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Episodic and semantic memory functioning in very old age: Explanations from executive functioning and processing speed theories

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Abstract: Structural equation modeling was used to investigate whether age-related episodic and semantic memory impairments are better explained by decline in processing speed or executive functioning (or both), rather than directly in terms of memory components. The models tested were based on an extensive review of the literature on cognitive decline in normal aging, up to very old age. A computerized test battery, measuring episodic memory (free and cued recall; recognition), semantic memory (fluency; naming accuracy and latencies), processing speed and executive functioning, was administered to 234 elderly persons ranging from young-old to very old age (55–96 years). To avoid large variance in response times due to physical instead of cognitive limitations, no motor responses were required from participants. Age-related decline in episodic and semantic memory performance was found to be the consequence of declines in processing speed and executive functioning. Processing speed mainly mediated decline of semantic memory, whereas executive functioning mainly mediated episodic memory decline. The most parsimonious model showed that both processing speed and executive functioning attributed to

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Pauline E.J. Spaan works part-time as an assistant professor of Clinical Neuropsychology at the University of Amsterdam, and part-time as a senior Clinical Neuropsychologist, conducting neuropsychological assessment and treatment, at the Department "Psychiatry and Medical Psychology" of the OLVG hospital, Amsterdam, and in her private practice.

Her research (PhD 2003) focuses on the early assessment of dementia and how various memory components may improve prediction. In particular, she is interested in the nature of semantic processing deficits in (early stage) Alzheimer's disease and how this may contribute to more reliable differential assessment.

Furthermore, she is interested in explaining patterns of age-related cognitive deficits within the *normal* aging spectrum: from young-old (55+) to very old age (up to 96 years old). More specifically, she studies (by means of structural equation modeling) the interplay between episodic and semantic memory components, on the one hand, and processing speed and executive functioning, on the other hand.

PUBLIC INTEREST STATEMENT

Are memory problems in elderly people caused by memory decline per se, or are these caused by attentional deterioration, such as cognitive slowing or impaired executive functioning? 234 non-demented elderly persons were tested with a new computerized neuropsychological test battery. Results revealed that the elderly were perfectly capable to retrieve information from their memory, as long as they were given enough time or cues. This research also pinpoints the disadvantages of memory tests ordinarily used in clinical practice: these are easily influenced by other factors. If (very) old people perform poorly, this tends to be interpreted as a memory deficit. However, they may simply need more time or structure, *or* they primarily suffer from reduced motor skills. The latter may also be caused by physical diseases (e.g. rheumatism), rather than brain diseases (e.g. dementia).
This study contributes to a better understanding of *normal* aging, and helps to improve diagnostic accuracy.

memory decline but independent from one another. The results suggest that at very old age, the impact of executive dysfunctions on episodic memory performance exceeds the influence of cognitive slowing.

Subjects: Amnesia & Memory Disorders; Attention; Clinical Neuropsychology; Computerized Testing; Dementia; Dementia & Alzheimer's Disease; Factor Analysis, SEM, Multilevel & Longitudinal Modeling; Gerontology (Ageing); Memory; Neuropsychological Tests & Assessments

Keywords: episodic memory; semantic memory; processing speed; executive functioning; very old age; structural equation modeling

1. Introduction

Age-related memory decline has been studied extensively for many years. More recently, studies have focused on cognitive functioning in very old age (i.e. 75 years and older; see Bäckman, Small, Wahlin, and Larsson (2000) for a review). Knowledge about what is normal at very old age and what is not is important for differentiating between normal and pathological cognitive aging processes such as dementia.

In the present study, episodic and semantic memory performance was investigated within the aging spectrum from young-old age (starting at 55 years) to very old age (up to 96 years old). Specific focus was on the interplay with two other cognitive constructs that are known to show decline in aging: processing speed (e.g. Salthouse, 1996a) and executive functioning (e.g. Dempster, 1992). The central question is whether age-related memory impairments are better explained by decline in processing speed or executive functioning (or both), rather than directly in terms of memory components. And do processing speed and executive functioning differ in their specific impact on episodic versus semantic memory? Hypotheses were tested by fitting various structural equation models that were based on the literature review below.

1.1. Episodic memory functioning in (very) old age: explanations from processing speed theories

Many studies have addressed whether, or to what extent, reduced memory performance is directly related to aging or to other cognitive variables that intervene between age and memory performance (for a review, see Luszcz & Bryan, 1999). A decline in processing speed (PS) has been proposed to account for the relationship between normal aging and memory loss (e.g. Salthouse, 1996a). This model suggests that reduced speed leads to cognitive impairments because of the *limited time mechanism* (i.e. relevant cognitive operations cannot be successfully executed in the available time) and the *simultaneity mechanism* (i.e. reduced amount of simultaneously available information needed for higher level processing or richer and more elaborate encoding).

PS has indeed been shown to be an important mediator of age-related episodic memory decline, particularly at free recall (Bryan & Luszcz, 1996). This finding is also reported in very old adults (Lindenberger, Mayr, & Kliegl, 1993; Luszcz, Bryan, & Kent, 1997; Salthouse, 1996b). In addition, Sliwinski and Buschke (1997) found that PS mediated age-related differences in cued recall and text memory. However, PS did not affect the decline in the ability to benefit from increased encoding specificity, which seems inconsistent with Salthouse (1996a) simultaneity mechanism. In a more recent study, Salthouse and Ferrer-Caja (2003) found direct age relations to a speed factor, as well to an episodic memory factor, and a common factor (sensitive to the executive functions). Thus, PS may not be able to fully account for age-related variance in episodic memory.

In order to test the hypothesis that PS accounts for age-related variance in episodic memory, a structural equation model as shown in Figure 1 may be used. In this model, age is assumed to affect PS (represented by parameter C: the path coefficient from age to PS). The assumption that PS, in turn, mediates age-related episodic memory decline is indicated by the path from PS to Episodic

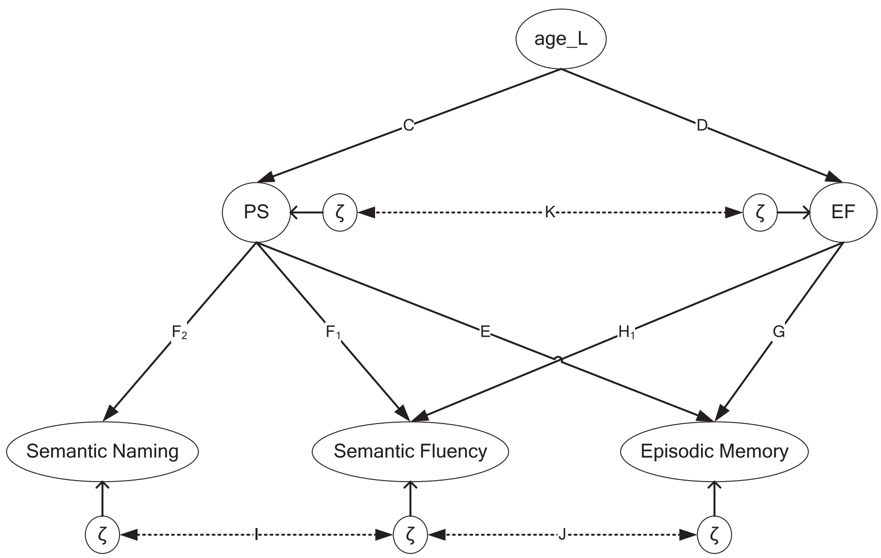

Figure 1. Illustration of theoretical model of processing speed (PS) and executive functioning (EF) explaining age-related variance in episodic and semantic memory, based on an integration of literature findings that formed the basis for the tested hypotheses (see also Table 4, section II).

Notes: Indirect decline of episodic memory, via age-related decline of PS (indicated by paths E and C, respectively; to be tested as M4) and/or EF (paths G and D; M7). Indirect decline of semantic fluency, via age-related decline of PS (paths F_1 and C; M5) and/or EF (paths H_1 and D; M8). Indirect decline of semantic naming, via age-related decline of PS (paths F_2 and C; M6). age_L = age represented as a latent variable. I = path from Semantic Fluency to Semantic Naming. J = non-directional relationship between the residuals of Episodic Memory and Semantic Fluency. K = non-directional relationship between the residuals of PS and EF. ζ (or zeta) = residual for a latent cognitive construct. A dashed line with double arrows indicates a non-directional relationship between (the residuals of) two latent cognitive constructs (represented in LISREL by the psi-parameter).

Memory (parameter E), in the absence of a direct path from age to Episodic Memory (this path is constrained to 0). This specific model is referred to below as Model 4 or M4.

1.2. Semantic memory functioning in (very) old age: explanations from processing speed theories

In the areas of semantic memory, age-related decline has been observed particularly in language production tasks (e.g. Burke & Mackay, 1997; Nyberg et al., 2003), such as verbal fluency and naming. Whereas fluency shows evident age-related impairments (e.g. Bäckman & Nilsson, 1996), performance on naming tasks is less clear. Nonetheless, impairments are found in very old age, as compared to young-old age, in picture naming accuracy (e.g. Au et al., 1995; Goulet, Ska, & Kahn, 1994; Kent & Luszcz, 2002). In addition, age-related reductions are reported in naming low-frequency items (Bowles, 1993; Craik, Anderson, Kerr, & Li, 1995), naming latencies (Bowles, 1993; Eustache, Desgranges, Jacques, & Platel, 1998; Mitchell, 1989), and naming in response to verbal definitions (e.g. Bowles & Poon, 1985; Maylor, 1990).

To my knowledge, no normal aging studies have been published that directly compared fluency and naming performance. However, it may be argued that persons perform differently on fluency tests than on naming tests (or they perform deficiently on both types of tests, but for different reasons) because of a difference in accessing words. In fluency, the participant is required to retrieve *as many words* as he or she can in response to a cue, whereas in naming, the presented cue should lead to the retrieval of *one specific word*.

Nevertheless, PS was found to mediate age-related variance in verbal fluency in very old adults (semantic category as well as phonemic fluency; e.g. Ghisletta & de Ribaupierre, 2005; Lindenberger et al., 1993). As far as we know, no cognitive aging study specifically examined PS in relation to naming performance, though naming latencies have been found to be generally longer (Bowles, 1993; Eustache et al., 1998; Mitchell, 1989).

Referring again to Figure 1, the hypothesis that PS mediates age-related decline in fluency may be tested by a model, in which the paths from age to PS (parameter C) and from PS to Semantic Fluency (parameter F_1) are freed, in the absence of a direct path from age to Semantic Fluency. This model is referred to below as M5. Similarly, the more tentative assumption that PS also mediates age-related decline in naming may be specified by the paths from age to PS and from PS to Semantic Naming (parameter F_2). This model is referred to as M6.

1.3. Episodic memory functioning in (very) old age: explanations from executive functioning theories

In addition to PS, executive functioning (EF) may also affect episodic memory performance in the normal aging spectrum. This is supported by the fact that the frontal lobes are affected relatively early, by elderly adults' worse performance on EF tasks, and by the similarity between the types of memory deficits experienced by healthy older adults and patients with frontal lobe lesions (for a review, see Dempster, 1992).

Efficient encoding and retrieval require strategic, goal-directed cognitive activity (e.g. Luszcz & Bryan, 1999). Crucial for this higher order, non-routine behavior is cognitive *flexibility*, or the ability to switch between responses or to *inhibit* automatic responses when this is required by the specific circumstances in order to achieve a certain goal. In addition, goal-directed behavior would not be possible if one was unable to adequately determine the main goal (and to recognize and neglect side issues), which requires *concept formation*, abstract thinking or reasoning ability. These capacities are typically affected in the dysexecutive syndrome (Baddeley, 1986; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). These capacities benefit deep or elaborate encoding of to-be-remembered information, initiating effective retrieval strategies at recall, and discriminating between target information and related, but irrelevant, information at (cued) recall and recognition (e.g. Craik & McDowd, 1987).

Hence, several studies report an association between older adults' diminished ability to actively adopt elaborate encoding strategies at episodic memory tests and disturbed EF (e.g. Backman & Larsson, 1992; Bryan, Luszcz, & Pointer, 1999; Crawford, Bryan, Luszcz, Obonsawin, & Stewart, 2000; Ferrer-Caja, Crawford, & Bryan, 2002; Sliwinski & Buschke, 1997). Therefore, decline in EF may offer a better explanation of reduced performance at subsequent recall than decline in PS, especially in very old adults (Crawford et al.).

Turning now to Figure 1, the hypothesis that EF mediates age-related decline in episodic memory may be tested by a model, in which the paths from age to EF (parameter D) and from EF to Episodic Memory (parameter G) are specified, in absence by a direct path from age to Episodic Memory. This model is referred to as M7.

1.4. Semantic memory functioning in (very) old age: explanations from executive functioning theories

Regarding the impact on semantic memory, note that the verbal fluency task not only makes speed demands on the word-finding process, but that performance is also influenced by executive control processes (e.g. Mayr & Kliegl, 2000; Troyer, Moscovitch, & Winocur, 1997). This task requires self-initiated effortful search strategies, at least to a higher degree than other semantic memory tasks, such as naming. This may be due to the fact that in verbal fluency tasks—contrary to naming tasks—the exact to-be-named items are not re-presented at test. Consequently, EF as an age-related mediator may be more pronounced in fluency than in naming tasks. Research to verify this assumption is, however, lacking.

The hypothesis that EF mediates age-related decline in fluency may be tested by a model that includes paths from age to EF (parameter D; see Figure 1 again) and from EF to Semantic Fluency (parameter H_1). This model is referred to as M8. Based on the literature and practical task experience, as was explained above, a relation between EF and naming was not assumed. Therefore, in Figure 1, no path is specified from EF to Semantic Naming.

1.5. Integration of theories: research hypotheses

Both PS and EF appear to influence age-related decline in episodic and semantic memory, though the impact on the latter memory system has not been examined as extensively as the impact on the former. In addition, the executive decline hypothesis of memory and aging has been investigated less often than cognitive slowing. Moreover, few studies have investigated these constructs simultaneously.

Based on the few studies that did integrate multiple cognitive constructs, a first hypothesis might be that PS explains age-related episodic memory loss better than EF does (Parkin & Java, 2000; see Section 1.1, illustrated by M4). An alternative, second, hypothesis is that in a sample including the very old, EF explains age-related episodic memory decline better than PS (Crawford et al., 2000; Ferrer-Caja et al., 2002; see Section 1.3, illustrated by M7). A third possibility is that aging influences these constructs in parallel (e.g. Salthouse & Ferrer-Caja, 2003; see also Section 1.1).

Because of the lack of normal aging studies that integrate PS, EF, and semantic memory, no specific hypotheses can be formulated in this area. Therefore, the hypotheses described in Sections 1.2 and 1.4, illustrated by M5, M6, and M8, are of exploratory nature.

1.6. This study

This study was aimed at the aging spectrum from young-old (55 years) to very old age (up to 96 years) because this age range is most relevant with respect to the differentiation with dementia. The central question was whether age-related variance in episodic and semantic memory was better explained by PS or EF (or both; see Section 1.5), rather than directly in terms of memory components (i.e. the latter hypothesis illustrated by models M1–M3, to be discussed in Section 3.3). In other words, are episodic and/or semantic memory decline directly or only *in*directly related to age? Furthermore, do PS and EF differ in their specific impact on memory?

These questions were investigated in a sample of 234 community dwelling elderly persons, using a computerized battery that contained a range of tasks reflecting episodic memory, semantic memory (fluency and naming), PS and EF, known to be sensitive to aging and/or dementia. As will be discussed in Section 2.3, tasks were developed that could measure the intended cognitive process as *purely* as possible. In addition, sufficiently *broad* constructs were created by choosing tests that represented different facets of each construct, but preventing overlap between these constructs. For example, the Episodic Memory construct involved measures of free and cued recall, as well as recognition. Furthermore, two separate semantic memory constructs were modeled: fluency and naming. As was reviewed in Sections 1.2 and 1.4, very old persons perform deficiently on both types of semantic memory, though these tests may represent essentially different measures of word-finding ability. Different structural equation models (M4–M8) were developed to test the theoretical expectations against alternative hypotheses (M1–M3).

2. Method

2.1. Participants

Participants were 251 community-dwelling volunteers between 55 and 96 years of age, recruited from different municipalities in the Netherlands through flyers and referrals from other participants. Participants were administered a semi-structured questionnaire to screen for a history of Cerebrovascular Accidents (N = 3), Traumatic Brain Injury (N = 1), or other neurological (N = 1) or psychiatric causes (N = 2) of cognitive dysfunctioning. In addition, persons with a history of substance abuse (N = 2) or using medication that might influence the central nervous system were excluded from the study. Participants that did not have Dutch as their native language were excluded as well (N = 1). To minimize the possibility of demented cases, participants with a score below 24 on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; N = 4) were excluded. Furthermore, participants with impaired vision that interfered with test performance or with too many missing values (i.e. on more than two measures) were also excluded (N = 3).

The institutional ethical review board of the department of psychology of the University of Amsterdam approved the study. Prior to the test session, participants gave their written informed consent. Afterwards, they received a small present to thank them for participating.

Table 1 reports the characteristics of the final sample of 234 participants. Although in this study, analyses were performed over the entire sample of 234 participants (i.e. applying age as a

Table 1. Sample characteristics: for the entire sample and per age group separately (for descriptive purposes only)

Participant-related variable	Age group (years)										Age r [c]
	Total (55–96)		55–64		65–74		75–84		85+		
	N = 234		*N* = 71		*N* = 66		*N* = 70		*N* = 27		
	M	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	
Age (years)	71.56	10.08	59.32	2.51	69.92	2.99	79.36	2.67	87.52	2.93	–
Level of education [a]	4.61	1.51	5.14	1.21	4.62	1.55	4.31	1.59	3.96	1.53	−.27**
Gender (% female)	66		56		67		71		78		.16*
Global cognitive status (MMSE)	28.68	1.30	29.08	.95	28.88	1.30	28.54	1.35	27.48	1.25	−.36**
Estimated IQ (DART)	108.47	12.51	110.34	11.67	108.62	12.16	107.61	12.51	105.37	15.12	−.16*
Depressive symptoms (CES-D)	12.72	6.63	10.34	6.29	13.39	6.17	13.80	6.72	14.58	7.02	.24**
Memory complaints [b]	2.78	1.38	2.82	1.32	2.85	1.48	2.90	1.35	2.19	1.30	−.06
Alcohol consumption (units/week)	7.04	7.68	7.80	7.05	8.08	8.25	5.97	7.36	5.26	8.41	−.15*

Note: MMSE = Mini-Mental State Examination (Folstein et al., 1975; Maximum = 30). DART = Dutch Adult Reading Test (Schmand, Lindeboom, & Van Harskamp, 1992). CES-D = Center for Epidemiologic Studies Depression Scale (Radloff, 1977).

[a]Education is coded according to Verhage (1964): 1 = elementary education not completed; 2 = elementary education; 3 = less than lower vocational training; 4 = lower vocational training; 5 = intermediate vocational training, 6 = higher vocational training; 7 = university.

[b]Measured by answers on three questions (Maximum = 10); asked to the participant at the beginning of the test session: (1) degree of perceived memory decline, rating on a scale of 0 (*Not at all*) to 3 (*Very much*); (2) degree of experienced inconvenience of memory functioning in daily life, rating on a scale of 0 (*none/hardly ever*) to 3 (*very much/(almost) all the time*); asked to the participant at the end of the test session: (3) perceived level of test performance, compared to similar age group, rating on a scale of 0 (*(very) good*) to 4 (*(very) bad*).

[c]Age *r* is the correlation of each variable with age.

*$p < .05$, two-tailed.

**$p < .01$, two-tailed.

continuous variable), Table 1 presents the sample characteristics for four different age groups as well. This merely serves the purpose of illustrating the distribution of these characteristics with respect to age.

ANOVA with Bonferroni *post hoc* comparisons showed that the mean educational level was significantly higher for the youngest group than for the two oldest groups ($F(3, 230) = 5.81$, $p < .01$). However, the age groups did not differ in estimated IQ ($F(3, 230) = 1.20$, $p = .31$) nor in the ratio of men to women ($\chi^2(3, N = 234) = 5.57$, $p = .14$). In addition, the oldest group showed a significantly lower MMSE score than the other groups ($F(3, 230) = 12.30$, $p < .01$). This is not of clinical concern because MMSE scores were still high in the oldest group (i.e. 89% had a score of 27 or above) and not indicative of possible dementia or cognitive impairment. The youngest group showed significantly fewer depressive symptoms than the other three age groups ($F(3, 230) = 4.83$, $p < .01$). However, the ratio of participants scoring above the (stringent) cut-off value of 16 (Beekman et al., 1997; 30% of the entire sample) did not differ between the age groups ($\chi^2(3, N = 234) = 2.23$, $p = .53$). Alcohol consumption, finally, did not differ significantly between the age groups ($F(3, 230) = 1.58$, $p = .20$). In sum, it is concluded that there are no seriously confounding participant-related variables that complicate the study of the relationship between age and cognition.

2.2. General procedure

The test battery was administered in the home environment of the participant using a laptop computer. The computer was operated by a trained neuropsychology student, supervised by a clinical neuropsychologist (PEJS). The participant only had to look at the screen, on which the stimuli were presented. No motor responses were required from the participants. The experimenter registered the participant's oral responses, for instance by means of a key press or a mouse click when the participant answered "yes" or "no" (in the Symbol Search Test and the Rule-Shift Test) or when the participant named the digit in the Symbol-Digit Coding Test. The test session lasted approximately 90 min, excluding breaks. The order of the tests within the battery was fixed, alternating between tests of memory, language, and attention, of verbal and visual nature, to prevent interference between tests.

2.3. Measurement variables: principles of task selection and construction

Several task characteristics complicate the understanding of what influences what. Particularly noteworthy is the mediocre validity of *EF* tasks, which is due largely to the multifaceted nature of the construct (e.g. Luszcz & Bryan, 1999). For example, verbal fluency tests are usually considered as EF measures and treated as indicators of the EF factor together with other tasks that do not comprise a semantic component, such as the Wisconsin Card Sorting Test (e.g. Crawford et al., 2000; Nelson, 1976; Parkin & Java, 2000). Thus, it is important to prevent overlap with other constructs that are studied simultaneously, but also to create a sufficiently broad EF construct, for example, by including tests of concept formation, as was argued in Section 1.3.

Furthermore, the problem with *PS* measures is that they typically require a motor response (e.g. writing symbols or digits; e.g. Wechsler, 1997), which leads to increased variability due to physical limitations common in elderly persons. This may reduce the validity of the task intended to measure *mental* (i.e. non-motor) PS. Thus, it is important *not* to require responses from elderly participants that involve (speeded) finger or hand movements.

Immediate recall measures of *episodic* memory are often confounded by short-term memory or attentional components as a result of recency effects on list-learning tests. These may be prevented by administering a distraction task between study and test phase.

As for *semantic* memory tests, naming tasks mostly utilize pictures, which introduces the unintended impact of visuoperceptual deficits (e.g. Au et al., 1995; Goulet et al., 1994). Moreover, naming in response to verbal definitions may be more representative for word finding complaints in daily life (e.g. Hamberger & Seidel, 2003). Naming latencies are, unfortunately, seldom recorded, though these might produce more sensitive measures of word-finding capacities (Eustache et al., 1998).

In sum, these task ambiguities complicate drawing conclusions concerning the extent and the nature of the age-related contribution of the respective cognitive constructs. It is, therefore, important to use multiple tasks for each construct: this not only improves the validity of the construct (e.g. Mitchell, 1989), but also its generalizability (e.g. Salthouse, 2000). Below, the measures of the test battery are described, ordered by the dependent, latent cognitive construct of which they were an observed variable.

2.3.1. Episodic memory

Note that the episodic memory measures represent newly constructed tests (though partly included in Spaan, Raaijmakers, & Jonker, 2005).

2.3.1.1. 10-word list-learning test. This test required free recall of 10 unrelated words (concrete imaginable nouns) in three trials. Each word was presented on the screen for 2 s, with an interval of .5 s. Between presentation and recall phase, the participant performed a 20-s Brown-Peterson distraction task, requiring to count backwards from a three-digit number that was presented on the screen. In each trial, the same words were presented but in a different sequence to prevent sequential learning effects. The score was the total number of words reproduced over three trials (possible range of scores: 0–30).

2.3.1.2. 10-Word-recognition test. This test involved explicit recognition (“yes” or “no”) of the words of the 10-Word List-Learning Test among 20 semantically related distractors. The distracters were not previously presented and were matched to the targets for word length. This test was administered immediately after the 10-Word List-Learning Test. The score was the sum of true positive and true negative answers (range: 0–30).

2.3.1.3. Paired-associate learning test: semantic pairs. This measure consisted of cued recall of five semantically related word pairs, constructed in the same format as the 10-Word List-Learning Test. Three trials were given. During the study phase, each pair was presented on the screen for 3 s, with an interval of .5 s. The participant was not alerted to the semantic association. Semantic associations were derived from Dutch word association norms (Groot, de, 1980; Loon-Vervoorn & Van Bekkum, 1991). The target word of each pair was moderately semantically related to the cue word, to prevent correct answers as a result of free association or guessing. Words were matched for word length and lexical frequency (Baayen, Piepenbrock, & Van Rijn, 1993). Between study and recall phase, the participant performed the 20-s Brown-Peterson distraction task (see Section 2.3.1.1.). During recall phase, the participant was asked to name the target word in response to each cue word; the cues were consecutively presented on the screen in an order different from the presentation order during the study phase. In each trial, the same word pairs were presented but in a different sequence to prevent sequential learning effects. The score was the sum of pairs reproduced over three trials (range: 0–15).

2.3.1.4. Paired-associate learning test: non-semantic pairs. This measure consisted of cued recall of five semantically *un*related word pairs, as part of the Paired-Associate Learning Test described above. The score was the sum of pairs reproduced over three trials (range: 0–15).

2.3.1.5. Paired-associate-recognition test. This test involved explicit recognition (forced choice) of the target words of the Paired-Associate Learning Test—among three (more strongly semantically) related distractors (derived from: Groot, de, 1980; Loon-Vervoorn & Van Bekkum, 1991)—in response to the presented cue words. Words were matched for word length. Between the Paired-Associate Learning test and the Paired-Associate-Recognition Test, the Raven Colored Progressive Matrices (described below) was administered. The score was the sum of correct answers (range: 0–10).

2.3.2. Semantic memory: fluency measures

2.3.2.1. Main category fluency test. This measure required the generation of as many exemplars—from the superordinate categories of animals and products to buy in a shop—as one could think of within 60 s per category. The score was the sum of correct and unique answers over both categories.

2.3.2.2. Sub-category fluency test. As part of the category fluency test mentioned above, the participant was required to generate as many exemplars that belonged to the subcategories of "birds," "fishes," "insects," "products to buy at the greengrocery," "products to buy in a clothes shop," and "products to buy in a do-it-yourself shop" as one could think of within 30 s per subcategory. By providing more specific semantic cues (as compared to the superordinate cues of the Main Category Fluency Test), a more pure semantic memory measure is obtained that requires less self-initiated retrieval or executive control processes. The score was the sum of correct and unique answers over six subcategories.

2.3.2.3. Letter fluency test. This test involved generating as many Dutch words starting with the letters D, A, and T as one could think of within 60 s per letter (Schmand, Groenink, & den Dungen, 2008; i.e. the Dutch version of the Controlled Oral Word Association Task; Benton & Hamsher, 1976). To prevent interference between the Category Fluency Tests and the Letter Fluency Test, the Stroop (described below) was administered in between. The score was the sum of correct and unique answers over three letters.

2.3.3. Semantic memory: naming measures

2.3.3.1. Visual naming test: total correct. This test involved naming line drawings of common objects and animals, presented on the screen. Material was taken from the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983) and consisted of 53 of the 60 original stimuli, appropriate for the Dutch language (Marien, Mampaey, Vervaet, Saerens, & De Deyn, 1998). The score was the sum of spontaneously and correctly named pictures within 20 s per item (range: 0–53).

2.3.3.2. Visual naming test: response time. This measure represented the average response time (in s) determined over the spontaneously, correctly named pictures of the Visual Naming Test, described above. Response times were recorded by the experimenter (by a mouse click), as soon as the participant correctly named a picture.

2.3.3.3. Verbal naming test: total correct. This test is based on the Auditory Naming Test (Hamberger & Seidel, 2003). Instead of the experimenter reading aloud the descriptions of the (to be named) words, the descriptions were presented on the screen (to minimize working memory load and to overcome hearing difficulties). Stimuli used by Hamberger and Seidel were translated into Dutch by Van den Dungen and Groenink (2004), which led to a few alterations in order to create 48 descriptions appropriate for the Dutch language. The score was the sum of spontaneously and correctly named descriptions within 20 s per item (range: 0–48).

2.3.3.4. Verbal naming test: response time. This measure represented the average response time (in s) determined over the spontaneously, correctly named descriptions of the Verbal Naming Test, described above. The registered response time reflected the time between presentation of the description on the screen and the moment that the participant gave a correct answer (within 20 s). Response times were recorded by the experimenter by a mouse click.

2.3.4. Processing speed measures

2.3.4.1. Symbol search test. This test is a variant of the Symbol Search subtest of the Wechsler Adult Intelligence Scale–Third edition (WAIS-III; Wechsler, 1997). The participant had to evaluate whether or not one of two symbols presented on the left of the screen was the same as one of five symbols presented on the right. The experimenter registered the answer of the participant, followed by the next line of symbols on the screen. The score was the sum of correct answers within 120 s.

2.3.4.2. Symbol-digit coding test. This test is a variant of the Digit-Symbol Coding subtest of the WAIS-III. To increase perceptual processing demands, a symbol presented in the middle of the screen had to be decoded to its corresponding digit according to a key presented at the top of the screen (instead of decoding digits to symbols). The experimenter registered the digit named by the participant, followed by the next symbol on the screen. The score was the sum of correct answers within 120 s.

2.3.4.3. Rule-shift test: base response time. This measure is a variant of part one of the Rule Shift Cards Test of the Behavioral Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996). The participant had to name as quickly as possible 20 playing cards that were consecutively presented on the screen according to the rule: say "yes" if the presented card is red, and "no" if it is black. The measure reflected the completion time (in s) of naming these cards.

2.3.5. Executive functioning measures

2.3.5.1. Rule-shift test: switching accuracy. This measure is a variant of part two of the BADS Rule Shift Cards Test. Subsequent to part one described above, the participant had to name as quickly as possible the same 20 cards according to a different rule: say "yes" if the presented card has the same color as the previous card, otherwise say "no." The score was the sum of correctly named cards according to rule 2 (range: 0–20; note that when rule 1 is consistently applied (i.e. unable to switch to the new rule), 11 out of 20 cards are named "correctly").

2.3.5.2. Stroop: interference time. This measure is a variant of Stroop (1935) and the Dutch version by Hammes (1997) and reflected the color-naming time difference (in s) between color-words (of inconsistent color) and colored rectangles. One stimulus at a time was presented in the middle of the screen. After the participant responded, the next stimulus appeared on the screen by a key press by the experimenter. Fifty stimuli were used for each condition (derived from the first five lines of the original version by Hammes (1997); stimuli of the last line were used for practice. The program registered the completion time of each test condition.

2.3.5.3. Raven colored progressive matrices. This test is an abbreviated version of Raven (1956), consisting of sets A and B (Smits, Smit, van den Heuvel, & Jonker, 1997). Stimuli were presented on the screen; the experimented registered the answer of the participant. The score was the sum of correct answers (range: 0–24).

2.4. Modeling issues and research design

Structural equation modeling (SEM) can accommodate multiple indicators for each construct. This enables analyses at the level of *latent* constructs instead of only at the level of manifest variables, thereby adjusting for measurement error of cognitive tasks when testing theoretical predictions about relationships among the cognitive constructs (e.g. Salthouse, 2000).

The presence of two *mediator* variables is assumed (i.e. PS and EF), in addition to two or three *dependent* variables (i.e. episodic memory and semantic memory, where the latter may be subdivided into fluency and naming). It is important to specify the relations among these cognitive variables independent of age (as is done in Figure 1). If these relations are not taken into account (i.e. if these parameters are constrained to 0), this will lead to overestimation of the age-related effect of a mediator variable (i.e. PS or EF) on the dependent variable (i.e. episodic or semantic memory), whereas, in fact, part of this effect results from individual variance in a mediator variable that is *un*related to age (Lindenberger & Pötter, 1998).

Mediator models are specified, based on the theoretical considerations discussed in the introduction, at the level of the latent variables in a full measurement model. This method allows for an explicit specification and estimation of the (age-independent) relations among dependent variables, *simultaneous* with analysis of the age-dependent relationships, in a cross-sectional design.

There are five mediation assumptions: PS affecting episodic memory and semantic memory (fluency and naming); EF affecting episodic memory and semantic memory (fluency). All of these assumptions are discussed in the literature review above and are referred to in the Results section as M4 through M8, respectively.

Finally, regarding potential sampling pitfalls, Salthouse (2000) stressed that continuous age samples are preferable to extreme age groups when research is aimed at describing the magnitude of age relations across the entire age range. Otherwise, the resulting variance proportions tend to overestimate the true magnitude of the age relations. Many studies reviewed above used extreme age groups, hence (further) complicating the study of age-related variance in cognition.

2.5. Statistical procedure

Models were estimated using LISREL 8.80 (Jöreskog & Sörbom, 2007; maximum likelihood method). Analyses were conducted on covariance matrices. In each model, age was constructed as the *independent (exogenous) variable* "age_L" by fixing the path from age_L to the manifest variable "age" (the lambda-x parameter in LISREL) to a value of 1.0 and by fixing the residual variance of "age" to 0 (i.e. equating the manifest variable age and the "latent" variable age_L).

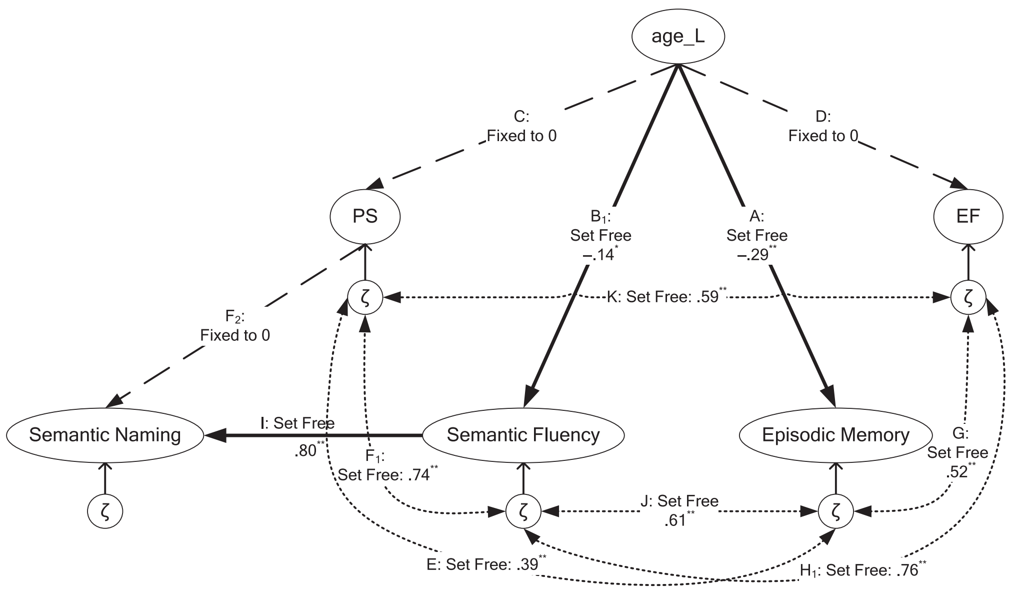

Figure 2. Initial structural model M1, including parameter estimates of the structural relations (*$p < .05$; **$p < .01$) (see also Table 4, section I): age-related decline of episodic memory and semantic fluency, indirect decline of semantic naming (via semantic fluency), and preserved processing speed (PS) and executive functioning (EF), with increasing age.

Notes: age_L = age represented as a latent variable. A = path from age_L to Episodic Memory. B_1 = path from age_L to Semantic Fluency. C = path from age_L to PS. D = path from age_L to EF. E = non-directional relationship between the residuals of PS and Episodic Memory. F_1 = non-directional relationship between the residuals of PS and Semantic Fluency. F_2 = path from PS to Semantic Naming. G = non-directional relationship between the residuals of EF and Episodic Memory. H_1 = non-directional relationship between the residuals of EF and Semantic Fluency. I = path from Semantic Fluency to Semantic Naming. J = non-directional relationship between the residuals of Episodic Memory and Semantic Fluency. K = non-directional relationship between the residuals of PS and EF. ζ (or zeta) = residual for a latent cognitive construct. A dashed line with double arrows indicates a non-directional relationship between (the residuals of) two latent cognitive constructs (represented in LISREL by the psi-parameter).

Scaling of the *dependent (endogenous) latent variables* (the cognitive constructs) was accomplished by fixing one cognitive measure (the reference indicator) for each construct to a value of 1.0 in the pattern matrix (the lambda-y parameter). In the initial model, age-independent relations among the residual terms of endogenous variables were allowed to vary (the psi-parameters), whenever consistent with theoretical considerations (e.g. Lindenberger & Pötter, 1998; see Figures 2 through 4).

Beforehand, *correlated residuals* were accepted that were theoretically interpretable as shared method variance between observed measures, in addition to being indicators of the same cognitive construct. This allowed to control for "method effects," to insure that a hypothesized cognitive construct was not an artifact of the peculiarities of a specific test or procedure (e.g. Herrmann et al., 2001). These correlated residuals were used across all measurement models and included: (a) 10-Word List-Learning Test with 10-Word-Recognition Test; (b) Paired-Associate Learning Test: semantic pairs with Paired-Associate Learning Test: non-semantic pairs; (c) Paired-Associate Learning Test: semantic pairs with Paired-Associate-Recognition Test; (d) Paired-Associate Learning Test: non-semantic pairs with Paired-Associate-Recognition Test; and (e) Main-Category Fluency Test with Sub-Category Fluency Test. Justification for these set of correlated residuals was based on the following features of the cognitive measures involved: (1) measures that belonged to the same test (as was the case in: b and e, mentioned above), or (2) measures of which the main score was derived from the same set of stimuli (applicable to: a, c, and d); in combination with: (3) performance on one measure may have facilitated or interfered with performance on the other measure (applicable to all five cases). Though criteria 1 and 2 were also applicable to the accuracy and the response time measures of the Visual Naming Test and the Verbal Naming Test, as well as to the base response time and the switching accuracy measure of the Rule-Shift Test, no correlated residuals were accepted in these three cases because criterion 3 did not apply.

All models were analyzed by *comparing nested models* that were obtained by changing a single constraint. The Chi-square difference test (χ^2_{Diff}) was used to test constraints. The critical value used for all comparisons was $p < .01$. When models achieved similar fit, the more *parsimonious* model was preferred. Thus, main focus in this study was on the *relative* fit of theoretically competing models.

In addition, *overall model fit* was evaluated by examining the following fit indices: (a) model Chi-square (χ^2); (b) root-mean-square error of approximation (RMSEA; Steiger, 1990), which focuses on the population discrepancy per degree of freedom. Values below .05 indicate good fit, between .05

and .08 adequate fit, between .08 and .10 mediocre fit, and above .10 poor fit (Browne & Cudeck, 1993); (c) comparative fit index (CFI; Bentler, 1990); (d) nonnormed fit index (NNFI; Bentler & Bonett, 1980). Both CFI and NNFI measure how much better the model fits as compared to the independence model (values above .90 usually indicate acceptable fits).

3. Results

3.1. Treatment of missing data

Twenty-one participants had missing values or evident outliers on one or two measures as a consequence of technical problems or sudden disturbances during test administration. Outliers were replaced and missing values were imputed using a regression approach applying other variables that best predicted performance on that measure.[1]

Table 2. Mean performance, estimated reliabilities, and age correlations of the cognitive measures of the entire sample (*N* = 234).

Cognitive measure	*M*	SD	Reliability	Age *r* [e]
Episodic memory				
10-Word list-learning test (1–28)	15.90	5.36	.85[a]/.69[b] **	−.51**
10-Word-recognition test (22–30)	28.74	1.68	.79[a]/.49[b] *	−.26**
Paired-associate learning test: semantic pairs (1–15)	11.81	2.32	.80[a]/.38[b]	−.16*
Paired-associate learning test: non-semantic pairs (0–15)	6.02	3.44	.83[a]/.65[b] **	−.24**
Paired-associate-recognition test (1–10)	9.10	1.45	.88[a]/.43[b] *	−.17*
Semantic memory: fluency measures				
Main-category fluency test (13–64)	37.16	8.66	.82[a]/.76[b] **	−.48**
Sub-category fluency test (27–84)	51.13	11.04	.89[a]/.69[b] **	−.44**
Letter fluency test (9–77)	39.63	11.03	.90[a]/.82[b] **	−.31**
Semantic memory: naming measures				
Visual naming test: total correct (28–53)	47.70	4.00	.89[a]/.92[b] **	−.33**
Visual naming test: response time (s) (1.6–5.5)	2.81	.75	.84[b] **	.37**
Verbal naming test: total correct (36–48)	45.40	2.57	.89[a]/.56[b] **	−.34**
Verbal naming test: response time (s) (2.5–8.8)	4.17	1.06	.81[b] **	.31**
Processing speed measures				
Symbol search test (13–42)	29.66	5.72	.78[c]/.83[b] **	−.54**
Symbol-digit coding test (31–88)	56.81	9.11	.82[b] **	−.54**
Rule-shift test: base response time (s) (15.4–54.2)	24.64	6.16	.28[b]	.25**
Executive functioning measures				
Rule-shift test: switching accuracy (9–20)	17.93	2.48	.77[a]/.13[b]	.25**
Stroop: interference time (s) (−5.1–103.7)	21.37	13.35	.62[b] **	.25**
Raven coloured progressive matrices (7–24)	17.96	3.43	.80[a]/.54[b] **.87[d]	−.36**

Note: Actual ranges per cognitive measure are presented between parentheses.

[a]Cronbach's alpha determined over a sample (*N* = 341), also including (dementia) patients, to prevent a restriction of range effect.

[b]Test–retest reliability (including level of significance) derived from 24 participants of the present study (with similar characteristics as the entire sample) that were retested two years later.

[c]Test–retest reliability estimated by Uterwijk (2000), using the original paper-and-pencil format.

[d]Internal consistency reliability (according to Item-Response Theory: the model of Mokken, 1971) estimated by Lindeboom, Smits, Smit, and Jonker (1999), who also used sets A and B.

[e]Age *r* reflects the Pearson correlation of each measure with age.

*$p < .05$, two-tailed.

**$p < .01$, two-tailed.

3.2. Properties of the manifest variables

Table 2 presents the psychometric properties of each cognitive measure. All measures were significantly related to age. Two PS measures (Symbol Search Test and Symbol-Digit Coding Test) and one episodic memory measure (10-Word List-Learning Test) correlated highest with age ($r > .50$).

Most measures had a good to excellent level of internal consistency, ranging from .77 to .90 (see Table 2). In addition, test–retest reliability was computed for each measure over a subgroup of 24 participants that was retested two years later. Though this subgroup is small and the interval is large (permitting aging effects), at least some indication was obtained of the reliability of the measures that did not allow internal consistency analysis (e.g. response time-based measures). Test–retest reliability levels ranged from as low as .13 (switching accuracy on the Rule-Shift Test, though internal consistency was adequate) to as high as .92 (Visual Naming Test: total correct). In general, all semantic memory measures showed high test–retest reliability, whereas most measures of episodic memory, PS and EF had a reasonable to high level of test–retest reliability. Overall, relative to measures of the other cognitive constructs, reliability of the EF measures was lowest (consistent with Luszcz & Bryan, 1999), though this was not considered as problematic.

Table 3 displays the correlations among the measures. In general, as expected, measures within a latent construct correlated more highly with one another than with measures of other constructs.

3.3. Structural equation modeling results

It was investigated whether age-related variance in episodic and semantic memory performance was better explained by PS, or EF, or both, rather than directly in terms of memory components. As discussed above, one broad Episodic Memory construct was modeled (reflecting free and cued recall, as well as recognition) and two separate semantic memory constructs (Semantic Fluency and Semantic Naming).[2] The subdivision into five cognitive constructs was also the best supported solution according to a principal components analysis (Varimax rotation; 68.31% variance explained).

In the initial model M1[3] (see Figure 2), episodic memory and semantic fluency are assumed to show direct age-related decline, expressed by direct age relations to Episodic Memory and Semantic Fluency (i.e. path A from age_L to Episodic Memory and path B_1 from age_L to Semantic Fluency are set free). In addition, in M1, PS and EF are assumed to show stable performance level with increasing age, expressed by absent direct age relations to PS and EF (i.e. path C from age_L to PS and path D from age_L to EF are fixed to 0). Fit indices of initial model M1 are listed in Table 4, as are fit indices of subsequently tested models that will be discussed below.[4]

From initial model M1, first, the relative contribution of PS and EF to the model was determined, *in parallel to* age-related decline of episodic and semantic memory (see section I of Table 4). M2 showed that freeing the path from age_L to PS (path C in Figure 2) led to improved model fit. The fit was further improved by a direct age relation to EF (freeing path D; M3). This implies that age-related decline of both PS and EF, in addition to age-related decline of episodic and semantic memory, contributed to the understanding of cognitive impairment at (very) old age. Figure 3 provides an illustration of M3, including parameter estimates of the structural relations.

3.3.1. Processing speed models explaining age-related variance in episodic and semantic memory

Next, it was examined whether PS could account for age-related decline in episodic and semantic memory (see Table 4, section II). These mediation models were specified by changing the nondirectional residual covariance between the mediator variable (PS in this case) and the dependent variable (Episodic Memory or Semantic Fluency; parameters E and F_1, respectively; see Figure 3) into a unidirectional path and, next, by constraining the path from age_L to the dependent variable (path A or path B_1) to 0.

Table 3. Correlation matrix of cognitive measures used as indicators of the dependent latent cognitive constructs

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. WLL-FR	–																	
2. PAL-sem	.46**	–																
3. PAL-n.sem	.54**	.63**	–															
4. WLL-rcgn	.60**	.37**	.40**	–														
5. PAL-rcgn	.42**	.61**	.51**	.48**	–													
6. Main-c.flc	.49**	.28**	.34**	.28**	.24**	–												
7. Sub-c.flc	.47**	.35**	.39**	.39**	.37**	.66**	–											
8. Letter-flc	.40**	.23**	.32**	.28**	.27**	.44**	.53**	–										
9. vs.n.-cor	.34**	.33**	.30**	.32**	.37**	.34**	.50**	.45**	–									
10. vs.n.-RT	−.23**	−.14*	−.12	−.13*	−.13*	−.24**	−.36**	−.37**	−.58**	–								
11. Vb.n.-cor	.38**	.29**	.33**	.32**	.36**	.36**	.52**	.48**	.70**	−.45**	–							
12. Vb.n.-RT	−.29**	−.17**	−.25	−.18**	−.19**	−.24**	−.40**	−.45**	−.56**	.62**	−.65**	–						
13. SS	.39**	.11	.16*	.21**	.14*	.37**	.38**	.43**	.41**	−.55**	.38**	−.52**	–					
14. SDC	.50**	.20**	.22**	.30**	.21**	.37**	.47**	.51**	.44**	−.58**	.41**	−.49**	.73**	–				
15. RS-RT1	−.19**	−.06	−.05	−.17**	−.08	−.18**	−.25**	−.36**	−.37**	.40**	−.29**	.47**	−.47**	−.51**	–			
16. RS-Sw2	.32**	.34**	.28**	.32**	.39**	.24**	.32**	.22**	.33**	−.14*	.33**	−.18**	.14*	.18**	−.08	–		
17. Stroop	−.16*	−.10	−.19**	−.10	−.13	−.18**	−.27**	−.28**	−.25**	.20**	−.34**	.36**	−.33**	−.24**	.20**	−.30**	–	
18. RCPM	.35**	.30**	.31**	.27**	.31**	.31**	.39**	.43**	.35**	−.26**	.37**	−.25**	.37**	.45**	−.23**	.44**	−.25**	–

Notes: WLL-FR = 10-Word List-Learning Test (free recall); PAL-sem. = Paired-Associate Learning Test: semantic pairs; PAL-n.sem. = Paired-Associate Learning Test: non-semantic pairs; WLL-rcgn. = 10-Word-Recognition Test; PAL-rcgn. = Paired-Associate-Recognition Test; Main-c.flc. = Main-Category Fluency Test; Sub-c.flc. = Sub-Category Fluency Test; Letter-flc. = Letter Fluency Test; vs.n.-cor. = Visual Naming Test: total correct; vs.n.-RT = Visual Naming Test: response time; Vb.n.-cor. = Verbal Naming Test: total correct; Vb.n.-RT = Verbal Naming Test: response time; SS = Symbol Search Test; SDC = Symbol-Digit Coding Test; RS-RT1 = Rule-Shift Test: base response time (rule 1); RS-Sw2 = Rule-Shift Test: switching accuracy (score rule 2); Stroop = Stroop: interference time; RCPM = Raven Coloured Progressive Matrices;.

*$p < .05$, two-tailed.

**$p < .01$, two-tailed.

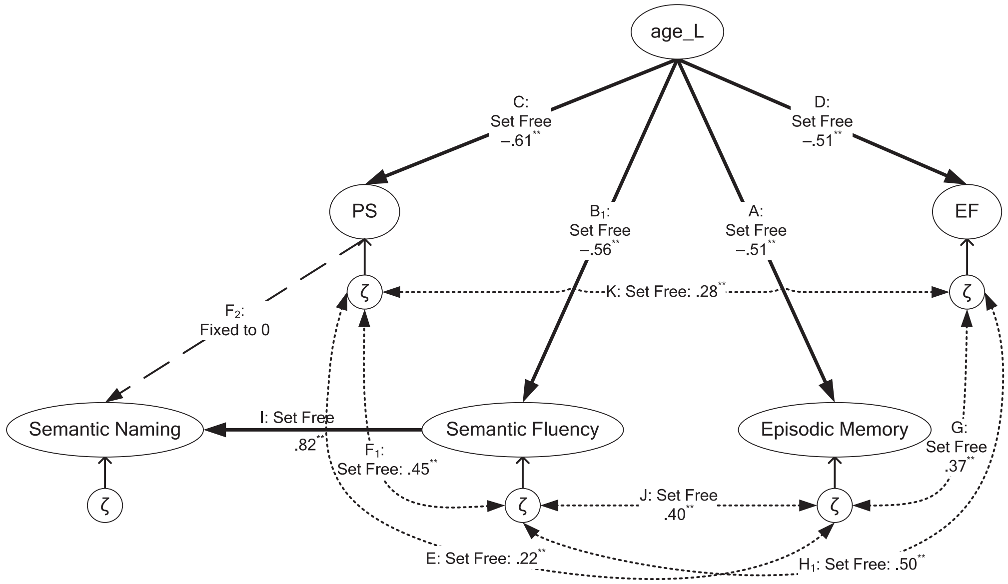

Figure 3. Structural model M3, including parameter estimates of the structural relations (p* < .05; ***p* < .01) (see also Table 4, section I): age-related decline of episodic memory and semantic fluency, and indirect decline of semantic naming (via age-related decline of semantic fluency), in parallel to age-related decline of processing speed (PS) and executive functioning (EF), with increasing age.**

Notes: age_L = age represented as a latent variable. A = path from age_L to Episodic Memory. B_1 = path from age_L to Semantic Fluency. C = path from age_L to PS. D = path from age_L to EF. E = non-directional relationship between the residuals of PS and Episodic Memory. F_1 = non-directional relationship between the residuals of PS and Semantic Fluency. F_2 = path from PS to Semantic Naming. G = non-directional relationship between the residuals of EF and Episodic Memory. H_1 = non-directional relationship between the residuals of EF and Semantic Fluency. I = path from Semantic Fluency to Semantic Naming. J = non-directional relationship between the residuals of Episodic Memory and Semantic Fluency. K = non-directional relationship between the residuals of PS and EF. ζ (or zeta) = residual for a latent cognitive construct. A dashed line with double arrows indicates a non-directional relationship between (the residuals of) two latent cognitive constructs (represented in LISREL by the psi-parameter).

First, model M4 was tested, which assumed indirect age-related decline of Episodic Memory, via decline of PS (relevant to the first hypothesis, described in Section 1.5). As Table 4 presents, M4 showed significantly *worse* fit compared to M3; therefore, M4 was rejected. Secondly, M5 was tested, which assumed indirect decline of Semantic Fluency, via decline of PS (relevant to the first exploratory hypothesis). In contrast with M4, M5 showed similar (i.e. not worse) model fit as M3. M5 was preferred to M3 because of its greater parsimony. Thirdly, M6 was tested, which assumed indirect decline of Semantic Naming, via decline of PS, in addition to decline mediated by Semantic Fluency (path I in Figure 3; also relevant to the first exploratory hypothesis). Despite reduced parsimony (by freeing path F_2; note that the path from age_L to Semantic Naming was already constrained to 0 when initial model M1 was developed, see Note 2), M6 led to significantly *improved* model fit compared to M5.

3.3.2. Executive functioning models explaining age-related variance in episodic and semantic memory

Next, it was examined whether EF could account for age-related decline in episodic memory and semantic fluency (see Table 4, section II). First, M7 was tested, which assumed indirect decline of Episodic Memory, via age-related decline of EF. This model was specified by changing the nondirectional residual covariance between the mediator variable EF and the dependent variable Episodic Memory (parameter G in Figure 3) into a unidirectional path and, subsequently, by constraining the path from age_L to Episodic Memory (path A) to 0. As Table 4 presents, M7 showed similar fit as M6. Because this more parsimonious model did not result in any appreciable deterioration of the fit, M7 was preferred to M6. Whereas the model of PS mediating age-related decline of episodic memory (M4) led to significantly worse fit (i.e. *in*consistent with the first hypothesis), the model of EF as a mediator of episodic memory did *not* lead to worse fit (i.e. consistent with the second hypothesis).

Secondly, M8 was tested, which assumed indirect decline of Semantic Fluency, via decline of EF (relevant to the second exploratory hypothesis). This model was specified by changing the nondirectional residual covariance between EF and Semantic Fluency (parameter H_1) into a unidirectional path. Note that path B_1 from age_L to Semantic Fluency was already constrained to 0 in M5. As Table 4 presents, M8 led to similar (not worse, even slightly better) fit as M7. Figure 4 depicts model M8, including parameter estimates of the structural relations.

Table 4. Fit indices for nested sequence of processing speed and executive functioning models in explaining age-related variance in episodic and semantic memory

Model		χ^2_{Diff} test						
		df	$\chi^{2\,a}$	comp.	χ^2	RMSEA	CFI	NNFI
I. Contribution of PS and EF to the model, *in parallel to* age-related decline of episodic and semantic memory								
M1	PS and EF ≈ (see Figure 2)	139	467.53	–	–	.101	.933	.918
M2	PS ↓; EF ≈ (path C freed)	138	411.62	M1	55.91**b	.092	.945	.932
M3	PS ↓; EF ↓ (path D freed; see Figure 3)	137	396.93	M2	14.69**b	.090	.953	.941
II. *Indirect* decline of episodic and semantic memory, via PS and EF decline, instead of a direct relation to age								
M4	Episodic Memory indirect ↓, via PS ↓ (dir. path E; A fixed)	138	408.78	M3	11.85**c	.092	.951	.939
M5	Semantic Fluency indirect ↓, via PS ↓ (dir. path F_1; B_1 fixed)	138	398.04	M3	1.11	.090	.953	.941
M6	Semantic Naming indirect ↓, via PS ↓ (path F_2 freed)	137	383.61	M5	14.43**b	.088	.955	.944
M7	Episodic Memory indirect ↓, via EF ↓ (dir. path G; A fixed)	138	385.28	M6	1.67	.088	.954	.943
M8	Semantic Fluency indirect ↓, via EF ↓ (dir. path H_1; Figure 4)	138	384.23	M7	1.05	.088	.955	.944
III. Most parsimonious model of PS and EF explaining age-related episodic and semantic memory decline								
M9	Independent PS ↓ and EF ↓ (path K fixed); indirect Episodic ↓ (via EF); indirect Fluency ↓ (via PS, EF and Episodic); indirect Naming ↓ (via Fluency and PS)	140	381.40	M8	2.83	.086	.951	.940
M10	As M9, except for path H_1 (EF→Fluency) constrained to 0 (see Figure 5)	141	386.22	M9	4.82*c	.086	.950	.939

Notes: χ^2_{Diff} test = Chi-square difference test (testing significance in χ^2 given the difference in *df*); comp. = model with which the tested model is compared; RMSEA = root-mean-square error of approximation; CFI = comparative fit index; NNFI = nonnormed fit index; M1–M10 = Models 1–10; PS = processing speed; EF = executive functioning; ↓ = reduced level of performance with increasing age (i.e. freeing the path from exogene variable age_L to the respective endogenous variable—the gamma-parameter in LISREL); ≈ = stable level of performance with increasing age (i.e. fixing the gamma-parameter to 0, but freeing the residual covariance between the respective endogenous variable and other relevant endogenous variable(s)); dir. = directional.

[a]Each Chi-square test showed a significant result: $p < .001$.

[b]Better fit compared to the model with which the tested model is compared.

[c]Worse fit compared to the model with which the tested model is compared.

*$p < .05$.

**$p < .01$.

In sum, both PS and EF mediated age-related variance in episodic and semantic memory. It is concluded that episodic and semantic memory did *not* contribute to the model directly, but only showed *indirect* decline from young-old to very old age.

3.3.3. The most parsimonious model of processing speed and executive functioning explaining age-related episodic and semantic memory decline

In the final series of models (see Table 4, section III), the focus was on determining the most parsimonious model of PS and EF that explained age-related episodic and semantic memory decline. This served the investigation of the relative importance of the different relationships. It was examined whether model fit significantly decreased by constraining specific relationships to 0 or by changing a nondirectional residual covariance between two endogenous variables into a unidirectional regression coefficient. Specific modifications were based on nonsignificant *t* values of covariances and coefficients ($p > .01$).

First, the non-significant covariance between PS and Episodic Memory ($t = .07$; parameter E in Figure 4) was constrained to 0, which led to similar model fit as M8 ($\chi^2(139, N = 234) = 384.03$; $\chi^2_{Diff} = .20$, $p = .66$; RMSEA = .087; i.e. *in*consistent with the first hypothesis). Secondly, the non-significant covariance between Episodic Memory and Semantic Fluency ($t = 1.81$; parameter J) was changed into a unidirectional path from Episodic Memory to Semantic Fluency ($t = 2.05$), which

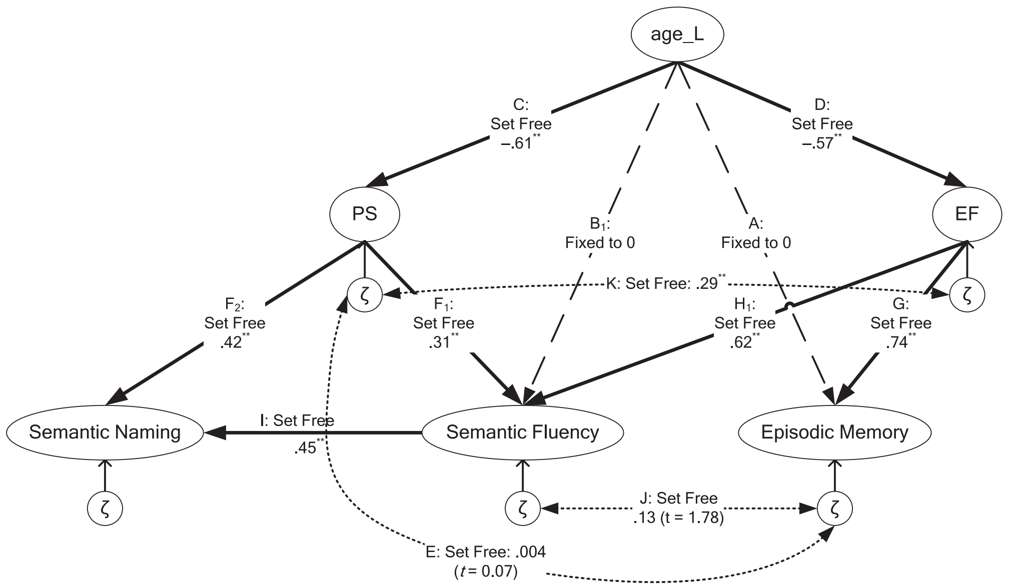

Figure 4. Structural model M8, including parameter estimates of the structural relations (p* < .05; ***p* < .01) (see also Table 4, section II): indirect decline of episodic memory, via age-related decline of EF; indirect decline of semantic fluency, via age-related decline of PS and EF; indirect decline of semantic naming, via age-related decline of PS and via indirect decline semantic fluency.**

Notes: age_L = age represented as a latent variable. A = path from age_L to Episodic Memory. B_1 = path from age_L to Semantic Fluency. C = path from age_L to PS. D = path from age_L to EF. E = non-directional relationship between the residuals of PS and Episodic Memory. F_1 = path from PS to Semantic Fluency. F_2 = path from PS to Semantic Naming. G = path from EF to Episodic Memory. H_1 = path from EF and Semantic Fluency. I = path from Semantic Fluency to Semantic Naming. J = non-directional relationship between the residuals of Episodic Memory and Semantic Fluency. K = non-directional relationship between the residuals of PS and EF. ζ (or zeta) = residual for a latent cognitive construct. A dashed line with double arrows indicates a non-directional relationship between (the residuals of) two latent cognitive constructs (represented in LISREL by the psi-parameter).

resulted in exactly the same model fit as the previous model. Fixing this parameter to 0 (χ^2(140, *N* = 234) = 388.80) or changing it into a unidirectional path from Semantic Fluency to Episodic Memory (χ^2(139, *N* = 234) = 387.05) led to (slightly) worse fit (χ^2_{Diff} = 4.77, *df* = 1, *p* = .03, and χ^2_{Diff} = 3.02, *df* = 1, *p* = .08, respectively).

In addition, it was investigated whether parsimony of the model improved by trimming the relationship between PS and EF (parameter K). First, the model in which PS and EF were joined together as one overall construct (specified by fixing parameter K to 1, parameter D to 0, and the residual variance of EF to 0) showed greatly reduced model fit (χ^2(143, *N* = 234) = 633.32; χ^2_{Diff} = 249.29, *p* < .01; RMSEA = .121). Secondly, the model assuming indirect decline of EF, via decline of PS, showed slightly reduced fit (χ^2(140, *N* = 234) = 389.99; χ^2_{Diff} = 5.96, *p* = .02; RMSEA = .088) and was rejected as well. Significantly better fit was, however, obtained for model M9, in which the direct age relation to EF (path D) was restored and parameter K was constrained to 0 (χ^2_{Diff} = 8.59, *p* < .01, compared to the previous model). Thus, direct age relations to both PS and EF (i.e. consistent with the third hypothesis; though independent from one another) seem necessary in view of the goodness of fit.

The last modification to arrive at the most parsimonious model (M10; see also Figure 5) was fixing the path from EF to Semantic Fluency to 0 (H_1, developed in M8; i.e. *contrary* to the second exploratory hypothesis). This path was only slightly significant (*t* = 2.25) in M9. M10 showed slightly reduced model fit compared to M9 (*p* = .03). However, in M10, the path from Episodic Memory to Semantic Fluency (J) was evidently significant (*t* = 6.17)—as were all the other non-constrained relationships—whereas in M9, this path was only slightly significant (*t* = 2.45).

Figure 5 visualizes the final, most parsimonious model M10. Construct reliability of each latent construct was also calculated, which turned out to be high for most constructs (> .70), except for EF (.57). Thus, it may be argued that the age-related influence of EF on, particularly, episodic memory is meaningful (consistent with the second hypothesis), despite its mediocre reliability. This may not as well be explained by PS, which seems to have a greater impact on (different aspects of) semantic memory (i.e. consistent with the first exploratory hypothesis). This is also reflected by the correlations between the latent constructs, which are presented in Table 5. Furthermore, age correlated highest with PS. Semantic Fluency showed high correlations with, in fact, all latent constructs, which may be illustrative of its heterogeneous nature.

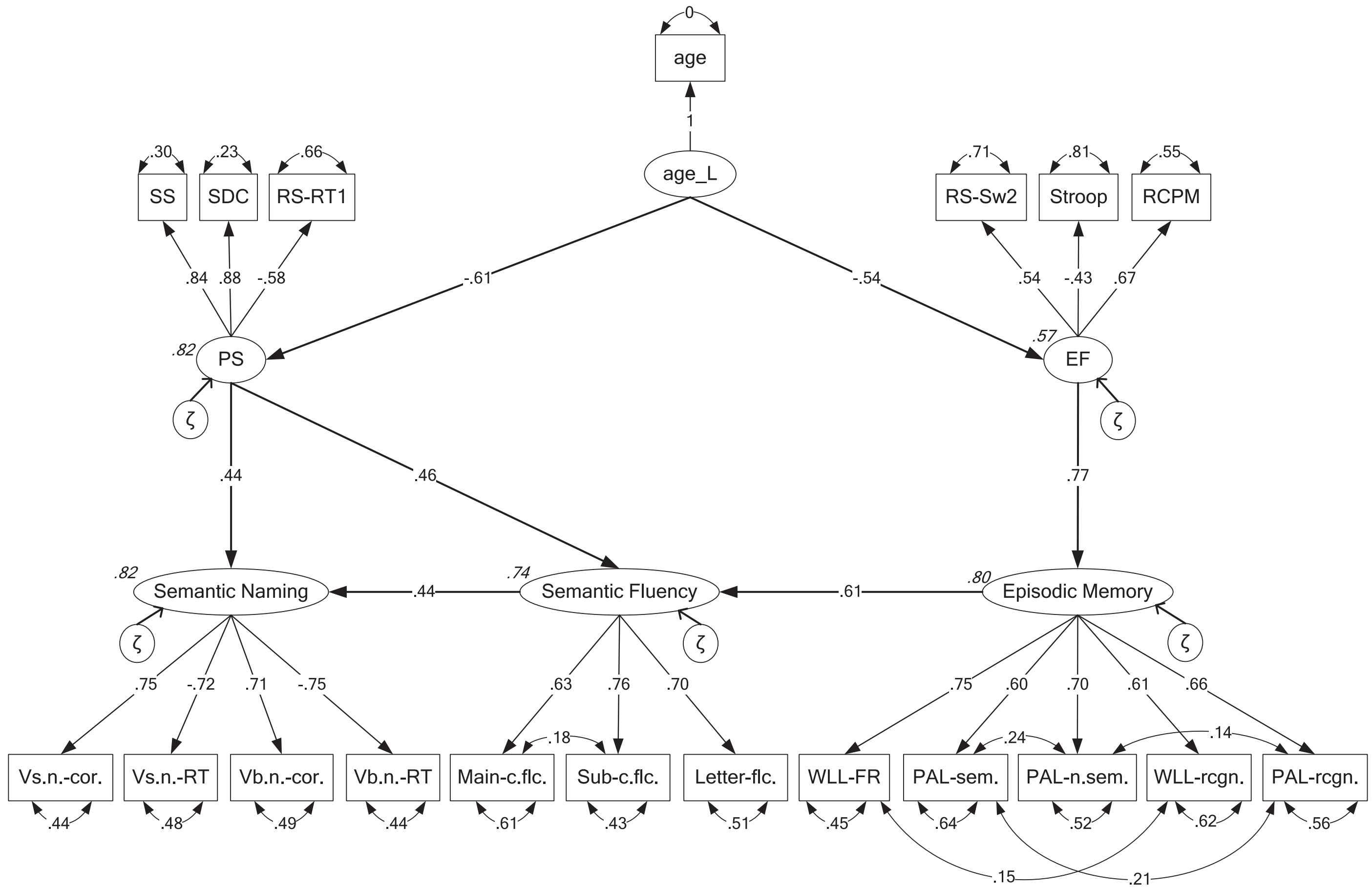

Figure 5. Measurement and structural part of the most parsimonious M10 (see Table 4, section III), representing the relations (expressed in standardized coefficients) between age_L (age represented as a latent variable), Processing Speed (PS), Executive Functioning (EF), Episodic Memory, Semantic Fluency, and Semantic Naming within the elderly sample (55–96 years).

Notes: Relationships that were constrained to 0 are not presented. The curved arrows indicate residuals for each indicator, as well as beforehand accepted correlated residuals between several indicators to control for shared method variance. All presented parameters are significantly different from zero (***t*** > 2.56; ***p*** < .01). Italicized digits indicate construct reliabilities of the latent cognitive constructs. WLL-FR = 10-Word List-Learning Test (free recall); PAL-sem. = Paired-Associate Learning Test: semantic pairs; PAL-n.sem. = Paired-Associate Learning Test: non-semantic pairs; WLL-rcgn. = 10-Word-Recognition Test; PAL-rcgn. = Paired-Associate-Recognition Test; Main-c.flc. = Main-Category Fluency Test; Sub-c.flc. = Sub-Category Fluency Test; Letter-flc. = Letter Fluency Test; vs.n.-cor. = Visual Naming Test: total correct; vs.n.-RT = Visual Naming Test: response time; Vb.n.-cor. = Verbal Naming Test: total correct; Vb.n.-RT = Verbal Naming Test: response time; SS = Symbol Search Test; SDC = Symbol-Digit Coding Test; RS-RT1 = Rule-Shift Test: base response time (rule 1); RS-Sw2 = Rule-Shift Test: switching accuracy (score rule 2); Stroop = Stroop: interference time; RCPM = Raven Coloured Progressive Matrices.

Table 5. Correlations between dependent latent cognitive constructs and age (M10)

Measure	1	2	3	4	5	6
1. Age	–					
2. Processing speed	−.61**	–				
3. Executive functioning	−.54**	.33**	–			
4. Episodic memory	−.42**	.26**	.77**	–		
5. Semantic fluency	−.54**	.62**	.62**	.73**	–	
6. Semantic naming	−.51**	.71**	.42**	.43**	.71**	–

$^{**}p < .01$, two-tailed.

In addition, *absolute model fit* of the best fitting and most parsimonious model was evaluated. Overall, absolute model fit according to the RMSEA (.086) was close to adequate (≤ .08, Steiger, 1990, p. 90; % confidence interval of RMSEA in M10 was .076–.097, straddling the value of 0.08). Furthermore, the CFI and NNFI values (see Table 4) were clearly above 0.90, which indicates that the model fitted the data evidently better than the independence model. Also, according to recommendations for model evaluation based on other goodness-of-fit measures[5] (Schermelleh-Engel, Moosbrugger, & Müller, 2003; see p. 52), model fit was generally acceptable, *despite* the high complexity (df = 141) as well as the parsimony of the final model.

Model complexity is a natural consequence of the research goal, which required the simultaneous study of relatively many cognitive constructs and their interrelationships, instead of focusing on only one or two factors. In addition, correlations between the cognitive measures are rather high (see Table 3), which reduces the chance of finding very good fitting models that are also parsimonious and do not compromise the theoretical foundations of the investigation. Finally, the sample size clearly exceeded the minimum sample size necessary to obtain adequate *power* (considering the high df) to reject the null hypothesis of acceptable fit ($RMSEA_0 \le .08$) when fit is actually mediocre to poor ($RMSEA_a = .10$; $N = 154$; MacCallum, Browne, & Sugawara, 1996).

Nonetheless, evidence was found that the best fitting and most parsimonious model is significantly *more* plausible than the alternative models that represented a different interplay between episodic and semantic memory, on the one hand, and PS and EF, on the other hand.

4. Discussion

In the present study, episodic and semantic memory performance was investigated in a sample of 234 community dwelling participants, varying from young-old age (starting at 55 years) to very old age (up to 96 years old). It was specifically examined whether age-related variance in episodic and semantic memory was better explained by PS, or EF, or both (i.e. the first, second, and third hypothesis, respectively, described in Section 1.5), rather than directly in terms of memory components. In correspondence with the literature review, episodic memory and semantic memory (fluency and naming) indeed showed only indirect performance decline with increasing age when PS and EF were taken into account.

4.1. Episodic memory functioning in (very) old age: explanations from executive functioning theories

Contrary to the processing speed theory of memory decline in normal aging (e.g. Salthouse, 1996a; see Section 1.1; the first hypothesis), it was found that the model which assumed indirect age-related decline of episodic memory, via PS, led to worse fit. Instead, age-related decline of EF mediated episodic memory (consistent with: Backman & Larsson, 1992; Bryan et al., 1999; Craik & McDowd, 1987; Dempster, 1992; see Section 1.3; the second hypothesis).

At first sight, this result seems in contrast with Crawford et al. (2000), who found that PS predicted age-related variance in episodic memory better than EF. However, they obtained this result only in a sample of participants aged between 18 and 75 years, not in an older sample. In a subsequent study using SEM performed over the same data-set, Ferrer-Caja et al. (2002) found that EF accounted for the largest variance in episodic memory. Thus, the results suggest that in *very old age*, the impact of executive dysfunctions on episodic memory performance exceeds the influence of cognitive slowing. Accordingly, Sliwinski and Buschke (1997) found that PS did not influence their very old participants' decline in the ability to benefit from conditions of increased encoding specificity.

The greater impact on episodic memory of EF, as compared to PS, may be explained by the rather *broad* nature of the episodic memory construct. This construct did not only include free recall of unstructured word lists, but also cued recall (and recognition) of semantically associated material. In addition, the broad nature of the EF construct may have influenced the results. The EF construct comprised cognitive flexibility and inhibition, which are frequently investigated (but are statistically less reliable). However, this construct also reflected concept formation or abstract thinking (measured by the Raven) since these may all be considered cognitive capacities that are called upon in elaborate episodic learning and in goal-directed behavior in general (e.g. Baddeley, 1986; Craik & McDowd, 1987; Wilson et al., 1996). Furthermore, the episodic memory measures probably reflect more pure tests of long-term memory because the confounding by short-term memory or attention (associated with PS) was prevented by administering a distraction task between study and test phase.

These sample and task aspects may explain why PS accounted for less age-related variance in episodic memory, compared to the results of previous studies. In general, the PS and EF tasks differ from traditional tests of PS and EF because the tasks that were used did not require motor responses from the participants, which give rise to large variance in response times, due to physical instead of cognitive limitations. Nonetheless, the impact of PS and EF has rarely been studied *simultaneously*, as was done in the present study.

4.2. Semantic memory functioning in (very) old age: explanations from processing speed theories

It was found that semantic fluency was mainly mediated by PS (consistent with Ghisletta & de Ribaupierre, 2005; Lindenberger et al., 1993; see Section 1.2; consistent with the first exploratory hypothesis). The impact of EF on semantic fluency was negligible when PS was taken into account (M10). Thus, decreased verbal fluency at very old age mainly indicates generally slowed word-finding processes, above less-efficient self-initiated search strategies, which may be more sensitive to EF. Nonetheless, consistent with the expectations, it was found that EF explained a higher amount of age-related variance in semantic fluency than in semantic naming.

Furthermore, it was found that semantic naming was also mediated by PS. This seems consistent with previous findings in young-old adults of generally longer latencies, both on naming to verbal definitions (Eustache et al., 1998) and on picture naming (Bowles, 1993; Mitchell, 1989). To my knowledge, no normal aging studies have been published that directly compared fluency and naming performance.

In sum, it is concluded that PS and EF *differ* in their specific impact on memory: PS mainly mediates age-related decline of semantic memory processes, whereas EF mainly mediates age-related decline of episodic memory. In addition, the modeling results showed that PS and EF influence these memory components in parallel and *independent* from one another (more or less consistent with Salthouse & Ferrer-Caja, 2003).

4.3. Limitations of the present study

The interplay of these different aspects of cognition in normal aging could, of course, only be revealed by investigating these aspects simultaneously (within the same sample of participants), and by applying sufficiently valid as well as broad constructs (see Section 2.3). In addition, it was important to model age-independent relations among the cognitive constructs (e.g. Lindenberger &

Pötter, 1998; see Section 2.4). Naturally, it is *not* suggested that the model, as was described above, is *the* model for explaining age-related cognitive decline at very old age. It simply represents the most plausible model, concerning the hypothesized set of cognitive components that were considered.

Thus, this does not mean that other cognitive components that were not included explicitly are not important. For example, working memory could still be relevant (e.g. Luszcz & Bryan, 1999). Although working memory presumably was involved in several of the EF and PS measures (particularly, the Symbol-Digit Coding Test and the switching accuracy measure of the Rule-Shift Test), measures that were specifically aimed at working memory were not included. This would also have caused overlap between the PS and the EF constructs, whereas the test battery was designed to *prevent* overlap between the various constructs that were investigated. In addition, a significant direct relation between (visual) PS and episodic memory might have been found if the latter construct had been measured by tests of visual-spatial nature (e.g. Park et al., 1996). Instead, cognitive constructs were chosen that are important in the differentiation between normal aging and dementia, Alzheimer's Disease in specific (e.g. Spaan, Raaijmakers, & Jonker, 2003; Spaan et al., 2005).

5. General conclusion and implications for clinical practice

It is concluded that in normal aging, up to very old age, age-related impairments in episodic and semantic memory are better explained by decline of EF and PS than (directly) in terms of memory components. These findings have important implications for the development of memory measures that differentiate between normal aging and (pre)clinical dementia at very old age. Because the prevalence of dementia increases exponentially with increasing age, knowledge about stable and deteriorating cognitive functions at very old age contributes to the reliability of differential assessment.

Dementia assessment is also more complicated at very old age, for example, because of comorbid medical diseases. In this population, it may therefore be important to try to correct for cognitive slowing and executive dysfunctions in assessing memory functioning, for example, statistically, in the calculation of normative data. But also, qualitatively, by *testing the limits* during test administration, thus allowing more time and providing more structure. In this way, false positive diagnosis of dementia may be reduced.

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Notes

1. Adopting Full Information Maximum-Likelihood missing data imputation produced the same results (regarding model fit indices and parameter estimates), probably related to the very low amount of missing data (i.e. only .85% of the total of measurements).
2. Beforehand, it was additionally investigated whether a response time-oriented subdivision of semantic memory showed better model fit: Semantic Naming Accuracy (representing the self-paced measures: the total correct scores of the Visual Naming Test and the Verbal Naming Test) versus Semantic Retrieval Speed (representing the other five semantic memory measures that make high speed demands). The task-oriented subdivision of Semantic Fluency versus Semantic Naming, however, showed better model fit (Akaike's Information Criterion (AIC; appropriate for non-nested model comparison) = 123.25 versus AIC = 142.32 for the response time-orient-

ed subdivision). Therefore, the task-oriented subdivision was used in subsequent analyses.

3. In developing the initial model M1 that contained these five constructs, the model of *in*direct decline of Semantic Naming, via age-related decline of Semantic Fluency, showed better fit than the model of direct age-related decline of Semantic Naming in addition to direct age-related decline of Semantic Fluency (χ^2_{Diff} = 20.80, $p < .01$). Therefore, M1 was based on the first model.
4. Each series of models was analyzed by comparing nested models that could be transformed into another by changing a single constraint. For reasons of brevity, not *each* nested model is listed necessary to arrive at the model to be discussed. Only theoretically relevant models are presented in Table 4. Intermediately tested models that showed relevant or unexpected results are listed in these tables as well or they are described in text.
5. Additional information on the goodness-of-fit of M10, which is not provided in Table 4: χ^2 = 386.22 is between 2*df* (282) and 3*df* (423); χ^2/df = 2.74 is between 2 and 3; standardized Root Mean Square Residual (SRMR) = .084 is between .05 and .10.

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