards and the *picture completion* task in which the participants have to find a missing detail in each of 17 pictures.

Apparatus and Materials

The experimental tasks were presented on a 17″ color monitor attached to an IBM-compatible PC. The tasks were programmed and run with the WMC2000 software (Sander, 2005).

Procedure

The younger and elderly participants were tested individually in a session of approximately 2 h duration. Participants were first given a short questionnaire to gather biographical information. To control for test order effects, half of the participants began with the DF tasks (listwise and then itemwise) and the others with the NP tasks (identification first and localization second). After the first two tasks (either DF or NP) there was a short break followed by three paper–pencil tasks (BIS-B). After these tasks another computer test block (either the two directed-forgetting tasks or the two negative-priming tasks) was administered. Speed and accuracy were equally emphasized in the verbal instruction. The paper–pencil-based intelligence measures (MWT-B and HAWIE-R) were collected in a second testing session approximately 1 week after the first testing session.

Parameterization and Statistical Analysis

Concerning the NP and DF tasks, analyses of latencies were based on correct responses only, i.e., latencies of error responses were set to missing values (younger adults: 2.9% of trials in the NP and 5.1% of trials in the DF tasks; older adults: 2.2% of trials in the NP and 12.3% of trials in the DF tasks). To minimize the effect of outliers on dependent variables, reaction times smaller than 200 ms were set to missing values and reactions larger than the individual mean plus 3 *SD*s were set to the individual mean value plus 3 *SD*s. Following the procedure described in numerous cognitive aging studies (e.g., Kray & Lindenberger, 2000; Oberauer, 2001; Oberauer et al., 2003), all reaction times for the experimental paradigms were log-transformed. This was done in order to normalize RT distributions (Ratcliff, 1993). Additionally, difference scores computed on the basis of log-transformed data represent ratio scores that are less dependent on differences in baseline (speed) performance (e.g., Oberauer et al., 2003; Salthouse & Hedden, 2002). For easier interpretability we will report the absolute reaction times in the descriptives (Tables 1 and 2; Figures 1 and 2) but use the log-transformed data for all inferential analyses. Further, the main dependent variables (time costs and benefits) were checked for outliers and extreme values to minimize statistical biases. Mean accuracy data of the directed-forgetting and negative priming tasks (Table 1) were subjected to a probit transformation (Cohen & Cohen, 1983). We conducted mixed factorial ANOVA analyses (design: 2 [age] × 2 [experimental condition]) for the different tasks separately: In case of the NP tasks, the control condition (CO) was contrasted with the ignored repetition condition (IR) to obtain negative priming effects (CO – IR) and with the attended repetition condition (AR) to get repetition priming effects (CO – AR), respectively. For the DF tasks, true negative probes (TN) were contrasted with to-be-forgotten probes (TBF) to

TABLE 1. Mean reaction times (RT) and accuracy (AC) data (with *SD*s) for the different conditions of the negative priming (NP) and directed forgetting (DF) tasks for the younger and elderly participants

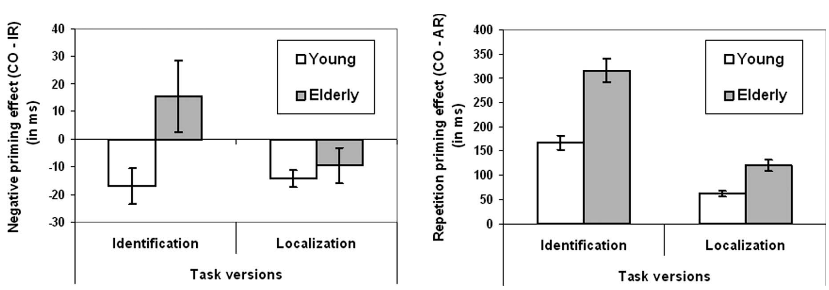
	Young (*N* = 49)		Elderly (*N* = 39)	
	M	*SD*	*M*	*SD*
NP Identificat. RT (AC)				
Ignored Repetition	747 (.95)	170 (0.04)	1141 (.96)	297 (0.04)
Attended Repetition	562 (.98)	97 (0.03)	841 (.98)	229 (0.02)
Control Condition	730 (.96)	164 (0.04)	1157 (.98)	288 (0.03)
NP Localizat. RT (AC)				
Ignored Repetition	480 (.97)	87 (0.04)	817 (.98)	284 (0.02)
Attended Repetition	403 (.99)	72 (0.02)	688 (.99)	278 (0.02)
Control Condition	465 (.98)	78 (0.03)	808 (.98)	274 (0.03)
DF Listwise RT (AC)				
To be remembered word	880 (.91)	208 (0.05)	1379 (.83)	307 (0.11)
To be forgotten word	1041 (.89)	240 (0.10)	1738 (.70)	370 (0.18)
New word	854 (.98)	201 (0.05)	1396 (.96)	331 (0.09)
DF Itemwise RT (AC)				
To be remembered word	741 (.96)	256 (0.05)	1241 (.92)	364 (0.09)
To be forgotten word	866 (.96)	323 (0.07)	1545 (.87)	444 (0.15)
New word	757 (.99)	265 (0.04)	1280 (.99)	390 (0.03)

TABLE 2. Magnitudes, significances and effect sizes of the negative priming, repetition priming and directed forgetting effects for the two age groups

	Effect in ms* (*SD*)		*t* and size of effect (Cohen's *d*)*		Reliability (Cronbach's α)	
	Young	Elderly	Young	Elderly	Young	Elderly
Negative Priming						
NP Ident.	–17 (45)	+16 (81)	–2.7 (0.10)	1.2 (0.06)	0.51	0.66
NP Local.	–15 (22)	–10 (40)	–4.7 (0.18)	–1.5 (0.03)	0.56	0.37
Repetition Priming						
RP Ident.	+168 (102)	+316 (154)	11.6 (1.30)	12.9 (1.22)	0.95	0.92
RP Local.	+62 (44)	+120 (72)	9.8 (0.83)	10.4 (0.44)	0.93	0.79
Directed Forgetting						
DF List. (AC)	.09 (.10)	.27 (.19)	6.6 (1.14)	8.7 (1.83)	0.53	0.76
DF Item. (AC)	.03 (.60)	.12 (.15)	3.3 (0.53)	4.8 (1.11)	0.53	0.80
DF List. (RT)	–186 (101)	–343 (293)	–12.9 (0.85)	–7.3 (0.97)	0.58	0.64
DF Item. (RT)	–109 (92)	–265 (180)	–8.3 (0.37)	–9.2 (0.63)	0.58	0.52

Note. *All effects reported represent reaction time differences scores between baseline performance and the particular experimental condition. Following the considerations of Dunlap, Cortina, Vaslow, & Burke (1996) for an unbiased estimation of the effect size in correlated designs we used the original *SD* for the computation of Cohen's *d*.

FIGURE 1. Negative priming (CO–IR) and repetition priming (CO–AR) effects with standard errors of the mean for the identification and localization task separated for the two age groups.



analyze intrusion effects (TN – TBF). For reasons of readability, we will only report the results referring to age differences in the inhibition tasks. The entire ANOVA results are summarized in Table 3. Effect sizes will be reported as partial η^2 values (η^2_p; for issues regarding η^2_p see e.g., Pierce, Block, & Aguinis, 2004) for ANOVA results and as Cohen's *d* for planned contrasts and *post-hoc* tests between groups. Analyses were performed with SPSS 14.

FIGURE 2. Intrusion effects (new words minus to-be-forgotten words) based on the reactions time and accuracy data (with standard errors of the mean) for the two directed forgetting tasks (listwise and itemwise) separated for the two age groups.

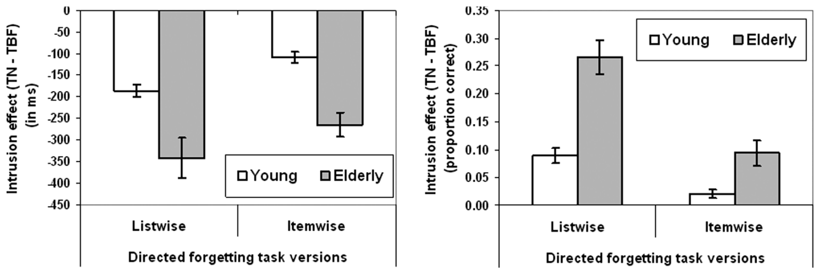


TABLE 3. Summary of analyses of variance for the two negative priming (NP) and directed forgetting (DF) tasks

	Reaction time (log transformed)			Proportion correct (probit transformed)		
Effect	*F* (1,86)	η_p^2	*p*	*F* (1,86)	η_p^2	*p*
NP (Ident.)	0.1	<.01	.72	5.0	.06	.03
Age	83.0	.49	<.01	3.2	.04	.08
Age × NP (Ident.)	5.3	.06	<.02	0.1	<.01	.71
RP (Ident.)	383.6	.82	<.01	18.5	.18	<.01
Age	95.2	.53	<.01	0.9	.01	.34
Age × RP (Ident.)	6.7	.07	.01	2.1	.02	.15
NP (Local.)	30.7	.26	<.01	<.1	<.01	.90
Age	114.2	.57	<.01	0.4	<.01	.56
Age × NP (Local.)	3.8	.04	.06	0.6	<.01	.45
RP (Local.)	239.2	.74	<.01	34.1	.28	<.01
Age	107.7	.56	<.01	0.1	<.01	.73
Age × RP (Local.)	3.1	.04	.08	1.7	.02	.20
DF (list)	179.9	.68	<.01	214.6	.71	<.01
Age	109.2	.56	<.01	17.7	.17	<.01
Age × DF (list)	1.2	.01	.29	9.6	.10	<.01
DF (item)	194.5	.69	<.01	68.7	.44	<.01
Age	71.2	.45	<.01	15.3	.15	<.01
Age × DF (item)	7.5	.08	.01	8.8	.09	<.01

Note: NP = negative priming; RP = repetition priming; DF = Directed forgetting effect (to-be forgotten words vs. new words)

RESULTS

Age Differences in Negative Priming (NP = CO – IR)

Figure 1 depicts the NP effects (CO – IR) of the two experimental paradigms (localization and identification) subdivided for the younger and elderly adults. The individual response latencies were analyzed (separately for each task) with 2 × 2 mixed ANOVAs with the two age groups as a between-subjects factor and the experimental conditions of the NP tasks (CO vs. IR) as a two level within-subjects factor (Table 3).

Age Differences in NP Identification

For the identification task, a significant age group × experimental condition interaction effect ($F(1, 86) = 5.3$, $p = .02$, $\eta_p^2 = .06$) was found. *Post-hoc* tests (within age groups) revealed that this interaction was based on significant slowing effects in the IR condition (i.e., NP) for the younger adults ($t(48) = 2.2$, $p = .03$, $d = 0.09$) and a lack of significant NP for the elderly participants ($t(38) = -1.2$, $p = .25$, $d = 0.06$).

Age Differences in NP Localization

In case of the localization task, there was only a trend toward a significant age group × experimental condition interaction effect ($F(1, 86) = 3.8$, $p = .06$, $\eta_p^2 = .04$). *Post-hoc* tests (within age groups) revealed that both, younger ($t(48) = 5.6$, $p < .01$, $d = 0.20$) and elderly ($t(38) = 2.4$, $p = .02$, $d = 0.05$) did show significant slowing effects in the IR condition (i.e., significant NP). Additionally, the marginal higher magnitude of the NP effect in the younger group is responsible for a trend toward a significant interaction of the NP effect with age.

Age Differences in Repetition Priming (RP = CO – AR)

Figure 1 depicts the RP effects for the two experimental paradigms (localization and identification) subdivided for the younger and elderly adults. Again, the individual response latencies were analyzed (separately for each task) with 2 × 2 mixed ANOVAs with the two age groups as a between-subjects factor and the referring experimental conditions of the negative-priming tasks (CO vs. AR) as a within-subjects factor with two levels (Table 3).

Age Differences in RP Identification

In case of the identification task, there was a significant age group × experimental condition interaction effect ($F(1, 86) = 6.7$, $p = .01$, $\eta_p^2 = .07$) indicating disproportional age effects depending on the experimental condition. *Post-hoc* tests (within age groups) revealed that this interaction originated in significantly larger RP effects in the AR condition within the older adults ($t(38) = 14.5$, $p < .01$, $d = 1.40$) compared to the younger group ($t(48) = 13.0$, $p < .01$, $d = 1.36$).

Age Differences in RP Localization

With respect to the localization task, *only* a marginal significant age group × condition interaction ($F(1, 86) = 3.1$, $p = .08$, $\eta^2_p = .04$) effect was obtained, indicating a trend toward disproportional stronger RP effects in the elderly group. As in the case of the NP effect, the inspection of raw (untransformed) reaction time data revealed slightly different results. The age group × condition interaction ($F(1, 86) = 21.6$, $p < .01$, $\eta^2_p = .20$) turned out much stronger, whereas the general pattern of the main effects remained unaffected.

In sum, the two task operationalizations of the NP paradigm yielded significant NP effects within younger adults in the identification task as well as in the localization task (Table 1). The elderly displayed significant NP only in the localization task. Disproportional stronger RP effects for the older adults were significant in the identification task, whereas the same pattern of results in the localization task was observed but failed to reach significance.

Age Differences in Directed Forgetting (Modified Sternberg Task)

Figure 2 depicts the results (latencies and accuracies) for the two DF paradigms (listwise and itemwise) subdivided for the younger and older adults. Individual response latencies and accuracies were analyzed (separately for each task) with 2 × 2 mixed ANOVAs (Table 3) with the two age groups as a between-subjects factor and the experimental conditions (TBF words vs. TN words) as a within-subjects factor with two levels.

Age Differences in DF Listwise

In the analysis of the latencies the age group × experimental condition interaction did not reach significance ($F(1, 86) = 1.2$, $p = .29$, $\eta^2_p = .01$) indicating the absence of significant disproportional age differences with regard to intrusion effects. Replicating the analysis for the accuracy data yielded a significant age group × experimental condition interaction effect ($F(1, 86) = 9.6$, $p < .01$, $\eta^2_p = .10$) indicating disproportional more errors in the relevant TBF-word condition compared to the new-word condition for the elderly (for raw accuracies see Table 2).

Age Differences in DF Itemwise

In the analysis of the latencies of the itemwise task, a significant age group × experimental condition interaction ($F(1, 86) = 7.5$, $p = .01$, $\eta^2_p = .08$) was found indicating disproportional longer latencies in the relevant TBF-word condition compared to the new-word condition for the elderly. Replicating the analysis for the itemwise accuracy data closely mirrored the results of the listwise accuracy data: A significant age group × experimental condition interaction ($F(1, 86) = 8.8$, $p < .01$, $\eta_p^2 = .09$) pointed to disproportional performance differences between the age groups.

Taken together, the two DF tasks revealed disproportional and age-specific declines in the ability to correctly reject words presented in the to-be-forgotten list (TBF) compared to real-new words (TN). Although accuracy data of both paradigms and latencies of the itemwise task yielded medium-sized age effects (larger intrusion costs for the elderly), the intrusion effect of the listwise task did not reflect any age-specific effect – a counterintuitive finding that will be addressed in the discussion later.

Age Differences in the Intelligence Tasks

Age Differences in Measures of General Mental Speed (BIS-B)

The three measures of the BIS were analyzed with a MANOVA where the three tasks served as dependent variables and age group as predictor. There was a strong overall effect of age group on the dependent variables ($F(1, 85) = 93.0$, $p < .01$, $\eta_p^2 = .77$) and considerable age-group differences in every single task ('marking letters of a certain typeface': $F(1, 85) = 189.1$, $p < .01$, $\eta_p^2 = .69$; 'classifying words': $F(1, 85) = 13.3$, $p < .01$, $\eta_p^2 = .14$; 'imputation of operators in simple equations': $F(1, 85) = 119.2$, $p < .01$, $\eta_p^2 = .58$).

Age Differences in Fluid Intelligence Tasks (Gf)

Similarly, the two figural intelligence tasks of the Wechsler intelligence test (block design and picture completion) were submitted to a MANOVA. Again, a strong overall effect of age group on the two dependent variables was obtained ($F(1, 69) = 16.7$, $p < .01$, $\eta_p^2 = .34$) reflecting large age differences in every single task ('block design task': $F(1, 69) = 28.7$, $p < .01$, $\eta_p^2 = .30$; 'picture completion task': $F(1, 69) = 24.5$, $p < .01$, $\eta_p^2 = .27$).

Age Differences in Crystallized Intelligence (MWT-B)

Comparing the two age groups in their performance on the Multiple Choice Vocabulary Intelligence Test as a measure of verbal intellectual abilities (crystallized intelligence) yielded significant better performance in the group of the older adults ($t(67) = 2.8$; $p < .01$; $d = 0.66$), underlining the statement that not only the younger participants (university students) but also the elderly can be considered as considerably educated.

Reliability of Experimental (Inhibitory) Measures

As far as measures of inhibitory control processes have been studied mainly in the area of experimental psychology, the issue of reliability has often been neglected (for an exception see Salthouse & Meinz, 1995). Furthermore, the terms *significant* and *reliable* are still used interchangeably in many studies. From a methodological and individual-differences perspective this represents an inaccuracy that might account partly for discrepant results. Significant results (in terms of mean differences) do not imply reliability of the difference scores in terms of internal consistency or stability over time. By computing measures of internal consistency for single difference scores (differences between single NP trials and the grand mean of control trials) we tried to highlight the issue of reliability. Table 2 displays the reliability coefficients (in terms of internal consistency) of NP and RP effects as well the reliability of the intrusion costs derived from the DF tasks. Table 2 shows that the reliability of the NP effect is rather low (range of Cronbach's α: .37–.66), whereas the α coefficients of the RP indicators appear considerably high (range of α: .79–.95) in both age groups. Corresponding α coefficients of the DF tasks turn out higher in the older adults (range of α: .52–.80) than in the younger group (range of α: .53–.58).

Validity of Inhibitory Paradigms

The validity of the inhibitory paradigms was evaluated in three steps: Firstly, we examined the zero-order correlations both within and between the experimental paradigms (NP and DF) that were supposed to measure inhibitory processes. Secondly, we computed the predictive validity of the inhibitory paradigms by correlating them with measures of general (fluid) intelligence (Gf). Thirdly, hierarchical regression analyses with mental speed (BIS-B) as additional predictor were utilized. This design allows for the detection of incremental predictive power of our inhibitory paradigms independent of general mental speed.

Communality Between Inhibitory Paradigms

To answer the first question whether or not there are substantial communalities between measures of inhibitory processes we examined correlations within and between the two experimental paradigms separately for each age group. Table 4 depicts the pattern of results. No significant correlation was found in any age group between both NP tasks. However, the RP effect of the two tasks turned out as being moderately correlated (younger adults: $r = .44$, older adults: $r = .35$). Only within the group of the elderly there was a significant correlation between the NP and RP effect ($r = .40$) regarding the identification task (indicating that lower NP was associated with stronger RP). This result seems plausible given the tendency in older adults to produce positive priming rather than NP in the IR condition (see Table 2). No significant correlations were observed within the DF tasks.

Focusing on the correlations between the two paradigms (NP and DF) revealed a mixed pattern of results: Within the younger group there was a

TABLE 4. Product moment correlations between the negative priming (NP), repetition priming (RP), directed forgetting (DF) and intelligence tasks (for the young and elderly participants)

	NP Ident.	NP Local	RP Ident.	RP Local	DF_{Rt} (list.)	DF_{Rt} (item.)	DF_{Ac} (list.)	DF_{Ac} (item.)	*Gf* [d]
				Younger adults (N = 49)					(*N* = 32)
NP Ident.									–.07
NP Local.	–.14								.07
RP Ident.	.25[c]	–.21							–.48[a]
RP Local	–.19	.25	.43[a]						–.47[a]
DF_{Rt} (list.)	–.19	–.22	.06	–.05					.21
DF_{Rt} (item.)	.07	–.35[b]	–.13	–.30[b]	.15				.05
DF_{Ac} (list.)	.19	–.15	.39[a]	.11	.20	–.35[b]			–.14
DF_{Ac} (item.)	–.12	.02	.16	.20	.02	–.09	–.09		–.26
BIS-B[e]	.12	.13	–.31[b]	–.02	.04	.21	–.08	–.12	.46[a]
				Older adults (N=39)					*(N = 37)*
NP Ident.									–.46[a]
NP Local.	.07								–.30[c]
RP Ident.	.48[a]	–.18							–.36[b]
RP Local	.09	.32[b]	.30[c]						–.20
DF_{Rt} (list.)	.28[c]	.06	.53[a]	.01					–.36[b]
DF_{Rt} (item.)	.19	–.01	.21	.06	.16				–.32[c]
DF_{Ac} (list.)	–.01	–.13	–.18	.22	–.37[b]	.11			.17
DF_{Ac} (item)	–.03	.24	–.11	.09	–.16	–.07	.02		–.23
BIS-B[e]	–.09	–.01	–.07	.25	–.28[c]	–.04	.18	–.31[c]	.32[c]

Note. Significance levels for product moment correlations: [a] $p < .01$; [b] $p < .05$, [c] $p < .10$ [d] Gf = composite score of two z-transformed tasks of the Wechsler intelligence test [e] BIS-B = aggregated score of three z-transformed speed tasks of the Berlin Intelligence Test

significant negative correlation (r = –.33) between the intrusion effect (latency) of the DF itemwise version and the NP effect in the localization task indicating that stronger NP was associated with less intrusion costs. However, no significant correlation was found between the DF listwise task and the NP identification task. With respect to the older adults, only the correlation between the RP effect in the identification task and the intrusion effect of the DF listwise task reached significance (r = .54). This indicates that lower intrusion costs are associated with stronger RP effects. As in the younger sample, no consistent pattern of significant associations between NP (and RP) and the DF intrusion effects were found.

Predictive Validity of Inhibitory Measures

As shown in Table 4 there was no significant correlation between the NP effects and the Gf indicator in the younger group. In contrast, the elderly participants yielded a significant negative correlation between the identification NP effect and Gf (r = –.33) indicating that stronger NP was associated with better performance in the two Gf tasks. The corresponding association with the localization NP effect pointed in the same direction ($r = -.26$) but missed significance, a fact that is conceivably attributable to the low reliability and power of the localization NP effect in the older group (see Table 2). Examining the RP effect, medium sized to strong negative associations to Gf in the younger group were observable indicating that smaller RP benefits are associated with better performance in Gf tasks. The same negative association can be found in the older group but here only for the RP effect of the identification task. Note that in line with our hypotheses none of the indicators derived from the NP tasks did significantly correlate with the general mental speed composite score derived from the three BIS-B tasks. Focusing the indicators of the DF tasks (intrusion costs), no significant correlation to Gf in the expected direction was observed in the younger group. Within the older adults both tasks seem to moderately correlate negative with Gf indicating that larger intrusion costs are associated with higher levels of Gf – a fact that is counterintuitive first and will be discussed later.

We further tried to explore the predictive validity of the inhibition measures and their relations to general mental speed by computing a series of hierarchical regression analyses in the sample of younger and elderly participants ($N = 69$) for which the Gf measures were available (Table 5). To control for differences in general mental speed, we first entered the BIS-B score in the analysis (equation 1.1). Table 5 depicts that in a second step NP and RP effects (equation 1.2) of the identification task uniquely explain incrementally 12 % of variance of our composite score of the two Gf tasks. Repeating the same analysis for the localization task yielded no significant predictive validity for the NP effect (equation 2.2) after entering the BIS-B Score in the first step (equation 2.1). In contrast, the RP effect explained a significant proportion of additional variance. With respect to both directed forgetting tasks neither the intrusion costs based on latencies (not shown in Table 5) nor the corresponding difference score based on the accuracy data did explain significant proportions of variance in Gf after entering BIS-B in the first step (equations 3.2 and 4.2).

In sum, the evaluation of validities of our inhibition-related tasks did not yield consistent overlap between the different scores within or between paradigms. However, the RP effects turned out to be significantly related across tasks and in both age groups. The zero-order correlations between inhibitory measures and Gf displayed the hypothesized inverse relation of stronger NP (solely in the identification task) being associated with better performance in Gf measures only in the group of the elderly. Questioning the predictive validity of inhibitory measures for explaining individual differences in complex intelligence tasks (Gf), zero-order correlations and regression analysis showed that the NP effect in case of the identification task and the RP effects in both NP-tasks were significantly related to Gf

TABLE 5. Hierarchical regression analyses for the prediction of general fluid intelligence (Gf) by the inhibition tasks with prior control of general mental speed (BIS-B) in the sample of younger and elderly participants (*N* = 69)

	GF		
	β	R^2	*incr.* R^2 *(p)*
Model 1: Negative Priming (Identification)			
Equation 1.1: BIS-B	.66[a]	.43	.43 (<.01)
Equation 1.2: BIS-B, NP, RP	.53[a], –.21[b], –.23[b]	.55	.12 (<.01)
Model 2: Negative Priming (Localization)			
Equation 2.1: BIS-B	.66[a]	.43	.43 (<.01)
Equation 2.2: BIS-B, NP, RP	.61[a], –.09, –.26[a]	.52	.09 (<.01)
Model 3: Directed Forget (Listwise; accuracy)			
Equation 3.1: BIS-B	.66[a]	.43	.43 (<.01)
Equation 3.2: BIS-B, DF	.62[a], –.10	.44	.01 (.34)
Model 4: Directed Forget (Itemwise; accuracy)			
Equation 4.1: BIS-B	.66[a]	.43	.43 (<.01)
Equation 4.2: BIS-B, DF	.62[a], –.14	.45	.02 (.16)

Note: Significance levels for *β* weights: [a] $p < .01$; [b] $p < .05$ Gf = composite score of two *z*-transformed tasks of the Wechsler intelligence test BIS-B = aggregated score of three *z*-transformed speed tasks of the Berlin Intelligence Test; Age did not explain incremental parts of variance after including mental speed and was therefore omitted from the analysis.

(negative β-weights) and explained significant amounts of variance even after controlling for general mental speed.

DISCUSSION

The current study focused on three main aims: Firstly, age differences in multiple inhibitory processes and well-established paradigms, negative priming (NP) and directed forgetting (DF), were evaluated. Secondly, the question was raised whether or not the processes measured by the different inhibition tasks share some communality both, within and across paradigms that would assign inhibition the status of a task-independent construct. Thirdly, we examined the predictive validity of the experimentally derived scores with respect to measures of fluid intelligence and general mental speed. On a highly general level, straightforward answers to these questions seem to be appropriate: In line with the inhibition deficit hypothesis, all of the different indicators across our experimental tasks yielded age-related decrements in the ability to inhibit distracting or to deactivate irrelevant or no longer relevant information. Within both age groups the communality between the respective indicators within and across experimental tasks was rather low and therefore no evidence was obtained in favor of a unitary construct of inhibition. Further, NP and especially RP within the identification task accounted for small but significant and mental-speed independent proportions of variance in Gf. This was not the case with respect to any DF indicator. Our initial aims will guide the remainder of this discussion.

Age Differences in Inhibitory Processes

Regarding the first objective, we detected significant medium sized age differences between younger and older adults in the identification version of the NP task. These results partly contrast conclusions of recent meta-analyses (Gamboz, Russo, & Fox, 2002; Verhaeghen & Cerella, 2002) and results of different single studies of the NP effect in aging research (e.g., Kramer & Strayer, 2001; Simone & McCormick, 1999). While a robust NP effect was observed within the younger adults the older adults displayed reduced NP effects. Reliability estimates of the NP effects are not be reported in previous studies that did not find significant age-related differences. Therefore, one can speculate that the reliability of the NP effect might not have been sufficient to detect individual differences in terms of age group differences in NP. Moreover, age effects were not only found for the identification condition but also for the localization task, although with a smaller effect size for the latter. This result seems to contradict different studies, which reported no age differences in the localization condition (e.g., Connelly & Hasher, 1993). Two main reasons might explain this discrepancy between results: Firstly, this effect strongly depends on data treatments of reaction time measures. By using ‘raw’ (untransformed) reaction-time measures, no significant difference in the amount of NP in the localization task was observable. Although different authors strongly argue in favor of the use of log-transformed reaction time data in aging research (e.g., Kray & Lindenberger, 2000; Oberauer et al., 2003; Verhaeghen & DeMeersmann, 1998), many studies on NP at least do not mention explicitly this major point of data treatment. The second argument refers to the sample sizes: Most of the studies on NP used much smaller sample sizes compared to our study (on average approximately 20 younger and elderly participants). The sample size might represent the ‘Achilles’ heel’ since the NP effect lacks reliability. We therefore expect that further studies with larger sample sizes and appropriate statistical power will replicate the finding of significant age differences in both versions of NP.

Interestingly, disproportionate age differences were also found for the attended repetition condition: In this case the older participants revealed larger amounts of facilitation effects in response to prime probe target repetition. McDowd and Filion (1995; Experiment 2) already reported this inverse pattern of results between the level of NP and RP for a localization task and attributed this result to a stronger reliance of the elderly on facilitative processes. Similarly, Kramer and Strayer (2001) found significantly stronger RP effects in the elderly. Unfortunately, the authors did not discuss the implications of this result. Findings by Marczinski, Miliken, and Nelson (2003) are also in line with our results. According to the authors, two distinct processes are involved in simple RT-task repetition effects: Firstly, a specific component comprising the mapping of stimulus characteristics onto specific responses to a given stimulus. The second (nonspecific) component depends solely on previous responses, irrespective of current stimulus characteristics. Depending on task characteristics the nonspecific component (Experiment 1) or both of these processes (Experiment 2) have been found increased in the elderly strengthening the finding of age sensitive repetition effects. Correlational findings that will be discussed below suggest that elevated RP effects are associated with poorer performance in measures of Gf within both age groups. Following Meiran (1996), we therefore suggest that larger RP effects reflect less efficient information dumping processes leading to poorer performance in complex intellectual performance situations such as intelligence or working memory tasks.

As for the DF paradigm, the older adults produced larger intrusion costs in both tasks (listwise and itemwise) with regard to the accuracy data. When considering the log-transformed reaction time data, significant age differences were observed only for the itemwise task but not for the listwise task. Two explanations are put forward for this unexpected finding. The first conceivable explanation is based on the assumption that different processes underlie the performance of both task versions (Basden, Basden, & Gargano, 1993). Therefore, it might be possible that especially the process of selective rehearsal, apparent only in the itemwise task version, is impaired in our sample of older adults. However, we consider a second explanation as more likely: The higher task difficulty of the listwise version, as documented empirically in the general lower accuracies compared to the itemwise version, might have provoked a shift of the relevant information from the latencies to the accuracy data. Note that on the highest load level four, eight words had to be memorized simultaneously until remember and forget cues appeared. In line with this explanation is the result of a *post-hoc* analysis: We examined age-related RT differences at lower load-levels with a maximum of four words, i.e., one and two words in the TBR and TBF list, respectively. Focusing these load levels, robust age differences of moderate size were observed (Age × condition interaction: $F(1, 86) = 10.6$, $p < .01$, $\eta_p^2 = .11$). We therefore conclude that the two age groups differ significantly in the ability to deactivate no longer relevant information in working memory, both in the itemwise and the listwise version of the DF paradigm.

Relations Within and Between Inhibitory Paradigms

Correlational analyses yielded no significant commonality between the two versions of the NP paradigm. Therefore, our results are in line with prior studies that stress the differences between the two tasks and propose different neuro-physiological correlates (e.g., dorsal and ventral visual pathways; Connelly & Hasher, 1993). It therefore seems likely that two distinguishable (inhibitory-like) processes account for our results: In the localization task a process similar to the IOR phenomenon (e.g., Buckolz, Boulougouris, O'Donnell, & Pratt, 2002) that is considered as qualitatively different from the identification NP effect might be relevant.

Similarly, no consistent pattern of association between the intrusion effects of the two DF tasks was found for any age group, neither for the latency data nor for the accuracies. We argue that this null finding should lead to reconsidering the two different underlying processes of the listwise and itemwise presentation modes (e.g., retrieval inhibition vs. selective rehearsal; Basden et al., 1993).

Finally, concerning the relation between the two investigated paradigms (NP and DF), we did not observe a significant relation in the two age groups, which would speak for inhibition as a unitary underlying construct. We therefore agree with Friedman and Miyake (2004) who proposed in a large scale latent-variable study on the construct validity of inhibitory processes that a more differentiated view of inhibitory processes is necessary and 'that theories positing inhibition as a unifying mechanism or theme may be overly ambitious' (p. 128).

Predictive Validity of Inhibitory Processes

Results concerning the associations of the obtained NP and DF effects with Gf produced a mixed pattern of findings: Concerning the negative-priming tasks, the expected significant negative associations were only found for the identification task in the elderly. The correlation in the younger group failed to reach significance. Contrary to the NP effect, the repetition-priming indicators showed adequate reliability coefficients and demonstrated medium sized to strong negative associations to Gf in both age groups, except for the localization task within the elderly. The direction of association indicates that smaller repetition-priming benefits are accompanied by better performance in the Gf measure. Concerning the DF tasks, there was a trend toward the expected pattern of results only in the younger group, that is, positive associations between Gf and the RT based intrusion costs and negative associations with the accuracy based scores. However, given the small sample size, the correlations did not reach significance. In contrast, in the group of the elderly the intrusion costs based on latencies were inversely related to Gf, indicating that larger intrusions were associated with better performance in the two Gf tasks. We can only speculate about the causes of this effect. Possibly, because of the comparatively high task difficulty, large intrusion effects might be ambiguous: They may not only display poor performance but also indicate that participants conformed more closely to the actual task demand, i.e., showed more effort in the initial encoding phase of the task at the expense of larger intrusions. In contrast, others with lower intrusion effects might have changed their strategy and invested less mental resources for the encoding or lost motivation during the task.

Since the inspection of zero-order correlations does not provide straightforward conclusions with respect to the incremental contribution of inhibition to higher-order cognitive functioning, we evaluated these different sources of inhibition simultaneously in hierarchical regression analyses. Two results seem noteworthy: Firstly, in case of the NP identification task the NP effect accounted for a significant proportion of variance in Gf in addition to RP and mental speed. Secondly, in both NP tasks the RP effect was a potential predictor of Gf with a negative sign after the inclusion of general mental speed. However, as already implied by the pattern of zero-order correlations none of the directed forgetting indicators accounted for significant proportions of variance in addition to mental speed in Gf.

As a consequence of the age differences and correlational findings we especially consider the RP effect worth a closer look. Our results concerning larger amounts of RP in elderly participants are in line with previous findings (Kramer & Strayer, 2001; identity negative priming; McDowd & Filion, 1995; location negative priming). We propose that age effects in the attended repetition condition reported here and in other recent NP studies show parallels to results obtained by Meiran (1996): In a reading-comprehension task, the author has studied the association between lexical RP and measures of verbal working memory. He found the same postulated inverse relationship between the level of RP and verbal working memory. According to Meiran (1996), the amount of RP indicates the efficiency of dampening previously activated information. The larger the amount of RP the slower or less effective the dampening occurs. Thus, we suggest that RP and NP may reflect two sides of the same coin, namely inhibition or dampening of residual activity of no longer relevant information (Neumann & DeSchepper, 1992). This interpretation fits the significant positive correlation between the negative and positive-priming costs within the identification task for the elderly participants. The positive direction of the correlation indicates that people with a smaller NP effect reveal a larger amount of RP. Furthermore, these significant correlations of the RP effect with the external criterion measure (Gf) found in both age groups provide at least an additional hint to the central role of activation and dampening processes for the successful performance in more complex tasks. Note that these correlations are independent of general mental speed. Thus, we would encourage researchers in this field to shift their focus of attention at least partly from NP costs to RP benefits and their predictive validity for individual differences in more complex cognitive demands. Comparing the rather low reliability of the NP effect with that of the RP scores, we clearly see another argument to partly shift attention from NP to RP.

Limitations

Although the sample sizes used in the current study can be considered as rather large compared to earlier studies in experimental cognitive aging research, future studies should aim at collecting even larger sample sizes in order to allow for the application of more powerful data analysis strategies like structural equation modeling (SEM). With SEM, one could elegant prove true score relations between different inhibitory measures and external criteria (e.g., mental speed and intelligence) simultaneously.

Problems with the NP effect in terms of reliability have been noted previously (e.g., Titz, Behrendt, Hasselhorn, & Schmuck, 2003). Although reliability coefficients in our study can be considered as comparatively substantial, they still remain unsatisfactory in terms of individual differences research. Since the data of a preliminary study in our laboratory has yielded no gain in reliability after a considerable extension of the number of trials in the NP task, further research has to prove alternative ways of increasing reliability of the NP task. The same problem of moderate reliability applies to the DF indicators, especially the ones based on latencies. Therefore, is has to be acknowledged that possible relations to other constructs (e.g., mental speed and intelligence) are limited by the moderate to small reliability coefficients of the different inhibition tasks.

Although the current study has demonstrated robust age effects in certain tasks presumably assessing inhibitory-like capabilities, as e.g., the ability to prevent previously presented distracting information from interfering with ongoing information processing in case of the NP tasks or the ability to deactivate the representations of no longer relevant words in case of the DF tasks, the mechanisms underlying these paradigms are still unclear and under debate. For both phenomena, NP and DF, additional explicative accounts exist that circumvent the terms of inhibition or deactivation. Concerning the NP paradigm, the hypothesis of an automatic retrieval of incidental stimulus-response associations (Rothermund et al., 2005) adds an interesting new explicative perspective: According to the authors the prime distractor gets associated with the response that is required in the prime trial. If a different response is now required in the probe trial the activation or retrieval of the prime trial episode (in terms of an association between the prime distractor and the executed response) leads to a slowing of the required probe trial response only if the probe trial response differs from the prime trial response as it is the case in typical NP trial constellations. For the DF paradigm similarly several non-genuine inhibitory explanations have been proposed, namely selective rehearsal (Sheard & MacLeod, 2005), source monitoring and recently the concept of context-content binding

(Oberauer, 2005a). As our current study was not designed to decide between the different hypotheses regarding the underlying mechanisms we remain cautious to what extend our results strengthen or abolish the original inhibition-deficit hypotheses. However, it was demonstrated that at least no single inhibitory concept could account for these results.

In sum, we found small to medium sized age dependent decrements in single task performances that are independent of general mental speed and to a small but significant degree predictive of more complex higher order cognitive functions (Gf). To our impression, these decrements so far fit best into theories that postulate an age-related decline in the efficiency of certain presumably inhibitory like processes, both automatic and controlled.

ACKNOWLEDGEMENTS

We are grateful to Monique Reichert, Veit Neubach and Stephen Pleines for their assistance in recruitment of participants and the data collection process. We thank Klaus Oberauer for helpful comments on an earlier version of this article.

Original manuscript received 26 September 2007
Revised manuscript accepted 15 July 2008
First published online October 28, 2008

REFERENCES

Andrés, P., Van der Linden, M., & Parmentier, F. B. R. (2004). Directed forgetting in working memory: Age-related differences. *Memory, 12*, 248–256.

Basden, B. H., Basden, D. R., & Gargano, G. J. (1993). Directed forgetting in implicit and explicit memory tests: A comparison of methods. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 603–616.

Bedard, A.-C., Nichols, S., Barbosa, J. A., Scharchar, R., Logan, G. D., & Tannock, R. (2002). The development of selective inhibitory control across the life span. *Developmental Neuropsychology, 21*, 93–111.

Bjork, R. A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In H. L. Roediger III & F. I. M. Craik (Eds.), *Varieties of memory & consciousness* (pp. 309–330). Hillsdale, NJ: Erlbaum.

Bowles, R. P., & Salthouse, T. A. (2003). Assessing the age-related effects of proactive interference on working memory tasks using the Rasch model. *Psychology and aging, 18*, 608–615.

Buckolz, E., Boulougouris, A., O'Donnell, C., & Pratt, J. (2002). *European Journal of Cognitive Psychology, 14*, 207–225.

Christ, S. E., White, D. A., Mandernach, T., & Keys, B. A. (2001). Inhibitory control across the life span. *Developmental Neuropsychology, 20*, 653–669.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression correlation analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Connelly, S. L., & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 1238–1250.

Connelly, S. L., Hasher, L., & Zacks, R.T. (1991) Age and reading: The impact of distraction. *Psychology and Aging, 6*, 533–541.

Conway, A. A. (1999). The time-course of negative priming: Little evidence for episodic trace retrieval. *Memory & Cognition, 27*, 575–583.

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford: Oxford University Press.

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake, & P. Shah (Hrsg.), *Models of working memory: Mechanisms of active maintenance and executive control* (S. 62–101). Cambridge: University Press.

Danthiir, V., Roberts, R. D., Schulze, R., & Wilhelm, O. (2005). Mental speed: On frameworks, paradigms, and a platform for the future. In O. Wilhelm, & R. W. Engle (Ed.), *Understanding and measuring intelligence* (pp. 27–46). Thousand Oaks, CA: Sage.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review, 12*, 45–75.

Dempster, F. N., & Corkill, A. J. (1999). Individual differences in susceptibility to interference and general cognitive ability. *Acta Psychologica, 101,* 395–416.

Dulaney, C. L., Marks, W., Link, K. E. (2004). Aging and directed forgetting: Pre-cue encoding and post-cue rehearsal effects. *Experimental Aging Research, 30,* 95–112.

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996) Meta-analyses of experiments with matched groups or repeated measures designs. *Psychological Methods, 1*, 170–177.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128,* 309–331.

Fox, E. (1995). Negative priming from ignored distractors in visual selection: A review. *Psychonomic Bulletin & Review, 2*, 145–173.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 133*, 101–135.

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General, 137*, 201–225.

Gamboz, N., & Russo, R. (2002). Evidence for age-related equivalence in the directed forgetting paradigm. *Brain & Cognition, 48,* 366–371.

Gamboz, N., Russo, R., & Fox, E. (2002). Age differences and the identity negative priming effect: An updated meta-analysis. *Psychology and Aging, 17*, 525–531.

Grant, J. D., & Dagenbach, D. (2000). Further considerations regarding inhibitory processes, working memory, and cognitive aging. *The American Journal of Psychology, 113*, 69–94.

Hasher, L. & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Eds.), *The psychology of learning and motivation* (Bd. 22, S. 193–225). New York: Academic Press.

Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 17*, 163–169.

Hasher, L., Zacks, R. T. & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII* (pp. 653–675). Cambridge, MA: MIT Press.

Hasselhorn, M., Jaspers, A., & Hernando, M.-D. (1990). Typizitätsnormen zu zehn Kategorien für Kinder von der Vorschule bis zur vierten Grundschulklasse. *Sprache & Kognition, 9,* 92–108.

Jäger, A. O. (1984). Intelligenzstrukturforschung: Konkurrierende Modelle, neue Entwicklungen, Perspektiven [Intelligence structure research: Competing models, new developments, perspectives]. *Psychologische Rundschau, 35*, 21–35.

Jäger, A. O., Süß, H.-M., & Beauducel, A. (1997). *Test für das Berliner Intelligenzstruktur-modell (BIS) [Test for the Berlin Intelligence Structure Model (BIS)]*. Göttingen: Hogrefe.

Kane, M., Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Connelly, S. L. (1994). Inhibitory attentional mechanisms and aging. *Psychology and Aging, 9*, 103–112.

Koshino, H., Boese, G. A., & Ferraro, F. R. (2000). The relationship between cognitive ability and positive and negative priming in identity and spatial priming tasks. *The Journal of General Psychology, 127*, 372–382.

Kramer, A. F., & Strayer, D. L. (2001). Influence of stimulus repetition on negative priming. *Psychology and Aging, 16*, 580–587.

Kramer, A. F., Humphrey, D. G., Larish, J. F., Logan, G. D., & Strayer, D. L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging, 4*, 491–512.

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging, 15*, 126–147.

Lehrl, S. (1999). *Mehrfachwahl-Wortschatz-Intelligenztest (4. Auflage) [German multiple choice verbal intelligence test; 4th edition]*. Göttingen: Hogrefe.

Lustig, C., May, C., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General, 130*, 199–207.

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding, & C. M. MacLeod (Eds), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Lawrence Erlbaum Associates.

Marczinski, C. A., Milliken, B., & Nelson, S. (2003). Aging and repetition effects: Separate specific and nonspecific influences. *Psychology and Aging*, 18, 780–790.

May, C. P., Kane, M. J. & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118*, 35–54.

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory & Cognition, 27*, 759–767.

McDowd, J. M., & Filion, D., L. (1995). Aging and negative priming in a location supression task: The long and the short of it. *Psychology and Aging, 10*, 34–47.

McDowd, J. M., & Oseas-Kreger, D. M. (1991). Aging, inhibitory processes, and negative priming. *Journal of Gerontology, 46*, 340–345.

Meiran, N. (1996). Is reading ability related to activation dumping speed? Evidence from immediate repetition priming. *Memory & Cognition, 24*, 41–59.

Miyake, A., Friedman, N. P., Emerson M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex 'frontal lobe' tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.

Neill, W. T. (1997). Episodic retrieval in negative priming and repetition priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 1291–1305.

Neumann, E., & DeSchepper, B. G. (1992). An inhibition based fan effect: Evidence for an active suppression mechanism in selective attention. *Canadian Journal of Psychology, 46*, 1–40.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*, 220–246.

Oberauer, K. (2001). Removing irrelevant information from working memory: A cognitive aging study with the modified Sternberg task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 948–957.

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 411–421.

Oberauer, K. (2005a). Binding and inhibition in working memory: Individual and age differences in short-term recognition. *Journal of Experimental Psychology: General, 134*, 368–387.

Oberauer, K. (2005b). Control of the contents of working memory – a comparison of two paradigms and two age groups. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 714–728.

Oberauer, K., Demmrich, A., Mayr, U., & Kliegl, R. (2001). Dissociation retention and access in working memory: An age-comparative study of mental arithmetic. *Memory & Cognition, 29*, 18–33.

Oberauer, K., Wendland, M., & Kliegl, R. (2003). Age differences in working memory – The roles of storage and selective access. *Memory & Cognition, 31*, 563–569.

Persad, C. C., Abeles, N., Zacks, R. T., & Denburg, N. L. (2002). Inhibitory changes after age 60 and their relationship to measures of attention and memory. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 57*, 223–232.

Pierce, C. A., Block, R. A., & Aguinis, H. (2004). Cautionary note on reporting eta-squared values from multifactor ANOVA designs. *Educational and Psychological Measurement, 64*, 916–924.

Rothermund, K., Wentura, D., & De Houwer, J. (2005). Retrieval of incidental stimulus-response associations as a source of negative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 482–495.

Rudinger, G., & Rietz, C. (1995). Intelligenz – Neuere Ergebnisse aus der Bonner Längsschnittstudie des Alterns (BOLSA). In A. Kruse, & R. Schmitz-Scherzer (Eds.), *Psychologie der Lebensalter* (pp. 185–199). Darmstadt: Steinkopff.

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*, 403–428.

Salthouse, T. A., & Hedden, T. (2002). Interpreting reaction time measures in between-group comparisons. *Journal of Clinical and Experimental Neuropsychology, 24*, 858–872.

Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 50*, 297–306.

Sander, N. (2005). *Inhibitory and executive functions in cognitive psychology: An individual differences approach examining structure and overlap with working memory capacity and intelligence*. Aachen: Shaker.

Schmuck, P., & Bloem, R. (1998). Negative priming designs: Comparison and improvement of measurements for detection of cognitive inhibition. *Zeitschrift für Experimentelle Psychologie, 45*, 60–79.

Schooler, C., Neumann, E., Caplan, L. J., & Roberts, B. R. (1997). Continued inhibitory capacity throughout adulthood: Conceptual negative priming in younger and older adults. *Psychology and Aging, 12*, 667–674.

Sheard, E. D., & MacLeod, C. M. (2005). List method directed forgetting: Return of the selective rehearsal account. In N. Ohta, C. M. MacLeod, & B. Uttl (Eds.), *Dynamic cognitive processes* (pp. 219–248). Tokyo: Springer-Verlag.

Simone, P. M., & McCormick, E. B. (1999). Effect of a defining feature on negative priming across the life span. *Visual Cognition, 6*, 587–606.

Süß, H.-M., & Beauducel, A. (2004). Faceted models of intelligence. In O. Wilhelm, & R. Engle (Eds.), *Handbook of understanding and measuring intelligence*. Thousand Oaks, CA: Sage.

Süß, H.-M., & Schweickert, S. (2001). Untersuchungen zur Konstruktvalidität von Intelligenz- und Aufmerksamkeitstests [Construct validity of intelligence and attention tasks]. *Paper presented at the 6. Arbeitstagung der Fachgruppe Differentielle Psychologie, Persönlichkeitspsychologie und Psychodiagnostik der DGPs, Leipzig, Germany*.

Süß, H.-M., Oberauer, K., Wittmann, W. W., Wilhelm, O., & Schulze, R. (2002). Working-memory capacity explains reasoning ability – and a little bit more. *Intelligence, 30*, 261–288.

Tewes, U. (1994). *HAWIE-R: Hamburg-Wechsler-Intelligenztest für Erwachsene, Revision 1991, 2nd edition* [German version of the Wechsler Adult Intelligence Test; WAIS-R]. Bern: Huber.

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *Quarterly Journal of Experimental Psychology, 54A*, 321–343.

Titz, C., Behrendt, J., Hasselhorn, M., & Schmuck, P. (2003). Is the negative priming effect a reliable measure of individual differences in cognitive inhibition? *Journal of Individual Differences, 24*, 135–147,

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: A review of meta-analysis. *Neuroscience and Biobehavioral Reviews, 26*, 849–857.

Verhaeghen, P., & De Meersman, L. (1998). Aging and the negative priming effect: A meta-analysis. *Psychology and Aging, 13*, 435–444.

Viskontas, I. V., Morrison, R. G., Holyoak, K. J., Hummel, J. E., & Knowlton, B. J. (2004). Relational integration, inhibition, and analogical reasoning in older adults. *Psychology and Aging, 19*, 581–591.

Zacks, R. T., Radvansky, G., & Hasher, L. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 143–156.