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**Individual Differences in Learning and Forgetting in Old Age:
The Role of Basic Cognitive Abilities
and Subjective Organization**

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ABSTRACT

Basic cognitive abilities and subjective organization have been suggested to account for age-related differences in episodic memory. These relations between basic cognitive abilities, subjective organization, and episodic memory have been mainly examined in cross-sectional studies and, thus, do not allow any conclusion regarding relations within the individual. In order to investigate mechanisms of cognitive aging, the present thesis extended this body of research by examining whether the suggested relations also exist at the individual level. In line with an individual-differences perspective of cognitive aging, variables may be considered as relevant explanatory variables of cognitive aging if these variables account for individual differences in the variable of interest in persons of similar old age. The present study used this approach regarding episodic memory, or more precisely, regarding learning and forgetting by conducting four studies. These four studies addressed the research question of whether there are individual differences in learning and forgetting in old age, how large these individual differences are, and whether subjective organization and basic cognitive abilities predict individual differences therein. In order to take into account general variables known to influence learning and forgetting, the four studies measured learning and forgetting by different designs. The present thesis presents and discusses three studies on learning (Study 1, Study 2, and Study 3). Study 1 used a fixed-trial free recall verbal learning task in a laboratory, whereas Study 2 investigated task-specific paired-associate learning in a naturalistic context. Study 3 investigated criterion-based dropout learning and included a measurement of retention. Finally, Study 4 analyzed forgetting of learned material within a fixed-trial learning design. Overall, the results indicated that there are reliable individual differences in learning and forgetting in old age and that basic cognitive abilities and subjective organization predict these and thus represent relevant explanatory variables of cognitive aging. Moreover, the results of this thesis imply possibilities of optimizing episodic memory in old age by taking into account life-span approaches of developmental psychology.

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1 INTRODUCTION

One of the most common assumptions concerning aging is that older persons forget more frequently and have greater difficulties to learn, that is, to acquire new knowledge (e.g., Ryan, 1992). In line with this societal expectation of a general decline in episodic memory, complaints of older adults themselves mostly refer to episodic memory (e.g., Hultsch, Hertzog, & Dixon, 1987). Thus, amongst lay persons, aging is often discussed in terms of undesirable age-related changes in episodic memory. Age-related declines in episodic memory are undesirable, because 1) it is known from an applied cognitive psychology perspective that the ability to learn (and to not forget) is essential to adapt to new environments (see Rast, 2011), and because 2) there is a trend in society of striving to acquire knowledge even in older age as, for example, reflected in political programs of lifelong learning (e.g., European Communities, 2007). Against this background, it is not surprising that also amongst lay persons, the question of what influences learning and forgetting in old age is of major interest.

This issue has also been addressed by many researchers from a cognitive aging perspective (see Shing et al., 2010, for a review). A large body of research investigated age-related trends and indicated that, on average, episodic memory is, indeed, negatively affected by old age (Davis et al., 2003; Kausler, 1994; Verhaeghen, Marcoen, & Goossens, 1993). However, recently a few studies clearly demonstrated that there are pronounced individual differences with regard to episodic memory in old age (MacDonald, Derwinger, Stigsdotter, & Bäckman, 2006; Rast & Zimprich, 2009; Zimprich, Rast, & Martin, 2008). An age-related decline in episodic memory may, thus, not affect all aging persons to the same extent.

One central aim of research on cognitive aging is to reveal mechanisms of individual aging with regard to episodic memory (see Hofer & Sliwinski, 2001): What are possible explanatory variables of individual differences in episodic memory? There are studies indicating that basic cognitive abilities such as working memory and processing speed decline

in old age and that these variables explain age-related differences in episodic memory (see Luszcz & Bryan, 1999, for a review). Briefly, the theoretical explanation is that higher processing speed and working memory ability may facilitate ongoing processes during encoding and retrieval, which, in turn, results in better episodic memory (Salthouse, 1991, 1996).

Another line of research emphasized the role of subjective organization for verbal learning, which is one form of episodic memory. It was shown that 1) subjective organization is related to recall performance (Tulving, 1962) and that 2) older adults may have difficulties to organize to-be-learned material (e.g., Davis et al., 2003). These findings warrant the conclusion that an age-related decline in episodic memory may be due to less subjective organization.

However, both lines of research, investigating basic cognitive abilities and subjective organization as possible predictors of episodic memory in older age, mainly refer to cross-sectional studies. One shortcoming of cross-sectional studies is that only between-person age-related differences are analyzed (Sliwinski & Buschke, 1999). Any conclusion regarding relations of the suggested variables within individuals is not possible, because cognitive aging is examined as an average process. Individual differences in aging are not taken into account. However, as noted by Hofer and Sliwinski (2001) “ageing occurs within individuals and it is at this level that theory must be evaluated” (p. 350). Thus, the stated findings, which suggest that basic cognitive abilities and subjective organization may explain age-related differences in episodic memory, are not well supported empirically from an individual-differences cognitive aging perspective and they are not unanimously informative. Yet, the suggested theoretical mechanisms of how basic cognitive abilities and subjective organization may influence episodic memory are still valuable, since they imply predictions regarding which variables may influence individual differences in episodic memory in old age.

Following this, approaches that analyze relations between basic cognitive abilities, subjective organization, and episodic memory *within* the individual are more informative from an individual-differences perspective of cognitive aging. This thesis presents one analytical approach that offers the possibility to examine whether the suggested relations regarding episodic memory are evident within the individual: Are basic cognitive abilities and subjective organization predictors of individual differences in learning and forgetting among persons of similar old age?

The rationale for using this approach is as follows: From an individual-differences cognitive aging perspective it is argued that any variable considered as explanatory for cognitive aging should have the power to explain individual differences in a cognitive ability, e.g., episodic memory, among persons of similar old age (Hofer & Sliwinski, 2001). Only if variance in a cognitive ability is explained by an assumed correlated variable (regardless of age-variance), this variable may be considered as a relevant explanatory variable of cognitive aging. In line with this argumentation, analyzing predictors of individual differences in episodic memory among persons of similar old age represents one approach of cognitive aging – of *individual* cognitive aging.

Note that a longitudinal design and a narrow age cohort (NAC) design represent additional approaches to analyze the suggested relations between basic cognitive abilities, subjective organization, and episodic memory directly within the individual (see Hofer & Sliwinski, 2001; Sliwinski & Buschke, 1999). The few studies that have used this approach, provided generally little support for the suggested relations (Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992; Sliwinski & Buschke, 1999; Sternäng, Wahlin, & Nilsson, 2008; Zimprich, 2002; Zimprich & Martin, 2002). However, these studies exclusively examined within-person relations between processing speed and learning. Relations at the individual level regarding further basic cognitive abilities such as working memory, subjective organization, and both learning and forgetting as two facets of episodic

memory remain an open issue up to date. In order to extend this research, the present thesis analyzed whether besides processing speed, working memory and subjective organization may be related to learning and forgetting in old age, more precisely, to individual differences therein.

This individual-differences approach of the present thesis was applied in conjunction with four different research questions. Before presenting these studies, a brief discussion of general findings will be presented with regard to variables influencing learning and forgetting (1.1). Learning and forgetting will then be discussed with regard to age-related differences, possible cognitive explanations of these, and limitations of cross-sectional studies in this context (1.2). Following this, the role of individual differences in learning and forgetting in old age is discussed (1.3). In order to gain insights into the question of why there might be individual differences in learning and forgetting in old age, theoretical mechanisms of basic cognitive abilities and subjective organization are outlined (1.3.1). In Chapter 2, four research questions that were investigated empirically in four different studies using the individual-differences approach described above are presented. After presenting these four studies, a final discussion with regard to implications of individual differences in learning and forgetting (3.1) and regarding basic cognitive abilities and subjective organization as relevant explanatory variables of cognitive aging (3.2) as well as an outlook (3.3) are addressed with regard to the core aim of the present thesis: Are basic cognitive abilities and subjective organization relevant predictors of individual differences in learning and forgetting in old age?

1.1 Learning and Forgetting

Learning and forgetting may refer to different kinds of memory, for example, skill learning, associative learning, etc. (see Squire, 2004, for an overview of different memory systems). From a cognitive aging perspective, the focus has been on learning and forgetting as part of episodic memory (e.g., Kausler, 1994). As mentioned above, episodic memory is an age-sensitive cognitive process (Balota, Dolan, & Duchek, 2000; see Shing et al., 2010, for a review). Furthermore, episodic memory is a relevant memory system in daily life. For example, learning and forgetting of verbal material as one form of episodic memory is relevant from an applied cognitive psychology perspective, because verbal learning and forgetting tasks are present in daily life if: For example, an older person wants to remember a name of a friend, or to read and understand instructions such as information on packaging (see Kausler, 1994).

Before addressing the question of which variables may explain individual differences in learning and forgetting in old age, this chapter reviews several robust findings with regard to variables influencing learning and forgetting in general. Note that the following review is selective. Influential variables that are also valuable from an individual-differences perspective are being presented - in particular, with regard to individual differences in learning and forgetting in old age and predictors of these.

1.1.1 The Relation between Learning and Forgetting

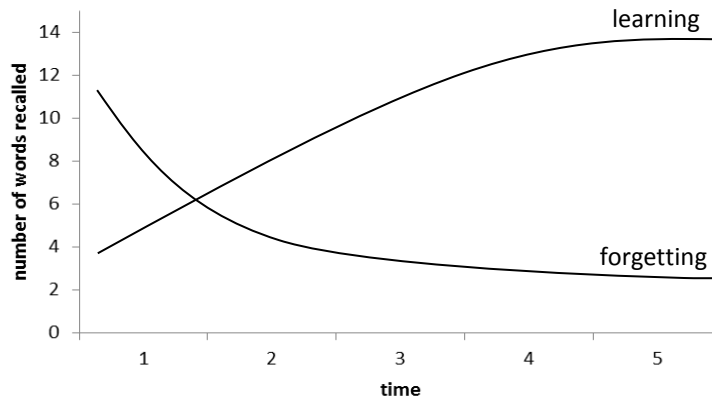
In this chapter, the relation between learning and forgetting is first discussed: Are learning and forgetting two sides of one coin (see MacDonald et al., 2006)? Learning is defined as “an adaptive change in the response of the organism as a result of a specific experience” (Phelps, 2007, p. 45), whereas forgetting may be defined as the inability to retrieve information because of inadequate retrieval cues (Tulving & Osler, 1968). These definitions already suggest that learning and forgetting are not the opposite of each other. Learning and forgetting may be considered as two different cognitive processes that overlap,

but not completely. Because of this, from a cognitive aging perspective, it seems necessary to include both processes learning *and* forgetting processes if the aim is to understand episodic memory in old age in its many facets.

What is learning and what is forgetting in the context of episodic memory? Episodic memory involves the encoding, consolidation, and retrieval of events (Underwood, 1969). Both learning and forgetting depend on these three stages, but with different weightings. Whereas learning mainly refers to encoding, that is, the transformation of information into memory, forgetting mainly refers to retrieval, that is, the attempt to retrieve and recall information from memory. Consolidation refers to the storage of the information and, thus, plays a role for both successful learning and successful (non-)forgetting. These considerations already imply that learning and forgetting may represent different cognitive processes.

Furthermore, if the process of learning and forgetting is considered, this issue becomes even clearer. Learning is represented by changes in recall performance after having had the opportunity to encode and to form associations, whereas forgetting is represented by changes (decreases) in recall performance after having had the opportunity to consolidate the material. Thus, learning and forgetting may both be represented by a curve reflecting recall performance (e.g., number of words successfully recalled) on several points in time (see Figure 1). With regard to learning, time refers to successive study trials, whereas with regard to forgetting, time refers to successive delayed recall occasions without further opportunities to study.¹

¹ Information gained by trajectories of performance has also been used for diagnostic reasons. In terms of dynamic testing such trajectories represent an alternative to conventional static tests of intelligence (Sternberg & Grigorenko, 2002).

Figure 1: Example of a learning and forgetting curve

Note. Time regarding the learning curve refers to subsequent trials; time regarding the forgetting curve refers to time since last trial.

Note that both trajectories represent non-linear trajectories. Whereas a typical learning curve is characterized by a gradual increase combined with a negatively accelerated trajectory (Ritter & Schooler, 2001), a typical forgetting curve is characterized by a gradual decrease combined with a negatively accelerated trajectory (Wixted & Ebbesen, 1991).²

Against this background, the issue of whether learning and forgetting are complementary may be further attenuated, because as described above, the process of learning and forgetting refers to different kinds of time scales. Additional evidence for the idea that learning and forgetting are not just the opposite of each other is also indicated by studies showing that various factors influence learning and forgetting differently (see MacDonald et al., 2006). Otherwise the same variables should influence learning and forgetting in opposite ways. This is not the case and will be illustrated in the following two chapters. Of course, forgetting is dependent on learning because learning is a prerequisite of forgetting. Hence, only information that was learned in advance may be forgotten (Rubin, 2007).

² The exact form of the curves, whether it is a, for example, a power (Newell & Rosenbloom, 1981), an exponential (Heathcote, Brown, & Mewhort, 2000), or a hyperbolic function (Zimprich et al., 2008b) with regard to learning and whether it is, for example, a power function (Wixted & Ebbesen, 1991) with regard to forgetting, remains unresolved.

Summing up, learning and forgetting may not be considered as two sides of one coin and therefore it seems important to investigate both processes. In line with this, learning and forgetting have been discussed separately as indicated by a large body of theories on learning and forgetting. These two research bodies will be discussed in the following, focusing on variables influencing learning and forgetting.

1.1.2 Variables Influencing Learning

What makes learning (more or less) successful? Before addressing this question regarding individual differences in learning in old age, general variables that should be taken into account for learning in old age and individual differences therein are discussed. The following review represents a selection of influential variables of learning that may be particularly relevant for individual differences in learning in old age. Of course, additional variables exist as well: For example, characteristics of word material such as arousal (Bradley, Greenwald, Petry, & Lang, 1992), word frequency (Sumbly, 1963), or concreteness (Paivio, 1965) are also known to influence learning.

Beginning with a review by Melton (1950) in the *Annual Reviews of Psychology*, learning has been discussed with regard to variables influencing learning. Whereas in this early review the focus was on stimulus-response learning, during the 1970s experimental psychologists shifted the focus towards verbal learning and possible variables influencing it.

An influential variable of learning is the number of study trials, or repetitions. The relation is straightforward: Repetition improves recall. The more repetitions, the better the association and, accordingly, recall performance across multiple points in time, that is, learning (Ebbinghaus, 1885/1964 as cited in Roediger, 2008). This increase in recall performance decreases over time as indicated by an upper asymptote (see Figure 1.1). However, Tulving (1962) noted that mere repetition of to-be-learned material may be ineffective. The crucial influential variable in the process of learning is, according to Tulving (1962), the organization of to-be-learned material. Subjective organization refers to learning

of unrelated material.³ The basic assumption of subjective organization as stated by Tulving (1962) is that individuals organize to-be-learned material into higher order units. Because of this organization it is argued that recall performance across trials may be facilitated. Subjective organization is reflected by the dynamics of retrieval, respectively, by the order in which individuals recall the learned material (Tulving, 1962). Therefore, subjective organization may be considered as a more qualitative measure of learning: How is to-be-learned material encoded and retrieved? This issue will be discussed in detail in Chapter 1.3.1.2, as subjective organization may also be considered as an explanatory variable of individual differences in learning and forgetting in old age.

During the 1970s, Craik and Lockhart (1972; see Craik, 2002, for a review) emphasized the relevance of the level of processing during encoding for learning by introducing their levels-of-processing approach (Craik & Lockhart, 1972). Briefly, it was shown that depending on the level in which to-be-learned material was encoded, recall performance was higher (or lower) (see Lockhart & Craik, 1990, for a review). For instance, a deeper encoding of to-be-learned material, that is, encoding due to the semantic meaning of the material (more meaningful processing), is related to higher recall performance than less meaningful processing (i.e., phonemic or orthographic processing) (Craik & Tulving, 1975). Recently, the idea of benefits of deep encoding was extended by findings showing that the levels-of-processing effect should be further differentiated. Nairne, Pandeirada, and Thompson (2008) provided evidence that words were better recalled if participants judged these words as relevant for personal survival.

The level-of-processing faced some limitations. One of these is the fact that there is no independent measure of depth of encoding (see Roediger, 2008), that is, the level of processing is not quantifiable. Furthermore, the effect of level of processing does not hold across different types of material and different testing conditions, for example, for perceptual

³ However, of course, pre-categorized material does have an effect on learning as reflected in an organization of material into categorical units (e.g., Mandler, 1967).

record tests the level of processing did not show an effect on recall performance (see Roediger, 2008). However, the levels-of-processing approach has been appreciated by many scientists, for example, with regard to advertisement issues (Saegert, 1979). As will be discussed in the discussion of the present thesis (Chapter 3.2.1), the effect of level-of-processing may also concern individual differences in encoding and possible interactions of these with individual differences in basic cognitive abilities.

A large body of literature is focused on schedules of learning and their possible influences on learning (see Cepeda, Pashler, Vul, & Wixted, 2006; DeJonge, Tabbers, Pecher, & Zeelenberg, 2012; Donovan & Radosevich, 1999, for a review). A so-called distributed schedule has been opposed to a massed learning schedule. Whereas a massed learning schedule means a presentation of stimuli without interruptions, a distributed or spaced schedule refers to a presentation with intervening stimuli across a broader time scale. Summing up studies on learning schedules, a spaced learning schedule, for example, learning across days, is associated with better recall performance than learning across several trials within one day. Thus, increased temporal spacing of repetition may improve recall performance and, consequently, learning. Cepeda et al. (2006) showed that this benefit of spaced schedules is robust regarding different lengths of retention intervals. As will be shown in Chapter 2.2, distributed, or spaced, learning may offer a possibility to improve learning in old age.

In conclusion, there are several variables known to influence learning (see Roediger, 2008, for a review). More precisely, the reported body of literature on variables influencing learning suggests that learning may be more or less facilitated depending on design factors. As will be discussed in 3.3, these may interact with each other. However, the large body of research has so far neglected the issue of individual differences. The between-person approaches mentioned do not warrant strong conclusions under which conditions an individual may benefit from certain learning conditions. By taking into account the influential

variables of learning described above, this thesis derived four research questions that take into account this body of research and combines this with an individual-differences perspective of learning.

1.1.3 Variables Influencing Forgetting

Similar to research on learning, a large body of literature is focused on possible variables influencing forgetting by examining effects of empirical design factors in order to reveal mechanisms of forgetting (Anderson & Neely, 1996; Crowder, 1976; Lansdale & Baguley, 2008; Underwood, 1957). This is reflected in several theories on forgetting (see Wixted, 2004b, for a review). Again, as argued in the previous chapter with regard to learning, the following review is selective and discusses influential variables of forgetting that may be promising regarding individual differences in forgetting in old age and therefore should be taken into account.

Before discussing influential variables of forgetting, it should be noted that forgetting in the present thesis always refers to unintentional forgetting. Hence, research on variables influencing forgetting may refer to two different forms of forgetting: Unintentional versus intentional forgetting. Whereas unintentional forgetting refers to the inability to retrieve desirable information, intentional forgetting, or positive forgetting (Bjork, 1970), describes an adaptive memory mechanism that decreases the accessibility of either irrelevant information or unpleasant memories (Sheard & MacLeod, 2005). In the following, I will focus on forgetting in the sense of unintentional forgetting.

Which variables may influence unintentional forgetting? One forgetting approach that has often been discussed is the decay theory (Brown, 1958). This theory postulates that information when it is not used is lost because of the passage of time. Forgetting is, thus, an automatic process, a passive one. However, it was shown that time passed is not a sufficient variable for forgetting, but rather the activity that the individual performs during retention (Lewandowsky, Duncan, & Brown, 2004).

Whereas decay theory has been neglected in recent decades because of these contradicting findings, a further theory that dominates research on forgetting still today is that of interference (Raaijmakers & Jakab, 2013; Underwood, 1957). In the first place, interference theory postulates that information may not be retrieved successfully because of competition between responses. Responses, that is, acquired information, may not be retrievable because they interfere with prior acquired knowledge (retroactive interference) or because they interfere with subsequent knowledge (proactive interference). More technically, it is argued that cues, with which responses (acquired information) have been associated, become associated with other information. Depending on the similarity between cues and responses, retrieval may be hampered more or less.

Whereas interference approaches argue that information may be lost, meaning that it is not possible to retrieve the target information, another approach emphasizes the idea that information is never lost (Tulving & Madigan, 1970). The main idea here is that forgetting refers to inadequate retrieval cues (Tulving & Osler, 1968). Thus, any learned information may be available, but not necessarily accessible (see also Wingfield & Kahana, 2002). Adequate retrieval cues refer to cues (internal or external) that are associated with to-be-learned material and so facilitate the search process in terms of random search models (Raaijmakers & Shiffrin, 1981). Following this, organization during encoding as reflected, for example, in subjective organization, may interact with forgetting in terms of finding an adequate retrieval cue. This relation has not been investigated yet, but will be highlighted in the discussion again (Chapter 3.2.2), because it offers a further insight into how individual differences in learning and forgetting may be related to each other.

Another approach to understanding forgetting and possible variables influencing forgetting is the testing effect (Carrier & Pashler, 1992; see Roediger & Karpicke, 2006, for a review). The testing effect emphasizes the role of retrieval itself for recalling successfully. Karpicke and Roediger (2008) showed in a series of studies that retrieval practice, that is,

testing, leads to higher recall performance after retention intervals of one week and more. The underlying theoretical assumption is that successful retrieval leads to better retention. As stated by Bjork (1975), retrieval is a memory modifier, because retrieval influences further retrieval positively. Consequently, cognitive processes that occur during retrieval, that is, testing, influence recall performance positively. This effect is also represented in the typical forgetting curve. As mentioned above, the forgetting curve is described by a negative acceleration. With longer retention intervals, the amount of material that is forgotten decreases. This may be at least to some part due to the testing effect. Hence, items that were retrieved successfully in the beginning of the forgetting curve will probably also be recalled successfully in longer retention intervals. By using a so-called dropout schedule, in which items are excluded from further studying and testing if they were once successfully recalled, the testing effect is minimized. Implications of this effect with regard to forgetting, but also learning, will be discussed in Chapter 2.3, with a focus on individual differences.

Summing up, variables influencing both learning and forgetting have been a topic of research for many years. All approaches have in common that they focus on average-learning and average-forgetting. They are based on general findings, which suggest that, on average, there is an effect of design factors for learning and forgetting. Accordingly, one might assume that the majority of people are influenced by the suggested variables as predicted by the approaches mentioned. However, what is missing is a prediction regarding the question of how strong the effects for an individual might be and which variables may influence the size of the effect for an individual learning and forgetting curve.

In the theories of learning and forgetting mentioned in this chapter, deviations from the mean were considered as nuisance, as a non-informative source. However, with regard to learning and forgetting in old age, individual differences as represented by deviations from the mean are essential if the aim is to understand mechanisms of *individual* cognitive aging. Note that the experimental approaches and theoretical assumptions reported in this chapter are

still valuable and should be taken into account, because as will be described below they can be discussed with regard to individual differences in learning and forgetting in old age: What persons with what characteristics may benefit most from the suggested design factors?

1.2 Learning and Forgetting in Old Age

Before addressing the question of when learning is more successful and forgetting less pronounced with regard to aging, some characteristics of learning and forgetting in old age will be discussed first. As already mentioned above, many studies indicate a general age-related decline in episodic memory (Davis et al., 2003; Kausler, 1994; Shing et al., 2010; Verhaeghen et al., 1993). More precisely, there is evidence for a positive relation between age and forgetting (Davis et al., 2003; Fisk & Warr, 1998; Giambra & Arenberg, 1993; Wheeler, 2000) and for a negative relation between age and learning (Davis et al., 2003; Kausler, 1994; Verhaeghen et al., 1993). However, the possibility that not all individuals show this age-related decline in episodic memory was not taken into account by these studies. The idea by Hofer and Sliwinski (2001) to analyze cognitive aging at the individual level has not been addressed.

1.2.1 Cognitive Explanations

One core aim of cognitive aging research is to analyze mechanisms of age-related changes (see Luszcz & Bryan, 1999, for a review). As the findings mentioned above indicate an age-related decline in episodic memory on average, the question of what may influence learning and forgetting (see Chapter 1.1) has been raised in cognitive aging research. Whereas the focus of general influential variables of learning and forgetting as discussed in Chapter 1.1 was on design factors, the focus on this issue from a cognitive aging perspective has been on cognitive variables as possible explanatory variables of age-related differences in episodic memory. The following review discusses the corresponding body of research by emphasizing the role of basic cognitive abilities, more precisely, of processing speed and working memory, as explanatory variables of age-related differences in episodic memory.

In order to examine possible explanatory variables of age-related differences in episodic memory, a common approach has been the cross-sectional mediation approach (see Hofer & Sliwinski, 2001, for a discussion). Probably the processing speed theory by Salthouse (1993, 1996) represents the most mentioned one in this context. Processing speed describes the speed with which cognitive operations that are required for higher order functioning, for example, episodic memory, are carried out (see Luszcz & Bryan, 1999). Salthouse (1996) argued that a general age-related decline in processing speed is related to a decline in various cognitive variables and also in episodic memory. By referring to the finding that age-related declines in different cognitive variables are not independent of each other, Salthouse (1996) argued that processing speed as a general, common factor accounted for age-related effects in different cognitive variables. Thus, processing speed is considered a mediator between chronological age and episodic memory performance. This analytical approach, which entails analyzing shared age-related variance of an assumed mediator and episodic memory, dominated the research field during the 90s (see Luszcz & Bryan, 1999, for a review).

1.2.2 Limitations of Cross-Sectional Mediation Approaches

The underlying assumptions of cross-sectional mediation models might limit conclusions that were drawn from these models. The rationale of mediation models is as follows: A correlation between age and a cognitive variable of interest, for example, episodic memory, is analyzed and statistically significant. Such a finding indicates that with increased age, episodic memory declines. Based on theoretical assumptions it is argued that this relation, however, may be mediated by another cognitive variable, for example, processing speed, which is related to age. In order to examine whether processing speed is indeed a mediator of the relation between age and episodic memory, it is controlled for shared between-person variance of episodic memory with between-person variance of processing speed. After doing so, the regression between the remaining (residual) between-person

variance of episodic memory and between-person variance of age is analyzed. If this regression decreases to a non-significant level, it is argued that the assumed mediator – in this case processing speed – works as a mediator, implying that the mediator explains age-related variance in episodic memory. For example, in a study by Salthouse (1993) processing speed explained over 80% of age-related variance in recall performance.

Besides processing speed, there is ample evidence that working memory may also explain age-related differences in episodic memory (Salthouse, 1991; see Verhaeghen & Salthouse, 1997, for a meta-analysis). Working memory, in general, describes the ability to hold information active over a short-term interval (Baddeley, 1992). Thus, similar to the processing speed approach, it is argued that age-related variance in episodic memory is explained by working memory. Working memory may thus also function as a mediator.

Summing up, studies using a mediation approach suggest that working memory and processing speed, two basic cognitive abilities, may be related to age-related differences in episodic memory. However, these relations were mainly based on cross-sectional mediation models using age-heterogeneous samples. Due to such age-heterogeneous comparisons, any age-related differences by far outweigh individual differences.

Like any developmental issue, cognitive aging may be analyzed by two different approaches: Using a cross-sectional versus a longitudinal approach. Whereas the cross-sectional approach addresses interindividual (between-person) differences of age-heterogeneous samples (implying different cohorts), the longitudinal approach focuses on within-person (intraindividual) changes across a specific period of time (Sliwinski & Buschke, 1999). Note that the latter one also permits analysis of interindividual differences in intraindividual change (Nesselroade, 1991), and individual differences in rates of change (see also Hofer & Sliwinski, 2001). Both the cross-sectional and longitudinal approaches have some limitations. Whereas the cross-sectional design is limited because of cohort differences (this issue will be explained in more detail below) leading to an overestimation of age-related

differences, the longitudinal design is limited because of practice and dropout effects leading to underestimation of age-related changes (see Sliwinski & Buschke, 1999; Zimprich et al., 2008a, for a discussion).

With regard to episodic memory and age-related effects, the majority of studies used a cross-sectional design indicating an overall age-related decline in episodic memory as noted above (e.g., Kausler, 1994). This finding is based on a comparison of age-heterogeneous samples, that is, a comparison of younger and older age-groups. One major limitation of any cross-sectional study is that due to cohort differences of different age-groups in cross-sectional findings age is always confounded with cohort differences. Cohort differences refer to historical characteristics of the corresponding cohort such as differences in sociocultural influences, which are reflected in differences in education opportunities, or socioeconomic status. As a result, non-comparable samples regarding these characteristics are compared to each other. Thus, the finding that younger persons, on average, outperform older persons with regard to episodic memory is not surprising, because per definition, cross-sectional studies refer to a broad age range and consequently to a large amount of between-person variance of age. Therefore, cross-sectional findings are not informative with regard to the mechanisms of cognitive aging, because age is confounded with cohort. There are few studies aimed at overcoming these limitations of cross-sectional designs by implementing a longitudinal approach. Overall, these studies indicated smaller age-related changes with regard to episodic memory than suggested by cross-sectional studies (e.g., Hultsch et al., 1992). However, overall, cross-sectional studies are the approach mostly used in developmental and aging research (see Schaie & Hofer, 2001).

As will be explained in the following, from an individual-differences cognitive aging perspective results of studies using a cross-sectional design in combination with a mediation approach as described above are limited. Implied in the issue of cohort dependencies, cross-sectional mediation studies have the further limitation of investigating average, age-related

mean trends (Hofer & Sliwinski, 2001). That is, there might be a relation between age-related variance of a mediator and age-related variance of episodic memory just because both the mediator and episodic memory are associated with age. This issue is, in particular, relevant for cognitive research, because variables of interest usually refer to age-sensitive variables that may change over time (see Hofer, Flaherty, & Hoffman, 2006). Hence, associations between the mediator and episodic memory may not represent associations that exist within the individual. This problem is also discussed in terms of illusory correlations, or spurious associations, which describe an inappropriate aggregation of heterogeneous groups. Heterogeneity refers to different means of variables that are correlated within different groups (see Hofer & Sliwinski, 2001). For example, with regard to cognitive aging, age may be associated with the number of wrinkles, on average, and independent of this, age may be associated with a decline in episodic memory, on average. However, the conclusion that age-related increases in number of wrinkles are associated with a decline in episodic memory is meaningless. One line of research argued that physical functioning is a mediator of age and episodic memory (e.g., Baltes & Lindenberger, 1997). However, this common-cause theory was not supported as shown, for instances, by Anstey, Hofer, and Luszcz (2003), who demonstrated longitudinally that sensory and cognitive aging processes are independent from each other also in older age.

In conclusion, the suggested theoretical explanatory accounts for cognitive aging arguing that basic cognitive abilities mediate age-related differences in episodic memory were not supported by cross-sectional mediation studies. At least, they are not informative with regard to mechanisms of cognitive aging, because they were based on indirect age-related effects, between-person differences, not within-person age-related changes (see Sliwinski & Buschke, 1999). Relations were based on between-person variance of the variables of interest, for example, age, processing speed, and episodic memory. These variables are fixed at cross-section for individuals. They do not vary within individuals, but only between individuals (see

Sliwinski & Buschke, 1999). Furthermore, any effect of a mediator in a cross-sectional design may also depend on non-age-related variance (Lindenberger & Pötter, 1998). In sum, conclusions regarding relations between cognitive variables *within* the individual were not implied by cross-sectional studies (Sliwinski & Buschke, 1999). As stated by Hofer et al. (2006) “many of the associations between age-related variables reported in the literature may be at least upwardly biased in terms of their importance, and some may be completely spurious” (p. 180).

If the aim is to understand mechanisms of aging, however, within-person relations should be the focus instead of between-sample variance (see Hofer & Sliwinski, 2001; Sliwinski & Buschke, 1999). Investigating relations of cognitive factors at the level of the individual may be more informative than investigating group differences (Zelinski, Gilewski, & Schaie, 1993). Consequently, approaches that measure within-person changes match more closely with a cognitive aging perspective. The longitudinal approach as mentioned above analyzes within-person changes. Individuals are observed over a period of time and the resulting individual rates of changes in variables of interest are the focus for analyses with regard to possible relations between cognitive variables. Only few studies exist that aimed at analyzing the postulated relations between basic cognitive abilities and episodic memory from an individual aging perspective by using a longitudinal approach (Hultsch et al., 1992; Sliwinski & Buschke, 1999; Zimprich, 2002; Zimprich & Martin, 2002). These studies indicated that the suggested association between processing speed and memory is lower than suggested by mediation cross-sectional studies with age-heterogeneous samples. For example, Sliwinski and Buschke (1999) showed that the total age effect mediated by processing speed was about 75% cross-sectional and about 10% longitudinal regarding memory. Zimprich (2002) argued that inconsistent findings with regard to relations between possible explanatory variables of age-related changes in episodic memory measured by cross-sectional versus longitudinal studies may result from different periods of time covered in both approaches.

Hence, the cross-sectional study usually covers a much broader age-range than the period of time covered in longitudinal studies. However, Zimprich (2002) showed that if time refers to the same interval in cross-sectional and longitudinal studies, evidence for the processing speed approach is comparatively low. Following this, processing speed accounts for some part of within-person variance, however, the relations were weaker than expected from cross-sectional studies. Thus, an approach that takes into account individual rates of change or individual effects of processing speed on episodic memory could not provide empirical evidence for Salthouse's mediation approach.

Hofer and Sliwinski (2001) suggested a different approach as an alternative to cross-sectional studies, which also permits within-person change to be analyzed, that is, individual aging as done in longitudinal studies: The narrow-age cohort (NAC) approach. The NAC approach suggests analyzing relations between cognitive variables of interest in age-homogeneous samples at cross-section. Within age-homogeneous samples, mean trends of variables of interests are minimized, because there is no (or only little) within-group age variance. If a relation between candidate mediators and cognitive variables of interest, for example, episodic memory is still evident, the candidate mediator may be considered as a relevant explanatory variable of cognitive aging. Suggested cognitive explanatory variables, for example, basic cognitive abilities, should have the power to explain individual differences of persons of same age. Individual differences in, for example, episodic memory of persons of same, or as argued below, of similar age, might be due to an individual history of development. This point will be highlighted in more detail in Chapter 3.1. Hence, only if the suggested relations between basic cognitive abilities and episodic memory exist within the individual, basic cognitive abilities are relevant explanatory variables from a cognitive aging perspective.

Using multiple age-homogeneous groups at cross-section as suggested by Hofer and Sliwinski (2001), a sequential narrow-age cohort design emerges that permits to analyze

differences in relations (correlations) of cognitive variables of different age-groups by analyzing narrow-age cohort (age) \times cognitive variable of interest-interactions. Following this, the aim of cognitive aging to analyze mechanisms of age-related changes is realized by investigating correlations among age-related variables within and across age-homogeneous samples by ruling out that correlations emerge because of population mean trends. To the best of my knowledge, there is only one study investigating the suggested relation between processing speed and episodic memory by using a NAC design (Sternäng et al., 2008). Sternäng et al. (2008) used a longitudinal approach combined with a NAC approach. Ten age cohorts (35, 40, 45, 50, 55, 60, 65, 70, 75, 80 years of age at Time 1) were assessed longitudinally on four points in time (Time 1: 1988-1990; Time 2: 1993-1995; Time 3: 1998-2000; Time 4: 2003-2005). Their analyses indicated that only about 2% of variance in episodic memory were explained by processing speed.

Summing up, basic cognitive abilities were suggested as possible explanations for an age-related effect of episodic memory. However, empirical findings mainly come from cross-sectional mediation studies that are limited regarding conclusions within individuals. If the aim is to understand mechanisms of cognitive aging, individual aging should be analyzed. In terms by Sliwinski and Hofer (1999): “reliance on between-person information for most theories of cognitive aging is a shortcoming that must be remedied for continued theoretical and methodological progress” (p. 353). Whereas longitudinal and NAC approaches represent one possibility to do so (see Hofer & Sliwinski, 2001), the present thesis relies on another one: Analyzing individual differences in learning and forgetting among persons of similar old age and predictors of these individual differences. The rationale for this will be explained in detail in Chapter 1.4. The following chapter focuses on individual differences in old age and possible predictors of individual differences in learning and forgetting in old age with a focus on basic cognitive abilities and subjective organization.

1.3 Individual Differences in Learning and Forgetting in Old Age

The age-related decline in episodic memory found in cross-sectional studies represents a robust finding. Verhaeghen et al. (1993) evaluated the decline as “omnipresent” (P166). However, there are findings suggesting a more differentiated pattern with regard to age-related declines in episodic memory. There is evidence that episodic memory does not decline in general, but rather that there are individual differences with regard to learning and forgetting in old age (MacDonald et al., 2006; Zimprich et al., 2008b). The role of individual differences with regard to learning and forgetting is the focus of the present chapter.

The theoretical approach of taking individual differences in abilities into account was raised many years ago (Carroll, 1978; Cronbach, 1957; Nesselroade, 2010; Noble, 1961; Scarr, 1992; Tucker, 1966; Underwood, 1957). Early accounts were mainly interested in the question of why and to what extent persons vary and how individual differences could be measured with regard to personality issues (see Revelle, Wilt, & Condon, 2011). However, as stated above, with regard to learning and forgetting in old age, individual differences have been neglected by a large body of research.

As mentioned above, according to Hofer and Sliwinski (2001), taking into account individual differences from a cognitive aging perspective is essential if the aim is to understand mechanisms of cognitive aging.⁴ An older individual has a relatively long history of individual development. Individual development may be due to individual experiences and different responding to individual life events (Hess, 2005). Thus, it is not surprising that individuals also age at different rates (Rabbitt, 1993) and that some individuals will show greater declines in, for example, episodic memory than others (see Salthouse, 2010). In line with this, there is evidence for an increase in individual differences within older age-groups (e.g., Ardila, 2007). Following this, already *within* an old age-group there might be a large amount of variance regarding learning and forgetting implying individual differences.

⁴ Note that this approach is similar to an idiographic approach formulated by Cronbach (1957). The idiographic approach focuses on individual development and deviations around general developmental patterns.

Whereas approaches of influential variables of learning and forgetting do not take individual differences in learning and forgetting into account (see Chapter 1.1.2), the aim of the present thesis was to analyze in which respect older persons differ regarding learning and forgetting. To sum up, it seems essential to consider cognitive aging as an individual process. Deviations from mean trends, that is, individual differences, do not only represent “noise”, but rather an informative source of mechanisms of individual cognitive aging that should be taken into account.

1.3.1 Possible Explanatory Variables of Individual Differences in Learning and Forgetting in Old Age

The present thesis explicitly takes into account the informative source of individual differences by analyzing predictors, respectively, explanatory variables of individual differences in learning and forgetting in old age. To do so, this thesis focused on two kinds of possible explanatory variables of individual differences in learning and forgetting in old age: 1) basic cognitive abilities and 2) subjective organization. Both kinds of variables have been found to be related to episodic memory and age-related effects in cross-sectional studies. According to Hofer and Sliwinski (2001), variables are relevant explanatory variables of cognitive aging only if they also explain individual differences in the variable of interest if there is no (or only little) age-related variance. Note that the following theoretical explanations of how basic cognitive abilities and subjective organization may be related to individual differences in learning and forgetting were formulated by researchers of cross-sectional studies mainly (e.g., Kahana & Wingfield, 2000; Salthouse, 1991). However, the theoretical assumptions can still be considered valuable and provide the basis for the research questions of the present thesis. The underlying mechanisms are not questioned, but rather they are examined regarding their relevance for cognitive aging from an individual-differences perspective.

1.3.1.1 Basic Cognitive Abilities

As Noble (1961) stated in his discussion on individual differences of learning, human factors might be considered as influential variables for learning curves. Of course, human factors may refer to a wide variety of individual difference variables. The present thesis focused on basic cognitive abilities as human factors influencing individual differences in learning and forgetting in old age.

Basic cognitive abilities may refer to processing resources that are defined as “our reservoirs of mental energy” (Luszcz & Bryan, 1999, p. 3). With regard to individual differences in learning and forgetting in old age, processing speed and working memory that represent two basic cognitive abilities should be taken into account. Hence, as described above, age-related differences in episodic memory were explained by working memory and processing speed accounts (e.g., Salthouse, 1991). Regardless of methodological limitations of cross-sectional mediation models, the underlying theoretical assumptions may still be valuable from a cognitive aging perspective. The underlying theoretical assumption formulated by Salthouse (1991) is that more elementary cognitive abilities such as basic cognitive abilities explain age-related differences in higher-order functioning such as episodic memory. In the following, the theoretical assumptions of how working memory and processing speed may influence individual differences in learning and forgetting are described in more detail.

Working memory

According to Baddeley (1992), working memory includes three different components: the central executive, the articulatory, and the phonological loop. Whereas the latter two components are so-called peripheral systems that hold information active over the short-term, the central executive component is relevant for coordinating ongoing processes that are performed simultaneously. Baddeley (2000) suggested that there is a fourth component: the

episodic buffer. The episodic buffer stores information and combines these together into episodes. Thus, there is a linkage from the short-term to long-term memory.

How might working memory influence individual differences in learning and forgetting? In order to answer this question one theoretical approach is to focus on executive functioning, because executive functioning includes facets of working memory (Engle, 2002). Executive functioning includes guiding behavior consciously in order to achieve certain goals, for example, new learning. Because of this relation, individual differences in working memory are often tested with inhibition effects: Is working memory performance influenced by inhibition tasks? With regard to aging, Radvansky, Zacks, and Hasher (2005) showed that interference effects were more often evident in older adults. In line with this finding, the account by Hasher and Zacks (1988) states that an age-related decline in working memory capacities is a consequence of the diminished efficiency of inhibitory processes. Recently, Lustig, Hasher, and Zacks (2007) argued that there are three functions of inhibition, which emphasize the relevance of inhibition for cognitive processes: 1) access to relevant information by ignoring distraction, 2) deletion of irrelevant information from working memory, and 3) suppression of inappropriate responses.

These findings suggest that working memory may be related to executive functioning and inhibition abilities, however, theoretical assumptions of how working memory may be related to individual differences in episodic memory were not mentioned in this line of research. One account, which closes this gap, is the model presented by Unsworth (2007; Unsworth & Engle, 2007). By focusing on random search models, Unsworth and Engle (2007) argued that individual differences in working memory influence the search process at retrieval. Depending on the individual working memory ability, the search process might be more or less successful because of bigger or smaller search sets with irrelevant cues. Search set sizes at retrieval with more irrelevant cues will lead to lower recall performance. Due to the fact that recall performance is the measure of both learning and forgetting (see Chapter

1.1.1), the postulated relations between working memory and retrieval may be reflected in individual differences in learning and forgetting.

Processing Speed

According to Salthouse (1996), age-related declines in processing speed are related to a diminished simultaneous and limited time mechanism. Briefly, declines in both mechanisms lead to disadvantages in ongoing processes that are required for learning. These mechanisms will be discussed in detail in Chapter 2. In line with this, it was shown that processing speed is related to episodic memory (Hertzog, Dixon, Hultsch, & MacDonald, 2003; Lemke & Zimprich, 2005; Zimprich et al., 2008b).

With regard to forgetting, processing speed might be an influential variable, because higher processing speed may be related to a faster and more accurate search during retrieval leading to lower forgetting. Hence, as with learning, during retrieval the amount of not yet recalled and correct items increased. The information of whether an item is a target item *and* has not yet been recalled has to be available simultaneously. Thus, due to lower processing speed and resulting influences in the limited time and simultaneous mechanism, forgetting may also be affected by individual differences in processing speed. To the best of my knowledge, there is no study investigating the effect of processing speed for individual differences in forgetting. Chapter 2.4 addressed this issue by analyzing the role of processing speed and working memory for individual differences in learning and forgetting in old age.

Summing up, because of these theoretical considerations, working memory and processing speed, two basic cognitive abilities, may influence individual differences in learning and forgetting in old age. There are studies, which indicated that working memory and processing speed are related to episodic memory (e.g., Salthouse, 1993). However, these studies considered aging as an average process with the resulting limitations as discussed in Chapter 1.2.1. If basic cognitive abilities are relevant explanatory variables for the aging of episodic memory, then individual differences therein should be related to individual

differences in learning and forgetting of persons of similar old age (see Hofer & Sliwinski, 2001).

1.3.1.2 Subjective Organization

Apart from basic cognitive abilities, individual differences in learning and forgetting in old age may also be explained by individual differences in an assumed related cognitive process of learning (and forgetting), that is, individual differences in subjective organization. Subjective organization facilitates encoding (learning) and retrieval (forgetting). Similar to studies on relations between basic cognitive abilities and episodic memory, Tulving (1966) investigated the relation between subjective organization and learning mainly by using analytical approaches that did not take individual differences in learning and subjective organization into account. To the best of my knowledge, there are no studies, which investigated the relation between subjective organization and episodic memory within the individual. Regarding age-related differences in subjective organization, there is evidence that, on average, subjective organization declines in older age (Davis et al., 2003; Hultsch, 1974; Sauzéon, Claverie, & N’Kaoua, 2006). However, these studies investigated the relation between learning and subjective organization by using cross-sectional designs. They did not address a relation within the individual. Following this, these cross-sectional results may not be informative from a cognitive aging perspective. Hence, as argued similarly regarding basic cognitive abilities, if subjective organization is a relevant explanatory variable of cognitive aging regarding episodic memory, then individual differences in subjective organization should be related to individual differences in learning and forgetting among persons of similar old age. Chapter 2.1 will address this issue by analyzing the relation between individual differences in subjective organization and individual differences in learning among persons of similar old age.

1.4 Concluding Remarks – Aims of the Present Thesis

From a cognitive aging perspective it seems essential to analyze mechanisms of age-related effects in episodic memory *within* the aging individual. However, a large body used cross-sectional mediation models in order to analyze mechanisms, respectively, to analyze explanatory variables of cognitive aging (e.g., Salthouse, 1991, 1996). With regard to episodic memory, it was suggested that basic cognitive abilities and subjective organization may explain age-related differences in episodic memory (Hultsch, 1974; Salthouse, 1991; Sauzéon et al., 2006). However, these studies do not imply inferences about these relations for the individual and might thus not be appropriate. In order to overcome this limitation, a longitudinal or NAC approach is recommended (see Hofer & Sliwinski, 2001). Few studies, which used one of these approaches, investigated whether the suggested relation, that is, age-related differences in processing speed are related to age-related differences in episodic memory, is also true for the aging individual (Sliwinski & Buschke, 1999; Sternäng et al., 2008; Zimprich, 2002). These studies indicated that the suggested relations found in cross-sectional studies are not well supported. In order to extend this body of research of individual cognitive aging by analyzing not only processing speed, but also working memory and subjective organization as possible explanatory variables of age-related effects of episodic memory, the present thesis used a different approach and analyzed the role of these variables for individual differences in learning and forgetting in old age. As mentioned above, in order to reveal mechanisms of cognitive aging, possible explanatory variables of cognitive aging should explain individual differences in a cognitive variable among persons of similar old age (Hofer & Sliwinski, 2001). Transferring this idea to the suggested relations between basic cognitive abilities, subjective organization, and episodic memory, these relations should also be evident within age-homogeneous groups. In order to analyze these relations, learning and forgetting as two related, but also different cognitive processes of episodic memory (see Chapter 1.1.1) are investigated in this thesis.

The underlying theoretical assumptions discussed in cross-sectional studies of how basic cognitive abilities and subjective may influence learning and forgetting in old age are still valuable. The present thesis did not question these, but rather examined whether these suggested relations exist at the individual level. Of course, the one prerequisite of finding these relations at the individual level is that there are individual differences in learning and forgetting in old age. That is why in all four studies two main research questions were addressed: 1) Are there reliable individual differences in learning and forgetting in old age and if so, how large are they and 2) what are predictors of these individual differences?

The studies of the present thesis were all based on a covariance-based individual-differences approach: Individual differences in basic cognitive abilities and subjective organization were directly related to individual differences in learning and forgetting in old age. More precisely, the four studies of the present thesis focused on the process of learning and forgetting. This means that learning and forgetting were modeled as individual trajectories across several points in time including recall performance of several trials. Thus, it was directly possible to analyze relations between basic cognitive abilities, subjective organization, and individual differences in different parameters of the learning and forgetting curve.

Furthermore, by not questioning general, robust findings of how learning and forgetting may be influenced by different variables (see Chapter 1.1), the present thesis explicitly took these variables into account, of course, with different weightings within the four different studies. Study 1 (Chapter 2.1) investigated whether individual differences in learning curve parameters are related to individual differences in subjective organization trajectory. Thus, the idea that subjective organization is a related process of verbal learning was examined at the level of the aging individual. Study 2 (Chapter 2.2) examined individual differences in task-specific paired-associate learning and relations with working memory and processing speed. Existing findings on individual differences in learning were thereby

extended by using a spaced learning schedule. Study 3 (Chapter 2.3) investigated individual differences in criterion-based dropout learning and predictors of these. The focus was on speed of learning in old age, which referred to the number of study-recall cycles needed in order to achieve a certain learning criterion. Furthermore, Study 3 included a delayed recall task in order to get an idea of how individual differences in speed of learning are related to the amount retained after having reached the learning criterion. Finally, Study 4 (Chapter 2.4) investigated relations between basic cognitive abilities and individual differences in forgetting. Forgetting was measured by a new analytical approach, which aimed at measuring forgetting more reliable at the individual level. Summing up, the aim of the four studies was to analyze relations of basic cognitive abilities, subjective organization, and episodic memory within aging individuals in order to reveal mechanisms of cognitive aging and thereby *understand* cognitive aging (see Hofer & Sliwinski, 2001).

2 EMPIRICAL INVESTIGATIONS OF FOUR RESEARCH QUESTIONS

In the following, the four studies mentioned above are presented. Note that these studies are presented in the form they were accepted by the corresponding journal. Study 2, 3, and 4 (Chapter 2.2, 2.3, 2.4) have been published in peer-reviewed journals (see corresponding remarks and copyright notices on the first page of each study). For these studies a license has been offered by the corresponding journal for reusing the manuscript in this dissertation.

2.1 Individual Differences in Subjective Organization and Verbal Learning in Old Age*

Abstract

Background. Previous research has shown an increase of subjective organization of stimuli and of recall performance across learning trials. However, up to date, it has not been examined whether subjective organization and recall performance are positively related also at the level of the individual. To close this gap, parameters of verbal learning were regressed on growth parameters of subjective organization. *Methods.* The sample for this investigation involved $N = 205$ subjects (65 to 80 years old). Participants learned a word list containing 27 unrelated words, presented randomly across five trials. Subjective organization was measured by using the Paired Frequency measure. *Results.* Overall, there were reliable individual differences with regard to both subjective organization and verbal learning. Results showed that the learning parameters were positively correlated with the initial level and linear slope of subjective organization. Furthermore, growth parameters of subjective organization turned out to be reliable predictors of verbal learning. *Conclusion.* The present study emphasized the role of analyzing individual differences in subjective organization. Implications are discussed, in particular, regarding the interdependency of subjective organization and verbal learning in old age.

Key Words: Individual differences – Verbal learning – Organization – Age differences Latent growth curve model – Non-linear growth curves.

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Introduction

Previous research has shown that subjective organization, that is, the idiosyncratic order in which previously learned material is recalled, increases across learning trials on average (Davis et al., 2003; Glidden, 1977; Pellegrino & Battig, 1974; Tulving, 1962; Witte, Freund, & Sebbby, 1990). Hence, the typical pattern of performance improvement across several trials of a verbal learning task might be due to an increasingly coherent subjective organization of the to-be-learned material (Tulving, 1964, 1968). For that reason, the analysis of subjective organization processes in free recall might provide insights into the understanding of verbal learning and the mechanisms underlying it as well as the organization of memory (Wood, 1972). However, previous studies of subjective organization have been based on group data and did not take into account individual differences in both subjective organization and verbal learning in old age. In following such an individual-based research agenda, the aim of the present study was to analyze whether individual differences in subjective organization are positively related to individual differences in verbal learning in old age.

Different Types of Organization

Typically, an analysis of verbal learning is confined to the *amount* of individual recall performance, that is, a quantitative measure of *how much* a person recalls. An analysis of organization, by contrast, focuses on recall performance from a more qualitative perspective. It uses the individual recall *order*, thus, the order in which items are retrieved, to investigate *what* is learned (Koriat & Melkman, 1981; Mandler, 1967). Put differently, verbal learning using a multi-trial free recall tasks provides the cumulative recall performance across trials as an indicator of the learning process, which was frequently used in previous studies on modeling verbal learning (Rast, 2011; Zimprich, Rast, & Martin, 2008). However, simultaneously, such task also always provides a different indicator that also reflects the learning process but from a different perspective: The order in which an individual organizes the to-be-learned material across trials.

The to-be-learned material may be organized according to temporal (Kahana, 1996), semantic (Bousfield, 1953), or subjective components (Tulving, 1962). Depending on the stimulus material and design (single- vs. multi-trial; fixed vs. random serial input order; serial recall vs. free recall), each way of organizing the to-be-learned material may be more or less salient.

Note that organization may refer to the degree of concordance between the presentation order (input order) and recall order (output order), or to the degree of concordance between subsequent recall (output) orders. For example, a recall task with fixed serial input order may support the use of the temporal information of word presentation as a basis of association (Kahana, 1996). In contrast to such input-output order effects, in a multi-trial free recall task with varying input orders across trials, organization that is established and strengthened across trials is reflected in the output-output order. The individual's task to recall the words in any order (as is typical for free recall tasks) allows investigating such output-output order regarding individual strategic processing (Schneider & Bjorklund, 1998) and the associative structure. One source of associations are, of course, pre-existing inter-item associations (Bousfield, 1953; Howard & Kahana, 2002). For example, if several items belong to the same category, these items would be expected to be recalled more and more adjacently because their common category can serve as a cue.

However, even if such semantic organization criteria are absent and if the input order of words across trials is randomized, still an organization of the to-be-learned material emerges (Bousfield, Puff, & Cowan, 1964; Davis et al., 2003; Pellegrino & Battig, 1974; Tulving, 1962, 1964; Witte et al., 1990). This type of organization, which does not necessarily relate to obvious, external criteria (e.g., input order or semantic associations), is denoted as subjective. Consider, for example, a subject who recalls the word *ocean* on position 2 and the word *game* on position 3 on recall trial t . If the subject recalls the words *ocean* and *game* in this sequential order or in the reverse order (*game*, *ocean*) at the next recall trial $t + 1$, such a

correspondence of recall orders is conceptualized as subjective organization (Sternberg & Tulving, 1977). Thus, subjective organization reflects the degree of concordance between subsequent recall orders of the to-be-learned material which is semantically unrelated (Hultsch, 1974). The unique property of subjective organization as a measure of organization processes in verbal learning is that the basis of organization remains unspecified (Koriat, Pearlman-Avni, & Ben-Zur, 1998). Hence, subjective organization is by definition composed of individual differences, as any subjective organization reflects the *individual* recall order. Individual associations among words are, in principle, less dependent of objective, external criteria, such as the serial position of the item or other characteristics of the material (imageability, word frequency, etc.). Note, this does not mean that these characteristics do not influence the order of recall at all. However, in line with the subjective organization approach by Tulving (1962), organizing unrelated verbal material is more affected by individual associations that are based on individual higher order units (see below).

Benefits of Subjective Organization

In an attempt to explain output-output (recall) order effects due to subjective organization, Tulving (1964, 1968) suggested that subjective organization results from higher order units in memory storage.⁵ These higher order units are composed of two up to several words which each serve as a retrieval cue for the remaining words of the higher order unit (Thomson & Tulving, 1970). Evidence for this notion comes from the whole-list/part-list paradigm (Tulving & Osler, 1967). Briefly, this study required subjects to learn two lists and to recall as many words as possible in any order. The first group of subjects received a second list, partly composed of items of the first one. The second group received a second list that was unrelated to the first one. Analyses of recall and organizational performance of the second list indicated that the second group outperformed the first group with regard to recall performance.

⁵ Subjective organization as well as the related concept of categorical clustering (see Bousfield, 1953), which emerges from using categorized lists, may be subsumed as secondary memory organization. By contrast, other order effects in memory, for example, the serial position effect, are part of the primary memory organization (Shuell, 1969; Tulving, 1968).

Presumably, in the first group associations that were built up for the first list interfered with the need to build up new associations with the new items of the second list. This finding was interpreted as evidence for the dependence of verbal learning on the subjective organization of single items into higher order units. Note that subjective organization can rely on different principles, for instance, alphabetization, phonetic characteristics (cf. Gross et al., 2011), or individually differing pre-experimental associations. On a more general level, subjective organization can be described as forming “chunks” (cf. Mandler, 1967). In principle, the process of subjective organization consists of a process of taking many individual chunks (words) and welding them into larger chunks (e.g., pairs of words). Compared to other forms of chunking, the chunks developing out of subjective organization are often meaningful only to the participant. These chunks, or associations, lead to higher order cognitive representations of the words on the list that are more easily remembered as a group than as the individual words. As mentioned above, subjective organization refers to the output-output order. Therefore, the phase of retrieval might be the critical phase, where the process of subjective organization is most pronounced. In line with Bjork (2011), every successful retrieval functions like a new learning trial. With regard to subjective organization, a successful retrieval of one pair of items across two subsequent trials leads to strengthening this association and making this association more accessible in the following trial.

Age-related and Individual Differences in Subjective Organization

Subjective organization has been analyzed with samples of various age-groups ranging from kindergarten children to persons in old age (Davis et al., 2003; Glidden, 1977; Jackson & Schneider, 1982; Ornstein, Naus, & Stone, 1977; Rankin & Battig, 1977; Sauzeon, Claverie, & N’Kaoua, 2006; Witte et al., 1990). With regard to old age, it seems especially important to investigate age-related effects in subjective organization due to the relation suggested by Tulving (1962), which states that an increased subjective organization across trials may explain increased recall performance. A deficit in subjective organization could then account

for an age-related decline in verbal learning (Kausler, 1994). Instead of using a cumulative recall score for describing the learning process, a measure of subjective organization may provide further hints regarding cognitive mechanisms of (declines) in verbal learning.

A number of studies have demonstrated that, on average, subjective organization and recall performance increase across trials also in old age (Bäckman & Wahlin, 1995; Davis et al., 2003; Jackson & Schneider, 1982; Witte et al., 1990). At the same time, some of these studies concluded that older adults exhibit a decreased amount of subjective organization compared to younger adults (Davis et al., 2003; Hultsch, 1974; Sauz  on et al., 2006; Witte et al., 1990). For example, Hultsch (1974) showed that older age was associated with less subjective organization. Such an age-related decrease in subjective organization was also found by Witte et al. (1990), who demonstrated a decrease in subjective organization for subjects in old age by measuring subjective organization with five different measures. As described above, subjective organization implies building associations between to-be-learned items due to individual higher order units. Following this, subjective organization may be considered as a (unconscious or conscious) strategy for recall performance. Taking into account a possible deficit in spontaneous strategy use of older persons for building associations (Naveh-Benjamin, Brav, & Levy, 2007; Rowe & Schnore, 1971), a decline in verbal learning might be due to a deficit in strategy use that is reflected in a deficit in subjective organization.

A further reason for analyzing the relation between subjective organization and verbal learning in old age is embedded in the issue of predictors of individual differences in verbal learning in old age. In line with two prominent approaches, the processing speed approach by Salthouse (1996) and the working memory approach by Unsworth and Engle (2007), it is argued that lower basal cognitive processes such as processing speed and working memory may be related to a deficit in verbal learning. Following this and by taking into account the assumption by Tulving (1962) that verbal learning and subjective organization are related to

each other, it might be that subjective organization is also influenced by these basal cognitive abilities. Processing speed and working memory may influence organizing successfully verbal material across trials. Persons with higher basal cognitive capabilities may develop more or stronger associations between items across trials, which in turn would be reflected in higher subjective organization scores. Note that previous studies showed that there is an age-related decline in these cognitive abilities (Hultsch, 1992). Whether this result is related to a decreased subjective organization has not yet been investigated.

Summing up, subjective organization might be a cognitive process at retrieval that is influenced by basal cognitive abilities such as processing speed or working memory. One prerequisite for these relations is that verbal learning and subjective organization are related to each other at level of the individual. The present study aimed at investigating this issue.

The Role of Individual Differences in Subjective Organization

Note that the results mentioned regarding a relation between subjective organization and verbal learning in old age are based on group data. A group-based approach does not answer to the question of whether verbal learning and subjective organization are related to each other also at the level of the individual. In other words, although the average values of subjective organization and verbal learning increase across trials, it is possible that they are only weakly associated in terms of individual differences and reflect relatively independent processes. If subjective organization influences verbal learning, however, one would expect that a person with a high level of subjective organization learns more than a person with a low level of subjective organization. Regarding verbal learning in old age, investigating this relation would be of interest in order to analyze whether those persons in old age, who exhibit a more pronounced decrease in verbal learning, also obtain lower subjective organization levels. A first approach to analyze individual differences in subjective organization was suggested by Earhard (1974) who analyzed the negative transfer paradigm in high- vs. low-subjective-organization persons. High organization persons reached a higher level of final

performance regardless of whether the task involved all new items or not. Although this sample split in two groups did not fully reflect individual differences, the study by Earhard (1974) can be seen as a first attempt to analyze subjective organization on a more fine-grained level than averages and, thus, highlights the awareness of this issue many years ago.

Aims of the Present Study

In the present study, we investigated at the individual level the idea suggested by Tulving (1964) almost half a century ago, namely, that an increase in subjective organization across trials is underlying verbal learning. With regard to aging, one would expect that individual differences in subjective organization in old age can explain individual differences in verbal learning in a sample of older persons. According to similar studies that have shown large individual differences in verbal learning even in samples with a relatively small age range (Zimprich & Rast, 2009; Zimprich et al., 2008b), in the present study we analyzed whether there are individual differences in subjective organization, and whether these individual differences are related to individual differences in verbal learning in old age. However, up to date, there is no study which has investigated individual differences in subjective organization in old age and related those to individual differences in verbal learning.

In the present study, individual differences were modeled by applying the latent growth curve model approach (e.g., Bryk & Raudenbush, 1992; McArdle, 1988) for the analysis of subjective organization processes and the structured latent growth curve approach (cf. Browne, 1993) in order to analyze non-linear verbal learning trajectories. Apart from allowing for individual differences in growth parameters, in both approaches correlations between growth parameters can be modeled.

The analyses of the present study comprised three steps. In a first step, we examined the trajectories of subjective organization changes and verbal learning changes across learning trials separately. For subjective organization and based on previous findings regarding average increases (Bousfield et al., 1964; Kahana & Wingfield, 2000; Sauzéon et al., 2006;

Witte et al., 1990), we expected a linear increase across trials, whereas for verbal learning, in line with previous studies (Heathcote et al., 2000; Jones et al., 2005; Rast & Zimprich, 2010; Zimprich et al., 2008b) we expected a non-linear increase that could be described by a hyperbolic function. In both growth curve models age was entered as a predictor of the growth parameters.

In a second step, both growth curve models, one for subjective organization and one for verbal learning, were estimated simultaneously in a combined model. More precisely, the growth parameters for subjective organization, initial level and linear slope, were correlated with three verbal learning parameters, initial status, potential amount of learning, and speed of learning. In a final step, the parameters of the verbal learning curve were regressed on initial level and linear slope of subjective organization. We hypothesized that initial level and linear slope of subjective organization would influence the three learning parameters positively in the sense that a higher degree of subjective organization would be a predictor for a higher performance in verbal learning.

Method

Participants

The sample for the present study comprised participants from the Zurich Longitudinal Study on Cognitive Aging (ZULU), a representative longitudinal study on cognitive and learning abilities in old age in Switzerland (Zimprich et al., 2008a). Data for the present study come from the first measurement occasion of ZULU in 2005. At this time, the sample included 364 older participants, who were 65 to 80 years old. Due to reasons of time and resources constraints, the recall output ordering was recorded only for $N = 205$ subjects that were randomly selected from the complete sample. Those 205 participants were 73 years old on average ($SD = 4.4$ years, 47% women). To examine selective sampling effects, we examined whether the analysis sample ($N = 205$) differed from those not included ($N = 159$) with regard to sex, age, verbal knowledge (German Vocabulary Test; Lehrl, 1999), processing

speed (Identical Pictures Test from the Educational Testing Service Kit ETS; Ekstrom et al., 1976), and the three verbal learning parameters, initial level, increment in performance and rate of learning. Overall, as one would expect based on a random selection, there were no sampling effects. The increment in verbal learning performance was the parameter for which the two samples differed most, but not to a statistically significant level and only with a small effect ($R^2 = 1.1\%$).

Materials and Procedure

Verbal learning. Verbal learning was measured by five trials of a word list recall task. The task comprised 27 meaningful but unrelated two- to three-syllable words taken from the *Handbuch Deutschsprachiger Wortnormen* (Manual of German Word Norms; Hager & Hasselhorn, 1994). Words were selected on the basis of their imagery value, meaningfulness, and concreteness. All words were relatively emotionally neutral with an average emotionality of 1.01 on a scale ranging from -3 = "emotionally very negative" to 3 = "emotionally very positive". All words were high in imageability (the average imageability of words was 5.68 on a scale ranging from 1 (low imageability) to 7 (high imageability) and neutral regarding arousal with an average arousal of 2.26 on a scale ranging from 1 (low arousal) to 5 (high arousal) (BAWL-R; Vö et al., 2009). The list includes 27 words in order to have an optimal amount of to-be-learned material that is able to reflect an expected variability in recall performance across five trials for persons in old age.⁶ To avoid pre-experimental categorizations, words were chosen in a way that inter-item-associations were as unlikely as possible and typicality was low. The 27 words appeared on a computer screen at a rate of 2 s each, and participants were asked to read them aloud. After all 27 words had been presented, participants were asked to recall as many words as possible in any order. This procedure was

⁶ However, it is important to note that the chosen list length might have an effect on the relation between subjective organization and verbal learning for different age-groups. Witte et al. (1990) argued that different list lengths might moderate an age-related effect in subjective organization. Short lists may not reveal an association between age and a decreased subjective organization because younger people need to make only a small organizational effort to learn them. We thank an anonymous reviewer for this comment.

repeated five times, with the order of word presentation being different for each trial. The number of correctly recalled words was scored for each trial (possible range: 0–27).

In order to model verbal learning, the hyperbolic function was utilized comprising three parameters. The first one, α , captures the upper asymptote of performance or the potential maximum performance if the number of learning trials were infinite. The second parameter, β , say, characterizes the initial level of performance. Finally, the third parameter, γ , describes the speed of learning, that is, the speed with which subjects reach their asymptote starting from their initial level (cf. Browne, 1993; Meredith & Tisak, 1990). In the present study, instead of potential maximum performance α , we defined a new parameter, δ , which is given as $\delta = \alpha - \beta$. Thus, δ reflects the difference between the potential maximum performance and initial performance. Following this, δ describes the potential performance increment due to learning---or the potential amount of learning by taking into account the individual initial level as a starting point of learning. δ is used here in order to analyze verbal learning by parameters that are main characteristics of the learning process: the initial level, the extent, and the rate of learning.

Subjective organization. Subjective organization was calculated by using the bidirectional subjective organization measure. Sternberg and Tulving (1977), who analyzed different measures of subjective organization with regard to their psychometric properties, concluded that the bidirectional subjective organization measure, typically referred to as pair frequency (PF), performed best (Bousfield & Bousfield, 1966). The PF measure takes into account the number of intertrial repetitions observed. An intertrial repetition is defined as a pair of items recalled on two successive trials on two adjacent recall positions---irrespective of the order in which the pair was recalled. The total number of observed intertrial repetitions per person is captured by $O(\text{PF})$. In order to account for the fact that item pairs could also be recalled in two adjacent recall positions by coincidence, $O(\text{PF})$ has to be corrected for chance

influences. To do so, the expected value of intertrial repetitions, $E(PF)$ is calculated. This expected value is given as

$$E(PF) = \frac{2c(c-1)}{hk}$$

where c is the number of items that were correctly recalled on trial t and on trial $t+1$, h denotes the number of items correctly recalled on trial t , and k is the number of items correctly recalled on trial $t+1$. Together, the pair frequency is given as

$$PF = O(PF) - E(PF) = O(PF) - \frac{2c(c-1)}{hk}$$

Because participants in the present study learned and recalled the verbal material in five successive trials, the bidirectional subjective organization measure PF provides four subjective organization scores, one for each of two adjacent trials (Trials 1-2, Trials 2-3, Trials 3-4, and Trials 4-5).⁷ The values of the bidirectional PF can range from $-E(PF)$ to $c-1-E(PF)$; higher scores indicate a higher degree of subjective organization.⁸

All analyses were conducted using the Statistical Package for the Social Science (SPSS; version 18) and Mplus (Muthén & Muthén, 2004) utilizing the maximum likelihood (ML) estimator. The goodness of fit of models was evaluated by using the chi-square test, the Comparative Fit Index (*CFI*) and the Root-Mean-Square Error of Approximation (*RMSEA*). For an acceptable model, *CFI* should receive a value above .95, whereas *RMSEA* values should be less than .06 (Hu & Bentler, 1999).

Results

Table 1 shows descriptive statistics and intercorrelations of the nine manifest variables and age. As expected, both recall performance and subjective organization increased across

⁷ Note, in principle, it is also possible to compute scores reflecting the degree of concordance between recall orders of trial 1 and trial 3, trial 1 and trial 4, and so on. However, according to Tulving (1962), subjective organization is reflected in concordant recall patterns between two adjacent trials.

⁸ Upon the request of an anonymous reviewer, we also conducted all analyses using the ARC' and ITR(2) measures of subjective organization (Sternberg & Tulving, 1977). Results regarding the regression of learning parameters (α , δ , γ) on level and slope of subjective organization very closely matched those obtained using the PF measure.

trials. With regard to verbal learning, it can be seen that the increase in the amount of recalled words is negatively accelerated, that is, the performance increase diminishes across trials. This pattern is consistent with the assumption that verbal learning follows a hyperbolic function. By contrast, the means of subjective organization appeared to increase linearly.

Table 1: Descriptive Statistics of the Manifest Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.
<i>Mean</i>	5.07	9.42	11.97	14.08	15.67	0.36	0.64	1.07	1.40
<i>SD</i>	2.06	3.05	3.51	3.76	4.29	0.72	1.00	1.29	1.57
1. Learn1	1.00								
2. Learn2	0.65*	1.00							
3. Learn3	0.59*	0.80*	1.00						
4. Learn4	0.56*	0.76*	0.85*	1.00					
5. Learn5	0.55*	0.72*	0.82*	0.85*	1.00				
6. PF12	0.42*	0.49*	0.40*	0.33*	0.37*	1.00			
7. PF23	0.31*	0.51*	0.50*	0.44*	0.40*	0.25*	1.00		
8. PF34	0.38*	0.49*	0.59*	0.56*	0.49*	0.25*	0.46*	1.00	
9. PF45	0.36*	0.44*	0.47*	0.54*	0.55*	0.24*	0.32*	0.35*	1.00

Note. $N = 205$. * $p < .01$ (two-tailed).

In a first step, two repeated measures ANOVAs including tests of polynomial trends were calculated. The main effect of recall performance across trials was statistically significant, $F(2.69; 547.64) = 938.91$, $p < .01$, generalized $\eta^2 = .70$ (Olejnik & Algina, 2003). The main

effect of PF scores across trials was also statistically significant $F(2.6; 526.26) = 50.73, p < .01$, generalized $\eta^2 = .15$. Regarding recall performance across trials there was a statistically significant linear ($F(1; 204) = 1724.57, p < .01$, generalized $\eta^2 = .58$) and quadratic trend ($F(1; 204) = 170.29, p < .01$, generalized $\eta^2 = .06$). In addition, there was a statistically significant but much weaker cubic trend ($F(1; 204) = 21.91, p < .01$, generalized $\eta^2 = .01$). Tests for trends of PF scores across trials revealed a statistically significant linear trend ($F(1; 203) = 113.83, p < .01$, generalized $\eta^2 = .15$).

Changes in Subjective Organization

To analyze the changes in subjective organization, in Model SO1 we examined whether the changes in subjective organization could be described as a linear growth curve model. As shown in Table 2, Model SO1 achieved an acceptable fit. The amount of explained variance in the subjective organization indicators ranged from 26% (PF12) to 46% (PF45), indicating that chance influences in subjective organization decreased relative to reliable influences during the course of verbal learning. The means of the two latent variables of the growth model, level and (linear) slope, were both estimated as 0.35 and statistically significant. On average, participants thus started out with a positive subjective organization score, indicating that there was some organization in form of intertrial repetitions in recall between trial 1 to trial 2. With regard to the linear slope of subjective organization, the positive mean indicated that the average rate of increase in subjective organization between adjacent trials pair was 0.35. Both level and slope variances were also statistically significant, showing that there were reliable individual differences in the initial level and linear change of subjective organization across trials. Initial level and linear slope were positively related ($r = .32$), but this correlation did not reach statistical significance.

Upon inspection, we found that the residual variances of the subjective organization indicators were increasing across trials, thus indicating possible heteroscedasticity. In an attempt to account for this increase of residual variances, in Model SO2 we specified a linear

increase of one common residual variance across trials. As can be seen in Table 2, Model SO2 achieved an even better model fit than Model SO1, with parameters estimates being essentially the same as in Model SO1. From this we concluded that not only did the reliable portions of the subjective organization indicators increase linearly, but also the residual variances. Due to its excellent fit, we considered Model SO2 as adequately describing the changes in the subjective organization indicators.

In the next model (Model SO3), we included age as a predictor of both level and slope of subjective organization. As shown in Table 2, Model SO3 had an excellent fit. While the negative effect of age on slope became statistically significant, the negative effect of age on level did not. Age accounted for 7% of variance in slope of subjective organization (2% in level). Thus, older persons had a somewhat less pronounced slope in subjective organization, implying that their subjective organization did increase less compared to the younger elderly persons.

Changes in Verbal Recall Performance

In line with previous studies on verbal learning, we started modeling the verbal learning data by fitting them to a hyperbolic curve (Model VL1). From Table 2, it can be seen that Model VL1 achieved an excellent fit. On average, the amount of explained variance in the verbal learning indicators was 78%. The mean of the initial performance parameter (β) was estimated as 5.1, while the mean of the potential amount of verbal learning parameter (δ) was 21. Finally, the learning rate parameter (γ) was estimated as .25. Thus, on average, participants started out at recalling five words after the first trial, would have increased their performance by 21 words if they had reached their potential maximum performance, and had a speed of learning of .25.

Each learning parameter had a statistically significant variance, implying that there were reliable individual differences in all three verbal learning parameters in old age: Participants started out at different initial levels, differed in their potential amount of learning, and learned

at different speed. The correlation between initial performance and potential amount of learning was positive ($r = .24$), whereas initial performance and rate of learning were negatively correlated ($r = -.21$). Both correlations were not statistically significant, however. The association between potential amount of learning and rate of learning was statistically significant and negative ($r = -.79$). This result means that those participants who learned more words across the five trials showed a slower rate of learning, that is, these participants would need more trials to reach their potential maximum performance. Because of its excellent fit, we regarded Model VL1 as capturing the verbal learning data adequately.

In a subsequent Model (Model VL2), we included age as predictor of all three learning parameters. Note that due to the non-significant correlations between initial performance and potential amount of learning and initial performance and rate of learning in Model VL1, these correlations were fixed to zero in subsequent models. Model VL2 had an excellent fit as well. As it turned out, only the age effect on initial level of learning became statistically significant. As one would expect, the effect was negative, but with 1.5% of explained variance rather small. Notwithstanding, this finding implies that older persons tended to start out at a lower level of initial learning, that is, after the first learning trial they remembered fewer words than younger elderly persons.

Table 2: Model fit statistics

Model	χ^2	<i>df</i>	CFI	RMSEA	RMSEA 90% C.I.
Model SO1	6.89	5	0.98	0.040	0.000-0.113
Model SO2	6.74	8	1.00	0.000	0.000-0.073
Model SO3	8.97	10	1.00	0.000	0.000-0.070
Model VL1	5.69	6	1.00	0.000	0.000-0.088
Model VL2	11.61	10	0.99	0.028	0.000-0.084
Model CO1	52.22*	30	0.98	0.060	0.031-0.087
Model CO2	53.39*	30	0.98	0.062	0.033-0.085

Note. $N = 205$. SO1 = Changes in subjective organization fit to a linear growth curve model. SO2 = Changes in subjective organization fit to a linear growth curve model with a linear increase of one residual variance across trials. SO3 = Age as a predictor of both level and slope of subjective organization. VL1 = Verbal learning data fit to a hyperbolic model. VL2 = Age as predictor of all three learning parameters. CO1 = Relation between subjective organization and verbal learning parameters. CO2 = Latent growth parameters of subjective organization as predictors for the verbal learning parameters.

Subjective Organization and Verbal Learning

In Model CO1 we analyzed the relation between subjective organization and verbal learning by estimating the correlations among the two latent growth parameters of subjective organization, initial level and linear slope, and the three learning parameters. As Table 2 shows, Model CO1 achieved an acceptable fit. Initial level of verbal learning (β) was positively and significantly correlated with level of subjective organization ($r = .68$) and slope of subjective organization ($r = .22$). Both correlations were statistically significant. Hence, those starting out with a better recall performance at the first recall trial also had a higher level of subjective organization, that is, organized more between the first and the second recall trials. Also, they tended to increase their subjective organization more, because they tended to

have higher slopes, but this association was about five times smaller than that with level of subjective organization.

Potential amount of learning (δ) was negatively correlated with level of subjective organization ($r = -.53$) and positively correlated with slope of subjective organization ($r = .58$). Both correlations were statistically significant. These results imply that those who increased their performance a lot tended to do so with a smaller organization level at the beginning, but later on increased their subjective organization much more across trials. Finally, rate of learning was positively and significantly correlated with level of subjective organization ($r = .73$), whereas the negative correlation with slope of subjective organization ($r = -.13$) did not reach statistical significance. These findings show that those who had a faster rate of learning, that is, needed less trials to bridge the gap between initial performance and potential maximum performance, started out with a higher level of subjective organization.

To summarize, Model CO1 shows that subjective organization and verbal learning are substantially correlated, implying that on the individual level both processes show associated changes across trials. These relations are complex, however, in the sense that four correlations were positive, whereas one correlation was negative. Thus, it appears that subjective organization is not always associated with an increase in all individual learning parameters. We will return to this issue in the discussion section.

In a further model (Model CO2), we examined whether the latent growth parameters of subjective organization were relevant predictors for the verbal learning parameters. Instead of correlating the learning parameters with level and slope of subjective organization, they former were now specified as dependent variables, while level and slope functioned as independent variables. We did so in order to investigate the multivariate relations. Model CO2 is depicted in Figure 2. According to Figure 2, the effects of the level of subjective organization on initial learning performance and the learning rate were statistically

significant, large, and positive. Also, the effects of slope of subjective organization on initial learning performance and potential amount of learning were significant, medium and large, and positive. While the standardized effects of level of subjective organization on initial performance and rate of learning were of almost equal size, for slope of subjective organization the standardized effect on potential amount of learning was much larger than that on initial performance. The amount of explained variance in the learning parameters was comparatively large, showing that individual differences in subjective organization and individual differences in changes in subjective organization accounted for about 76% of individual differences in initial learning performance, 68% in rate of learning and 64% in potential amount of learning.

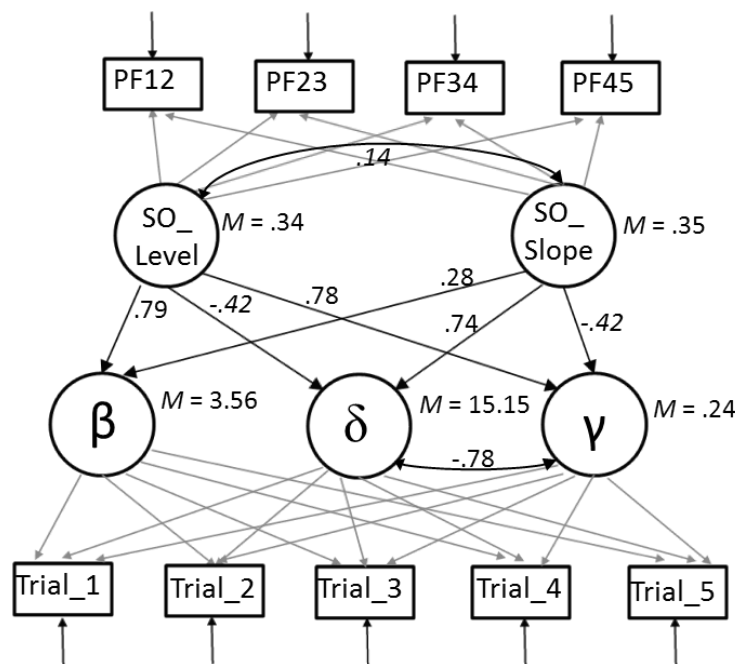


Figure 2: Structural Equation Model of CO2: Latent growth parameters of subjective organization as predictors for the verbal learning parameters. $N = 205$. All parameters are standardized. Non-significant paths are in italics. PF12-PF45 = Intertrial repetition measure of two subsequent trials; Trial_1-Trial_5 = Recall performance of trial 1 to 5; SO_Level = Initial Level of Subjective Organization; SO_Slope = Linear Slope of Subjective Organization; β = Initial Performance; δ = Potential Amount of Learning, γ = Rate of Learning. $R^2 = 76\%$ (Initial Level); 64% (Potential Amount of Learning); 68% (Rate of Learning).

To summarize, as expected, subjective organization increased linearly, whereas verbal learning could be adequately described as a hyperbolic function. Regarding the relation

between subjective organization and verbal learning in old age, results of the present study have shown that changes in subjective organization and verbal learning across five trials are related to each other at the individual level. Parameters of the subjective organization trajectory predicted individual differences in the verbal learning parameters.

Discussion

The present study investigated individual differences in subjective organization in order to examine whether the relation between verbal learning and subjective organization also exists at the individual level for persons in old age. By modeling verbal learning as well as subjective organization as latent growth curve models, we linked the growth parameters of subjective organization and analyzed the relation with regard to individual differences in verbal learning. In what follows, we will discuss implications of the results of the present study regarding the relation between subjective organization and verbal learning. We will explicitly focus on individual differences, age-related effects, and finally discuss open issues.

The Relation between Subjective Organization and Verbal Learning

Results of the present study have shown that subjective organization increased linearly across five trials, whereas verbal learning could be described as a hyperbolic function. Regarding subjective organization trajectories, one could argue that the finding of a linear increase is limited to a specific number of learning trials (five in our case). For example, Tulving (1962) illustrates that subjective organization increased to a smaller degree in the end of a verbal learning task including 16 trials than in the beginning. Note however, that the specific form of increase in subjective organization given more trials, although important in its own right, is secondary for the goals of our study, which focused on the relation between individual differences in subjective organization and verbal learning.

With regard to the relation between subjective organization and verbal learning in old age, the present study extended existing research on mean comparisons between subjective organization and verbal learning by demonstrating that changes in subjective organization and

verbal learning are positively related to each other at the individual level. According to Tulving (1964), an increase in subjective organization is an explanatory variable for verbal learning. The results of the present study are consistent with this idea. Whereas the bivariate Model CO1 implied that there are strong relations between subjective organization and verbal learning, the regression Model CO2 additionally emphasized the relevance of subjective organization for explaining individual differences in verbal learning by quantifying the amount of explained variance in the verbal learning parameters. One should note that the subjective organization measure of the present study (pair frequency) is limited, because organization is measured only when words are recalled in form of word pairs across trials. It is reasonable to argue that subjective organization could be measured by larger organization units, regardless of the exact position of a word, for example triplets (Mandler, 1967; Pellegrino, 1971). Thus, maybe an extended measure of subjective organization would increase the correlation with verbal learning parameters.

In Model CO2 up to 76 % of variance was explained by parameters of subjective organization in individual differences of verbal learning. Thus, persons in old age organize, indeed, words in a specific order that is strengthened across trials and that subjective organization is a process that distinguishes between persons with different levels of verbal learning performances. In particular, the effect of the initial level of subjective organization was strongly related to a higher initial level of learning and faster learning rate, whereas the slope of subjective organization was strongly related to a higher potential amount. These results imply that the benefit of organization across trials is mainly associated with the potential maximal increment. Thus, persons exhibiting a higher organization across trials may also benefit more from multiple trials in terms of more persistent learning. Contrary, a high degree of organization in the very first two trials influences positively the initial level of learning and learning rate, parameters of the learning curve describing aspects of the learning trajectory before reaching the potential maximal increment.

Note that it is possible to include different scores of learning as indices for modeling learning, e.g., gained or lost items across trials. Whether the relation with subjective organization and verbal learning based on such scores is different than the one found in the present study remains an open issue at present. However, with using the absolute recall performance as the indicator for learning as the present study did, it was possible to describe learning on a process-based approach.”

Age-related Effects in Subjective Organization and Verbal Learning

Analyses of the present study imply that age had only small effects on both verbal learning and subjective organization changes---although, of course, in a sample with a limited age range. Following this, age was excluded from the subsequent analyses. The age-related effects and amount of explained variance in subjective organization and verbal learning parameter, which emerged in Model SO3 and Model VL2, were relatively small. However, as stated in the introduction, the goal of the present study was to analyze if there are individual differences in subjective organization in a sample of older participants, thus, in a rather age-homogenous group, in order to verify whether there are also individual differences in subjective organization for this age group. Results of the present study have shown that there are reliable individual differences in both the subjective organization and verbal learning parameter estimates. Old people differ in changes in verbal learning and in subjective organization. Taking into account the result of present study that the relation between subjective organization and verbal learning is highly pronounced for persons in old age, one could argue that there are other variables than age, which explain individual differences in subjective organization and verbal learning. For example, Taconnat et al. (2009) concluded that executive functions are related to organization in old age---although their findings refer to categorical organization. Taconnat et al. (2009) concluded that “reduced executive control may affect memory in many ways, one of which, as shown by our results, is delayed application of organization strategy” (p. 10). Whether subjective organization is also related

to executive control capacities, or to further basic cognitive abilities, such as processing speed (Salthouse, 1996), represents an important issue for future research in order to find explanations for individual differences in subjective organization and, thus, in verbal learning in old age. As mentioned in the introduction, processing speed and working memory may influence subjective organization by facilitating the amount and strength of associations between to-be-learned items. If this is the case remains unanswered in the present study and should be focus of future research. However, the present study could show that subjective organization and verbal learning in old age are related to each other at the level of the individual, which implies a first hint that basal cognitive predictors might also influence subjective organization.

Why might an analysis of individual differences in subjective organization of persons in old age be of particular interest? Implications of the relation between subjective organization and verbal learning in old age could be drawn from the idea that subjective organization is conceptually related to using a memory strategy (method of loci etc.). Hence, it could be of interest whether subjective organization is an implicit process without control or whether subjective organization might be also used as a conscious organization process. Thus, the question of whether persons in old age, who exhibit a higher cognitive decline regarding memory performance, could benefit from (subjective) strategy use, could be of interest regarding possible interventions for memory performance in old age.

An extended study including a younger sample or even more relevant a longitudinal sample could further shed some light on the question of whether the relation between subjective organization and verbal learning is similar across the lifespan and whether predictors of these cognitive processes are to a different degree important regarding the age of the individual. However note that age might only be one individual difference variable showing an influence on the relation between subjective organization and verbal learning. From a theoretical point of view, it is also possible that individual difference variables such as

verbal knowledge may also have an effect, because it might be that persons with a higher verbal knowledge possess more pre-existing associations between to-be-learned items, although these items are unrelated. The present study did not aim at investigating age-related differences of the relation between subjective organization and verbal learning, but rather focused on whether the relation exists also in old age or not. If subjective organization is an underlying process of verbal learning as suggested by Tulving (1962) the relation should also be evident for persons with more limited verbal learning capacities that might be the case for persons in old age. The present study could show that this is the case.

Open Issues

A further straightforward extension of the present study is given by the question of how individual differences in changes in verbal learning and subjective organization across time would look like. As there is already evidence that individual differences in verbal learning in old age emerge over time (Zimprich & Rast, 2009), of particular interest for future research is the question of individual differences in changes in subjective organization longitudinally over time, and following this idea, the question of whether the relation between verbal learning and subjective organization changes across the lifespan for an individual (cf. Mandler, 1967). A similar approach has already been applied by Small, Dixon, Hultsch, and Hertzog (1999) who investigated the relation between changes in memory performances and organization. Results of this study indicated an increase of organization for older adults over six years. However, this study focused on categorical clustering, not on subjective organizational processes.

A further extension for future research refers to the interdependency of the two processes of verbal learning and subjective organization. In the present study we argued that subjective organization is an explanatory variable of verbal learning. However, there are studies showing that the opposite may hold as well. For instance, recent studies on the testing effect (Roediger & Karpicke, 2006) implied the possibility that the relation might be inverse: Subjective

organization emerges because of multiple study and test trials (Congleton & Rajaram, 2012; Zaromb & Roediger, 2010). The authors argue that due to repeated occasions of retrieving (compared to only repeated occasions of studying) and a relational processing, organization emerges that facilitates recalling the to-be-learned material over even longer study intervals (Congleton & Rajaram, 2012). Note, however, that this study used pre-categorized material and thus, measured semantic organizational processes. If a benefit of multiple testing opportunities, thus, of verbal learning, for subjective organization is also evident in tasks with unrelated material remains an open issue at present. Furthermore, investigating the role of subjective organization for forgetting, thus, the inverse of learning as we argued elsewhere (Zimprich & Kurtz, 2013), could be of particular interest regarding the interdependency between verbal learning and subjective organization as one study has already shown that subjective organization is also related to delayed recall performance (Zaromb & Roediger, 2010).

A related issue is how subjective organization varies across trials when subjects already reached their maximal performance. Does subjective organization still increase? Do subjects still differ with regard to subjective organization? The present study used a design with learning a list containing 27 words across five trials. By taking into account issues of motivation we did not extend the learning phase. However, regarding the interdependency of the two processes, a design including more trials might be very promising.

Investigating these open questions could provide further important evidence for the understanding of verbal learning in old age and its associated process of organization. To conclude, we have shown that verbal learning and subjective organization are related to each other in old age. Overall, the results of the present study imply that a positive relation between verbal learning and subjective organization is evident for persons in old age at the level of the individual.

2.2 Individual Differences in Task-Specific Paired Associates Learning in Older Adults: The Role of Processing Speed and Working Memory*

Abstract

Background=Study Context: The role of processing speed and working memory was investigated in terms of individual differences in task-specific paired associates learning in a sample of older adults. Task-specific learning, as distinct from content-oriented item-specific learning, refers to gains in performance due to repeated practice on a learning task in which the to-be-learned material changes over trials. *Methods:* Learning trajectories were modeled within an intensive repeated-measures design based on participants obtained from an opt-in Internet-based sampling service ($M_{\text{age}}=65.3$, $SD=4.81$). Participants completed an eight-item paired associates task daily over a 7-day period. *Results:* Results indicated that a three-parameter hyperbolic model (i.e., initial level, learning rate, and asymptotic performance) best described learning trajectory. After controlling for age-related effects, both higher working memory and higher processing speed had a positive effect on all three learning parameters. *Conclusion:* These results emphasize the role of cognitive abilities for individual differences in task-specific learning of older adults.

Key Words: individual differences, paired associate learning, processing speed, working memory, non-linear growth curves

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Introduction

Previous research on paired associates (PA) learning demonstrated that there is an age-related decline in performance, especially for semantically nonrelated word pairs (Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008). Explanations for this age-related decline include age deficits in associative memory (Kausler, 1994; Naveh-Benjamin, 2000), (temporal) item-context binding (Kahana, Howard, Zaromb, & Wingfield, 2002; Provyne, Sliwinski, & Howard, 2007), and strategy use (Dunlosky & Hertzog, 1998; Verhaeghen & Marcoen, 1994). Notably, nearly all studies on PA learning of older adults have focused on item-specific PA learning, that is, learning of some specific to-be-learned material, for example, learning of the word pair pencil-flower over several trials. By contrast, the present study investigated task-specific PA learning. By the term task-specific PA learning, we refer to gains in performance due to repeated practice on a learning task—irrespective of the to-be-learned material. This type of learning can be achieved by mere repetition of the same task, with the material presented in the task changing over trials. The goal of the present study was to quantify the amount of this task-specific learning in older adults, to examine individual differences in such learning, and to investigate the role of cognitive abilities in accounting for these individual differences.

Task-specific Learning

Repetition of study trials and subsequent recall trials is, in addition to strategy use (Rogers & Gilbert, 1997) and item spacing (Cepeda, Pashler, Vul, & Wixted, 2006; Donovan & Radosovich, 1999; Peterson, Wampler, Kirkpatrick, & Saltzman, 1963), a key component of verbal learning (Karpicke & Roediger, 2007). However, note that repetition may refer to content repetition or task repetition. Item-specific learning involves content repetition, and refers to gains in performance associated with the repeated presentation of the identical to-be-learned material over several trials. Task-specific learning involves repetition of the task (i.e., demands, duration, procedure of the task) but with different sets of to-be-learned material.

Thus, content repetition requires task repetition, but not vice versa. In the case of PA learning, task-specific learning could be examined by presenting different sets of word pairs in every learning trial and measuring performance changes over trials. Thus, the task requires a participant to associate cue and target stimuli and to recall the target stimuli when prompted with the cue. However, because the corresponding word pairs vary from trial to trial, there is no overlap regarding the to-be-learned material. As will be argued in the following, such repetition of the same type of task may result in increasing mastery of the type of task (i.e., task-specific learning), as indicated by performance gains from trial to trial.

The distinction between item-specific versus task-specific learning implies a distinction between two different effects of learning occurring in the same task: learning due to the repetition of the to-be-learned material or learning due to the type of task alone. With regard to multitrial PA tasks, learning may be decomposed into the two effects mentioned: learning due to repetition of the content (item-specific learning) as well as due to repetition of the task demands (task-specific learning). For example, Rast and Zimprich (2009) took into account the beneficial effect of multiple study and retrieval trials (Grimaldi & Karpicke, 2012; Karpicke & Blunt, 2011; Karpicke & Roediger, 2007, 2008; Pyc & Rawson, 2011) by using a multitrial PA task to investigate individual differences in PA learning of older adults. Nevertheless, it remains an open issue of how large the contribution of each type of effect is. Learning may be due to repetition of the content (item-specific learning) as well as due to repetition of the task demands (task-specific learning). To quantify the effect of task-specific learning, the present study used a multitrial PA task with the to-be-learned material changing over trials.

Task-specific learning as described above has been an issue in memory research for a long time, albeit such learning processes have been called learning to learn, or nonspecific learning (Gorfein & Viviani, 1978; Hultsch, 1974; Moely & Shapiro, 1971; Schwenn & Postman, 1967). Central to this research is the question of why repeating task procedures but

changing to-be-learned material results in performance gains. Schwenn and Postman (1967) suggested that task-specific learning occurs because of “the development of instrumental habits that facilitate the acquisition of prescribed verbal associations, e.g., the use of coding devices and mediators” (p. 565). Accordingly, task-specific PA learning might include an alteration in the way and the strength with which associations between cues and targets are formed. Schwenn and Postman (1967) presented a list of word pairs either 4 or 10 times (only study trials). Afterwards, a new, critical list of word pairs was presented. The authors showed that more learning trials (10 vs. 4) of the same type of a PA task led to better performance in recalling the critical list of word pairs. Thus, the learning curve for subjects who had received 10 trials prior to the final test was characterized by a faster learning rate and a higher maximal performance. These results indicate that the type of task and the demands involved had been learned in ways that were unrelated to the to-be-learned material. Thus, it appears as if participants had acquired task-specific skills that enhanced the readiness to form associations in the to-be-learned material, which could have resulted to more time being available for rehearsing cues and targets (Schwenn & Postman, 1967). These increases in performance may refer to nonspecific warm-up effects and other learning effects, e.g., strategy use that is content independent or increased familiarity with task procedures and demands. This increased familiarity with the type of task can free up attentional resources to devote to performance, e.g., rehearsal processes (Baumeister & Maisto, 1974).

Apart from learning-to-learn studies, studies on interim test effects provide a further approach that is related to task-specific learning (Rogers & Gilbert, 1997; Szpunar, McDermott, & Roediger, 2008; Wissman, Rawson, & Pyc, 2011). Interim test effects refer to the benefits of repeated testing for subsequent performance in recalling new verbal material. Whereas many studies focused on item-specific interim test effects, recently, interim test effects have also been investigated in terms of task specificity (Szpunar et al., 2008; Wissman et al., 2011). For example, Wissman et al. (2011) presented unrelated stories. In one group,

the interim-test group, participants recalled the first part of the story after reading it. The other group read the story without any interim recall test. Following this, all participants were asked to recall the last part of the story. Thus, participants in the interim group received a study and a test trial of different to-be-learned material (first part of story) prior to study and recall of the second part of the story. Results indicated that participants in the interim-test group showed a better recall performance than participants in the no-interim test group. Explanations for such a task-specific interim testing effect are, for example, a facilitated comprehension of subsequent text material due to a higher accessibility of prior information (cf. Wissman et al., 2011), an increased use of effective encoding strategies (cf. Wissman et al., 2011), or a better discrimination of words and their corresponding belongingness to different lists (cf. Szpunar et al., 2008). Wissman et al. (2011) argued that a retrieval attempt of previous to-be-learned material and the realization that retrieving is difficult might enhance the use of effective encoding strategies during subsequent learning trials, which would result in improvements in performance over trials—even if the to-be-learned material changes from trial to trial. Such enhancements in encoding strategies use should be reflected in task-specific learning trajectories, thus, in performance gains because skills that are required for the type of task are enhanced and subsequent learning becomes easier.

Note, however, that previous studies of interim effects have focused on group differences in recall performance between interim test versus no interim test conditions. In extending this type of research, the question of the present study was not only whether there are individual differences in benefiting of interim tests, but rather whether recall performance continues to increase over several interim tests. More specifically, as with other types of learning, one might expect that recall performance increases across trials, but with diminishing returns, thus resulting in nonlinear task-specific learning curves. Furthermore, whereas interim tests usually took place over short intervals, the present study focused on the preservation of benefits that might be reflected in task-specific learning curves over days

(Newell, Liu, & Mayer-Kress, 2001). Time scales in learning studies may refer basically to two different time scales of learning: persistent (long-term) and transitory (short-term) learning (Newell et al., 2001). Transitory learning refers to changes in performances, which may fluctuate over learning sessions. In contrast, persistent learning means slow and durable performance gains over longer time intervals. Note that Newell et al. (2001) primarily focused on multiple time scales in motor learning; however, the authors also emphasized that any human learning may be composed of those multiple time scales. Thus, item-specific and task-specific PA learning can be described as transitory or persistent learning, respectively. As the aim of the present study was to analyze performance gains across trials with changing material, in terms by Newell et al. (2001), a persistent learning condition of task-specific learning was implemented.

Predictors of Individual Differences in Task-Specific Paired Associates Learning of Older Adults

In the field of research on item-specific verbal learning, recently, the focus has been complemented by the examination of individual differences in learning (Kyllonen, Tirre, & Christal, 1991; Rast & Zimprich, 2009; Rast & Zimprich, 2010; Zhang, Davis, Salthouse, & Tucker-Drob, 2007; Zimprich, Rast, & Martin, 2008). Note that individual differences in learning may contribute to different characteristics of the learning curve. With regard to episodic memory (Rast, 2011; Zimprich et al., 2008b) and item-specific paired associates learning (Rast & Zimprich, 2009), learning and individual differences therein have been described by a model comprising three parameters: initial level of learning, learning rate, and asymptotic performance (cf. Meredith & Tisak, 1990).

When individual differences in these three learning parameters are modeled, a naturally occurring subsequent question is whether there are characteristics of the individual that may explain these individual differences. Those studies focusing on predictors of individual differences in item-specific verbal learning provided evidence that basic cognitive

abilities such as working memory and processing speed account for individual differences in learning of older adults (Hertzog, Dixon, Hultsch, & MacDonald, 2003; Rast, 2011; Zimprich et al., 2008b). For example, faster processing speed was related to a faster learning rate (Rast & Zimprich, 2009). Basic cognitive abilities, such as working memory and processing speed, may influence individual differences in item-specific verbal learning because of their involvement in both encoding and retrieval (Salthouse, 1996; Unsworth & Engle, 2007). Accordingly, the present study investigated whether the associations also exist between learning parameters in task-specific PA learning trials and basic cognitive abilities in older adults. How might working memory and processing speed affect task-specific learning? Unsworth and Engle (2007) suggested a framework in which individual differences in working memory were related to retrieval processes. The authors argued that depending on the successful use of cues, which delimit the size of the search set as suggested by random search models (Raaijmakers & Shiffrin, 1981), the search set at retrieval might be larger or smaller. If the search set is smaller and contains only or mainly relevant information, retrieval may be facilitated. Individuals with lower working memory capacity may execute the search process less effectively because of a poorer use of cues or because they rely on noisier context cues, which may result in lower recall performance (Unsworth, 2007; Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, 2011).

Regarding processing speed, Salthouse (1996) proposed two mechanisms, which may help explain individual differences in task-specific PA learning of older adults due to lower processing speed: the limited time and the simultaneity mechanism. Due to lower processing speed, a limited mechanism sets in that is characterized by canceling ongoing elementary operations because of an internal lack of time. Additionally, a simultaneity mechanism sets in, which impedes the availability of previous executed operations and their products and thus leads to less information activated that is requested for other processes (Salthouse, 1996). As the mechanisms of working memory and processing speed have been evaluated primarily in

terms of item-specific learning, the present study extends this investigation of the role of working memory and processing speed to task-specific PA learning. As in item-specific learning, we expect that working memory and processing speed are fundamental components to complex learning skills, including task-specific learning effects.

Aims of the Present Study

The overarching goal of the present study was to investigate individual differences in task-specific PA learning in older adults. The analysis of the present study comprised two steps. In a first set of analyses, we examined whether task-specific PA learning trajectories of older adults could be described by three parameters, each reflecting a different characteristic of learning, namely, initial level, learning rate, and asymptotic performance as indicated by prior studies regarding item-specific PA learning over minutes (Rast & Zimprich, 2009). To do so, we investigated whether any of the three nonlinear functions captured task-specific PA learning best. More specifically, we examined the exponential curve (e.g., Heathcote, Brown, & Mewhort, 2000), the hyperbolic curve (e.g., Mazur & Hastie, 1978), and the power curve (e.g., Logan, 1988). As a standard of comparison, we also examined a linear and a quadratic curve model. In a second set of analysis, we investigated whether there are relations between basic cognitive abilities and task-specific PA learning trajectory parameters of older adults. To do so, we included between-person differences in processing speed and working memory as predictors of the three learning curve parameters, adjusted for age-related differences in learning.

Method

Participants

Participants in the current study were $N = 65$ participants recruited from an opt-in internet-based sampling service (StudyResponse) hosted at Syracuse University. Both StudyResponse and the current study received approval from the Syracuse University Institutional Review Board. Participants were on average 65.3 years of age ($SD = 4.81$; range

56-74 years) and had 14.2 years of education ($SD = 3.55$). Fifty-six individuals (95%) self-identified as white/Caucasian (1 as African-American; 2 as Other; and 6 with missing demographic data). Participants rated themselves as in good health on the 5-point general health item of the SF-36 ($M = 3.20$, $SD = .96$; Turner-Bowker, Bartley, & Ware, 2002).

Procedure

An initial sample of participants was generated through a prescreening survey by an opt-in online research service (StudyResponse). Participants saw an advertisement for the service on several Web sites. After signing up to the service, participants were asked about interest and willingness to complete an 8-day daily diary study. Four hundred and seven individuals between the ages of 55 and 75 were screened and, of those, 236 (58%) indicated they were interested. From these individuals, a random sample of 50 young-old (ages 55-65) and 50 old-old (ages 66-74) stratified by gender were sent invitations to the current study. The random sample of the 100 participants was slightly older than the sample of the 236 participants ($t[234] = -4.93$, $p < .01$) because we specifically included proportionally more old-old participants than were registered (50% selected vs. 21% registered). Similarly, there were also slightly more males ($\chi^2[1] = 4.13$, $p = .04$) again due to specific sampling for equal numbers of men and women in the random sample of the 100 participants. The sample of the 236 participants who were willing and interested in participating did not differ from the current sample ($N = 65$) regarding gender ($\chi^2[1] = .53$, $p = .47$). The current sample was slightly older than the sample including the 236 participants ($t[234] = -2.75$, $p < .01$). The difference was about 2 years. Individuals who completed the daily diary did not differ either in age ($t[98] = .99$, $p = .33$) or gender composition ($\chi^2[1] = 1.10$, $p = .29$) from the sample of 100 that was invited.

Invited participants were provided with a link that allowed them to access the log-in page for protocol. During the first session, which approximately lasted 30 minutes, participants provided demographic information and reported on their affect, physical health

and functional limitations, perceptions of aging, personality, and life events. Participants also completed a measure of fluid intelligence during the first session. Subsequently, participants completed up to 7 online sessions over the next 7 days. Participants were required to wait 20 hours between each session to prevent participants from completing all sessions in a short period of time. Participants were given 10 days to complete all 8 sessions. After the 10 days participation was ended and participants were compensated for all sessions completed at that time. On average, participants completed sessions approximately 1.38 days apart ($SD = .63$). The average number of days between the first cognitive session and the last was 6.93 ($SD = 1.34$). $N = 25$ participants completed all 7 sessions. Of those participants, who did not participate on all 7 sessions ($N = 40$), the average number of sessions was 4 ($M = 4.00$, $SD = 1.96$). Note that there were no participants that missed a session and came back the next session.

During each of the fifteen-minute daily sessions, participants completed a variety of cognitive tasks assessing processing speed, working memory, and episodic memory. These daily cognitive tasks could, thus, be used to investigate the trajectory of task-specific learning and to examine the role of cognitive predictors for individual differences in task-specific learning, that is the individual working memory and processing speed performance. At each daily session they also completed questionnaires measuring affect, physical health, and daily stressors. Measures used in the current analyses are described below. On average, participants completed 5 of the 7 follow up sessions with 80% of participants having completed 4 or more of the daily sessions.

Measures

Processing speed. Participants completed a symbol search task that assessed the speed with which they could make simple decisions. Participants saw a pair of symbols on the bottom of the screen and had to decide whether that pair was among six pairs at the top of the screen. There were 40 trials of this task. Participants could take as much time as needed. The

dependent variable for this task was the number of correct answers per session. This task was repeated in every session with material changing across sessions. In order to investigate between-person differences in processing speed as a predictor of learning curve parameters, the mean performance, hence the mean of the number of correct answers per day across all sessions, was computed per individual. This score reflects the individual processing speed performance.

Working memory. Participants completed a subtract 2 span task (Waters & Caplan, 2003) that assessed their ability to process information while holding it in primary memory. Participants were asked to recall a series of digits presented after subtracting 2 from each. Presented numbers ranged from 3-11 so that response options ranged from 1-9. Span lengths for this task ranged from 3-8 and participants attempted two trials at each span length. Score for this task was the number of items correctly recalled in the correct serial order per session. This task was repeated in every session with material changing across sessions. The mean performance, hence the mean of the number of items correctly recalled in the correct serial order per day across all sessions, was computed per individual. This score reflects the individual working memory performance.

Paired-Associate Learning. In the paired associates task, participants viewed a series of 8 word-number pairs, each presented for 1.5 seconds. The word from each pair was then presented and participants had to recall the number that was paired with that word. Study and recall trials were repeated four times for a total of 32 items per session. Items were presented in random order for both presentation and for recall trials. Trials were completed consecutively. There were no tasks in between trials within a given session. This task was repeated in every session. Word-number series varied across the daily sessions, but cue words were equated on imageability and familiarity (Friendly, Franklin, Hoffman, & Rubin, 1982). The total number of correctly recalled numbers across the four trials was the dependent

variable for this task per session. Thus, seven PA scores were computed each reflecting the daily total amount of correctly recalled target items of each individual (max. 32 items).

All analyses were conducted within a mixed-effects approach using SAS PROC NLMIXED in order to fit non-linear learning curve models. The integration method was adaptive Gauss-Hermite quadrature (Pinheiro & Bates 1995). The goodness of fit of the non-nested models was evaluated by using the Akaike information criteria (AIC) and the Bayesian information criteria (BIC) indices (maximum likelihood estimation).

Results

Task-specific Learning Trajectories

Table 3 shows descriptive statistics and intercorrelations of education, age, the WM, PS, and seven daily PA scores. As expected, the means of the daily PA scores suggested a non-linear process. To verify if task-specific learning in older adults is characterized by a nonlinear trajectory, we examined in a first series of analyses, whether the exponential, power, or hyperbolic function adequately captured the performance gains in PA recall across the seven daily sessions. As a standard of comparison, we also examined a linear and quadratic curve model. The corresponding indicators for these parameters were the seven PA scores each reflecting the daily total amount of correctly recalled target items of each individual.

Table 3: Descriptive Statistics of Age, Years of Education, WM, PS, and seven daily measures of PA

	Mean	SD	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Age	65.34	4.80		-.05	-.14	-.18	-.10	-.23	-.10	-.02	-.37	-.13	-.04
2. YEduc	14.20	3.55			.17	.08	.04	.27	.02	.05	.25	-.17	-.15
3. PA2	8.72	7.34				.70*	.71*	.61*	.57*	.56*	.66*	.31	.11
4. PA3	11.17	9.61					.81*	.79*	.79*	.81*	.81*	.51*	.16
5. PA4	11.77	10.26						.78*	.80*	.82*	.70*	.40*	.08
6. PA5	11.94	9.69							.86*	.86*	.87*	.47*	.19
7. PA6	14.02	10.73								.95*	.87*	.42*	.07
8. PA7	13.51	10.32									.83*	.35	.12
9. PA8	15.20	12.02										.51*	.32
10. WM	5.42	2.40											.37*
11. PS	37.22	1.59											

Note. $N = 65$. YEduc = Years of Education. WM = Working Memory. PS = Processing Speed. PA2-PA8 = Paired Associates Performance of Session 2-8. * $p < .01$ (two-tailed).

The first model, which described learning across seven daily sessions as a linear trajectory, captured the data compared to the next model, which comprised initial level, linear slope, and quadratic slope, less well as indicated by a higher BIC and AIC (see notes in Table 4). In a second step, an exponential, power, and hyperbolic model was fitted. As can be seen in Table 4, the hyperbolic model (Model Hyp) described the learning trajectory best as indicated by lower BIC and AIC. The fixed effects of the hyperbolic model indicated that, on average, older adults started to recall correctly 8 target numbers by presenting the corresponding cue word at the end of the first day. After the seventh day, participants recalled on average twice as many target numbers (17). The learning rate parameter indicated that on

average, participants improved their daily performance by recalling one additional number per day.

Table 4: Parameter Estimates and Fit Statistics

Model					
Parameter	Exp	Pow	Hyp	HypCog	HypCogAge
Fixed effects					
α	16.52*	19.53*	16.55*	14.55*	14.91*
β	9.68*	9.39*	7.74*	8.83*	10.44*
γ	0.53*	0.26*	1.04*	1.08*	0.64*
WM on α				2.25*	2.44*
WM on β				1.01*	1.04*
WM on γ				0.10*	0.50*
PS on α				1.27*	2.15*
PS on β				0.89*	0.69*
PS on γ				0.27*	-0.39*
Age on α					-0.33*
Age on β					-0.15*
Age on γ					-0.02
Drop on α					0.28
Drop on β					-0.86*
Drop on γ					0.86
Educ on α					0.60*
Educ on β					0.29
Educ on γ					0.22

Table 4
Continued

Random effects					
Std α	11.11*	15.78*	11.06*	11.47*	9.66*
Std β	6.54*	7.15*	5.51*	5.63*	5.81*
Std γ	0.38*	0.33*	1.28*	0.35*	0.57*
Std res	3.63*	3.88*	3.62*	3.82*	3.41*
Correlations					
$\alpha \beta$.75*	.87*	.76*	.83*	.58*
$\alpha \gamma$.09*	.18*	.01*	.39*	.04*
$\beta \gamma$	-.04	.07	-.01*	.04	.00
Goodness of fit					
-2 LL	2106.4	2114.4	2093.7	2095.1	2061.3
AIC	2126.4	2134.4	2113.7	2127.1	2111.3
BIC	2148.1	2156.1	2135.4	2161.9	2176.9

Note. $N = 65$. Fit-Indices of the linear Model: -2 LL = 2136.1, AIC = 2148.1, BIC = 2161.2; Fit-Indices of the quadratic Model: -2 LL = 2117.9, AIC = 2137.9, BIC = 2159.7. α = asymptotic performance; β = initial level; γ = learning rate. WM = working memory; PS = processing speed; age = grand-mean centered; Drop = dropout with 0 = no missing, 1 = missings; Educ = years of education; Exp: exponential function; Pow: power function; Hyp: hyperbolic function; HypCog: learning modeled by a hyperbolic function, working memory and processing speed as predictors of learning; HypCogAge: learning modeled by a hyperbolic function, working memory, processing speed, dropout, education, and age as predictors of learning. * $p < .05$ (one-tailed).

Significant random effects implied individual variability in all the learning parameters. Thus, participants started out at different initial levels, differed in their rate of learning, and in their asymptotic performance. In particular, individual differences in asymptotic performance and initial performance were positively related. Participants who tended to have a higher asymptote also started out at a higher learning performance.

Predictors of Task-specific Learning

Working memory and processing speed were then included as predictors of the three learning curve parameters (Model HypCog). Table 4 shows that both working memory and processing speed were associated with the learning parameters in the same manner: Higher working memory abilities as well as higher processing speed abilities were related to a higher initial level, a faster learning rate, and a higher asymptote (see also Figure 3). Thus, older adults with relatively higher basic cognitive abilities benefit from these abilities with regard to task-specific learning. Note that all random effects remained statistically significant indicating the need for further ideas to explain why persons of older adults may differ with regard to their initial levels, learning rates, and asymptotic performances.

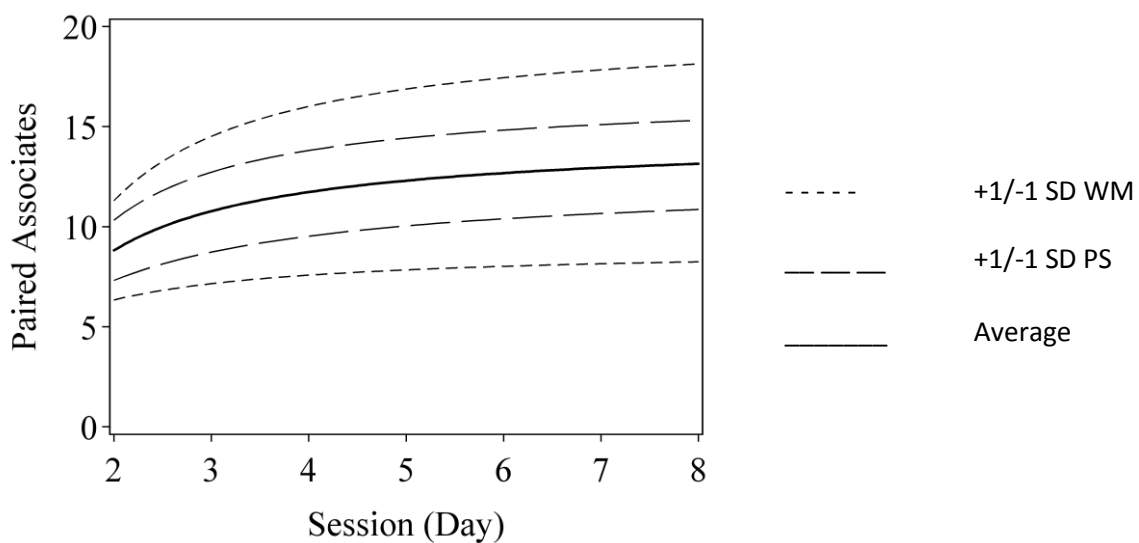


Figure 3: Predicted trajectories of the Model HypCog by ability groupings. +1/-1 SD WM = Mean trajectory of learning by +1 SD of working memory (upper curve) and by – 1 SD of working memory (lower curve). +1/-1 SD PS = Mean trajectory of learning by +1 SD of processing speed (upper curve) and by – 1 SD of processing speed (lower curve). Average = average learning trajectory of all participants. $N = 65$.

In order to investigate age-related effects, age was entered as a further predictor of individual differences in task-specific learning (Model HypCogAge). In order to take into account possible effects of education and attrition on task-specific PA learning, years of

education and a dummy dropout variable were included as further predictors of learning parameters in Model HypCogAge. Results of this model indicated that after adjusting for age, processing speed and working memory remained as influential predictors of all three learning parameters (see Table 4). However, note that the effect of processing speed was now related negatively to learning rate, whereas in the previous model (HypCog) this relation was positive. Age had a statistically significant effect on the initial level and asymptotic performance, with older individuals exhibiting a lower initial level and a lower asymptotic performance (see Figure 4). Regarding effects of education on task-specific PA learning, Table 4 indicates that more years of education are related to a higher asymptotic performance. The dropout indicator was related negatively to the initial level. Thus, participants that did not participate in all seven sessions recalled a lower number of word-number pairs after the first session compared with those participants who did not drop out of the study.

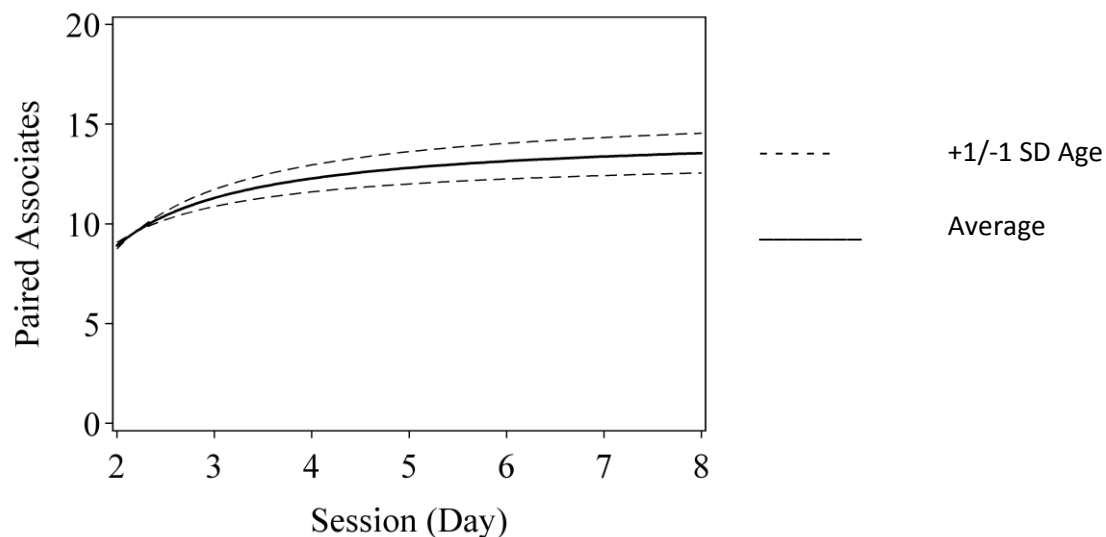


Figure 4: Predicted trajectories of the Model HypCogAge by age groupings. $+1/-1$ SD Age = Mean trajectory of learning by $+1$ SD of age (upper curve) and by -1 SD of age (lower curve). Average = average learning trajectory of all participants. $N = 65$.

With regard to the random effects within this final model, each random effect was still statistically significant indicating that beyond the influence of age, education, dropout,

working memory, and processing speed, there were still significant unexplained individual differences in learning parameters due to other between-person differences.

Discussion

The results of the present study demonstrate that higher basic cognitive abilities, working memory and processing speed, influenced task-specific PA learning of older adults positively even after adjusting for age-related effects on learning parameters. We used a new approach to gain insights into mechanisms of PA learning in older adults. Hence, an increase in recall performances over multiple trials with new to-be-learned material within every trial is reflective of the ability of older adults to learn the instrumental habits required for this type of learning task (Schwenn & Postman, 1967).

Results indicated that task-specific learning of older adults across seven sessions could be described by a three-parameter hyperbolic function comprising initial level, learning rate, and asymptotic performance. The present study, thus, extended existing research on item-specific “content” learning to that of task-specific learning across days (i.e., not across trials within one learning session). Note that there are studies on effects of practice in different time scales (Anderson, Fincham, & Douglass, 1999; Rickard, 2007; Sliwinski, Hoffman, & Hofer, 2010). However, these studies refer to cognitive skill learning, i.e. speedup effects, not with regard to PA learning of older adults. Thus, the present study could extend previous research on learning in different time scales by investigating individual differences in task-specific learning of verbal material across days, a time scale that has not been used in previous verbal learning tasks. Besides the mentioned discussion of persistent vs. transitory learning (Newell et al., 2001) mentioned in the introduction, research on spaced vs. massed learning (for reviews see Cepeda et al., 2006; DeJonge, Tabbers, Pecher, & Zeelenberg, 2012; Donovan & Radosevich, 1999) implies further implications for the results of present study regarding task-specific learning over days. Spaced vs. massed learning research has focused on the issue of sampling time effects of item presentation, in particular, how massed vs. spaced presentation

exactly influence retention of the learned material. Most studies provide evidence that with regard to verbal learning tasks more spacing between item presentations results in a more effective and longer retention than massed presentations (Cepeda et al., 2006; Donovan & Radosevich, 1999; Janiszewski, Noel, & Sawyer, 2003; Peterson et al., 1963). In order to account for this spacing effect, several theoretical explanations have been forwarded including attention, rehearsal, retrieval, encoding variability, and different encoding strategies accounts (Delaney & Knowles, 2005; Janiszewski et al., 2003). In line with the distinction between massed and spaced presentation, the present study, where PA learning trials were separated by days, can be considered as invoking a spaced learning condition. As indicated by one study (Balota, Duchek, & Paullin, 1989), there is evidence that older adults benefit from spaced learning as well indicating the relevance for future research on spaced learning conditions of older adults, in particular, on learning due to repetition of task demands, and the underlying mechanisms. Furthermore, it would be interesting to investigate within and between session effects of repetition of task demands. Whereas the present study focused on between session effects, research on item-specific learning indicated that mechanisms of within and between session effects of practice, e.g. effects of forgetting, or fatigue, and gains due to consolidation processes might differ (Rickard, 2007). If those mechanisms also exist with regard to task-specific learning remains an open issue at present. Future research should focus on this issue as this is important for studies on learning of older adults, because there are likely age-related differences regarding the effects of delays (unknown periods of time) between learning sessions. The length of these periods could potentially affect the aging-related deficits found in closely spaced longitudinal studies and influence how researchers choose to space assessments in time.

The present study emphasized that individual differences in basic cognitive abilities may influence skill learning (Ackerman, 1987), or the use of task-related strategies (Cokely, Kelley, & Gilchrist, 2006). Hence, task-specific learning refers to learning skills required for

the type of task that may result in a facilitated processing for subsequent learning (Schwenn & Postman, 1967; Wissman et al., 2011). Results of the present study implied that individual differences in task-specific learning were predicted by processing speed and working memory abilities: Both higher working memory and processing speed were related to a higher initial level, faster learning rate, and higher asymptote. These results imply that once task demands are learned, working memory capacity for actual items could be released as working memory capacity might be required for both the understanding and mastering demands of the type of task and the rehearsal of actual items. If one assumes that within every session a content-based (item-specific) learning process took place, working memory and processing speed could be used more efficiently for learning the specific content of the PA list of the corresponding day as there is no need for processing further task demands. To verify mechanisms of these complex relations between cognitive abilities and learning that is both content-free and content-based due to repetition of the content and repetition of task demands, future studies should analyze the effects of content and task repetition more systematically.

After adjusting for effects of processing speed and working memory on learning parameters, age had an effect on the initial level and asymptotic performance. Note that age did not moderate the effects of processing speed and working memory on the learning parameters. The non-existent influence of age on learning rate indicates implications for longitudinal studies as the oldest participants may benefit regarding task-specific learning to a similar degree from exposure to the testing procedures as their younger counterparts. However, at least within a period of days as shown in the present study, older persons do have difficulties to reach a similar recall performance after seven days of task-specific PA learning.

To account for effects of possible unique properties of the Web-based procedure of the present study, we include education and attrition as predictors of task-specific learning. Results indicated that participants with a higher education and participants that did not drop out also performed better in task-specific learning. However, note that there were still

individual differences in all three learning parameters. Between-person differences such as verbal knowledge, using memory strategies in daily life, or cognitive organization (Hultsch, 1974) might be further predictors of task-specific learning of older adults. Also note that the effect of processing speed on learning rate turned out to be negative after adjusting for effects of education and dropout on task-specific learning. We conducted an additional analysis that included only processing speed, working memory, and age as predictors of task-specific PA learning without education and dropout as further predictors. Within this model, processing speed had an effect of .21 on learning rate. Thus, the reverse (negative) effect of processing speed on learning rate in the final model might be due to the inclusion of education and dropout as predictors of learning, not due to the inclusion of age as a predictor. Thus, the positive effect of processing speed on learning rate in the previous unadjusted model changes with the adjusted model.

Regarding effects of education on task-specific learning, one should note that all participants of the present study were relatively high educated. Possibly the Internet procedure of the present study resulted in a select sample of older adults who might be higher educated and/or more likely to have experience in using a computer. All participants in the present study possessed a computer; therefore, they had some computer experience. Thus, our model remains to be further validated with a sample that has less computer experience and for a sample with a broader range of years of education.

Note that the present study investigated task-specific PA learning of older adults in a naturalistic context, in which participants conducted the test battery self-regulated at home, in order to gain insights into optimal conditions of task-specific learning that are related to the natural process of learning. A limitation of this procedure might be that there is no information available regarding what participants actually did during task completion. Compared to a lab-based sample there is less control over correct task completion. With regard to the task of the present study, a paired associate task, it would be possible that

participants were writing the word pairs during study trials. In order to find indicators of an incorrect task completion, we considered the duration of task performance and also calculated the correlation between this duration and recall performance. Hence, if participants were taking time to write down information we would expect the time on task to be relatively long in the internet sample as it would take more time to write down responses and to look up answers to items as they were presented for recall in a different random order compared with presentation. Furthermore, a correlation between duration of task and recall performance would indicate the possibility that participants did anything in order to succeed in the PA task resulting in actual higher recall performance. Both indicators suggested that participants in the present study completed the PA task without any additional activity that was not part of the instruction of the task. The duration of task completion was relatively short ($M = 4.36$ minutes, $SD = 1.59$) indicating that participants in the current sample did not spend hours trying to get the answers right. Furthermore, the correlation between task duration and recall performance was not statistically significant, individuals who required more time were not more likely to get higher PA scores ($r = .128, p = .312$).⁹

Unlike typical lab-based research participants could complete the tasks at a time and place of their choosing. This reduces pressure on participants by allowing them to remain in the comfort of their typical environment and to select a time when they perceive themselves to be prepared and motivated for the testing. In contrast, bringing participants into the lab for this testing may unintentionally induce anxiety, either through the novelty of the lab environment itself or from the implications of performing poorly in front of a research assistant. Additionally, lab-based research is limited to hours of operation that require alteration of the participant's daily routine. Previous work has shown that older adults show better performance on memory tasks that are part of a structured routine (Neupert, Patterson, Davis, & Allaire, 2011; Rose, Rendell, McDaniel, Aberle & Kliegel, 2010). Home-based

⁹ We thank an anonymous reviewer for suggesting these alternative analyses.

testing as realized in the present study may reduce performance deficits due to these factors. Mogle (2006) verified that among a computer lab with and without supervisor as well as a location of participants' choosing there were no differences between these conditions regarding factor structures as indicated by measurement invariance. However, it remains an open issue if lab-based assessments would produce different results with regard to task-specific learning trajectories of older adults.

A further open issue of the present study is the question of what the underlying mechanism of task-specific learning might be. In the beginning we argued that in line with Schwenn and Postman (1967) as well as with Wissman et al. (2011) skills required for a PA task are enhanced. However, if a skill and its related mechanisms, as suggested by the growing literature on cognitive skill learning (Rickard, 2007; Touron, Hoyer, & Cerella, 2001; Wilkins & Rawson, 2010), was learned, the exact skill remains an open issue.

In conclusion, the present study emphasized the role of individual differences and cognitive correlates of task-specific PA learning over several days. Future measurement intensive studies should take into account individual differences in task-specific learning and further analyze between-person differences in task-specific learning across the lifespan. Further questions remain as to the generality of such learning effects across stimuli and task type and how particular task-specific PA learning may transfer and affect other types of task-specific learning without a PA component.

2.3 Individual Differences in Criterion-Based Dropout Learning in Old Age – The Role of Processing Speed and Verbal Knowledge*

Abstract

In the present study, individual differences in criterion-based dropout learning in old age were investigated. The predictive role of processing speed and verbal knowledge for individual differences in this type of learning was analyzed. Learning trajectories were modeled using a multi-level approach based on $N = 47$ older participants ($M_{\text{age}} = 69.3$, $SD = 6.4$). Participants learned five lists of eight cue-target word pairs across 6 study-test cycles maximally possible. Results indicate that there were reliable individual differences in the initial level, speed of learning, and quadratic growth of learning. After adjusting for age-related effects, both higher verbal knowledge and higher processing speed had a positive effect on speed of learning. Additionally, verbal knowledge had a negative effect on quadratic growth of learning. Speed of learning and quadratic growth had a positive effect on a delayed recall test after adjusting for effects of processing speed and verbal knowledge. These results emphasize the role of cognitive abilities for individual differences in criterion-based dropout learning in old age.

Key Words: individual differences, dropout schedule, processing speed, verbal knowledge, paired associate learning, multi-level

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Introduction

If a person is asked to learn, e.g., new vocabulary, there are several possibilities to arrange a learning schedule and the according learning process. In case of vocabulary learning, a common arrangement would consist of using flash cards and successively excluding vocabularies that have once been successfully retrieved from further studying (cf. Karpicke, 2009; Karpicke & Roediger, 2008; Pyc & Rawson, 2007). The present study aimed at investigating this so-called criterion-based dropout learning and individual differences therein in old age. In addition, predictors of individual differences in criterion-based dropout learning were examined.

Criterion-based Learning

The criterion-based learning approach is one out of two dominant approaches to investigate individual differences in verbal learning, be it in old age or with younger participants. The criterion-based learning approach is characterized by a fixed learning criterion that keeps the amount of to-be-learned material constant for every person. Different persons may need a different number of study-test cycles in order to achieve a particular learning criterion. Individual differences in learning can then emerge with respect to the initial performance and speed of learning (cf. MacDonald et al., 2006). By contrast, the fixed-trial approach, which was used in previous studies on verbal learning (Zimprich & Rast, 2009; Zimprich et al., 2008b), is characterized by a constant number of study-test cycles (cf. Pyc & Rawson, 2011). Compared to the criterion-based approach, then, what can differ between persons is the initial performance, rate of learning, and asymptotic performance (Rast & Zimprich, 2009; Zimprich et al., 2008b). Briefly, in the fixed-trial approach, the number of trials is fixed, but the amount of learning is variable, whereas in the criterion-based approach, the number of trials is variable and the amount of material learned is fixed.

Dropout Learning

Note that both the fixed-trial and the criterion-based approach can, if a whole-list procedure is implemented, lead to overlearning of some items (Karpicke & Roediger, 2008). The whole-list procedure involves presenting the complete to-be-learned material during all study-test cycles. Some items of the to-be-learned material are then practiced beyond the point of initial mastery, that is, items are repeatedly studied and tested although they have, at least once, successfully been recalled (cf. Rohrer et al., 2005; Slamecka & Katsaiti, 1988). Due to repeated encoding and repeated retrieval, memory performance regarding these overlearned items is assumed to be better (cf. Karpicke & Roediger, 2008). Indeed, according to a meta-analysis conducted by Driskell, Willis, and Copper (1992), overlearning produces a positive effect of moderate magnitude on recall performance. However, the meta-analysis also showed that the positive effect of overlearning depends on the retention interval, the amount of overlearning, and the type of task. Consequently, overlearning may not always be an effective way of learning. The time and effort invested into restudy of already successfully recalled material typically does not lead to a proportional increase in recall performance.

In order to avoid overlearning and to save time and effort, so-called dropout schedules have been developed. Dropout schedules refer to different schedules of excluding items once retrieved successfully from further studying and, or from further testing (Karpicke & Roediger, 2008; Kyllonen & Tirre, 1988). Clearly, using a dropout schedule, it will take less time to reach a learning criterion than using the whole-list procedure (cf. MacLeod, 1985; Pyc & Rawson, 2007). Karpicke and Roediger (2008) showed that for younger adults the exclusion of successfully recalled items from study *and* from test cycles was the most economic and efficient dropout schedule as reflected in fewest study-test cycles required to achieve a learning criterion. With respect to short-term retention, this dropout schedule appears to be the most economical way to master a verbal learning task (Pyc & Rawson,

2011). The present study investigated this type of dropout learning in persons in old age by simultaneously using a criterion-based learning approach as described above.

Which cognitive processes might underlie criterion-based dropout learning? Dropout learning is characterized by successively smaller amounts of the to-be-learned material. According to the item noise approach (Criss & Shiffrin, 2004), learning successively smaller amounts is easier because less interference among items exists. Recently, it was shown that such list length effects (Ratcliff et al., 1990) may not only result from less interference, but also be due to other factors, such as a shorter retention interval typically resulting from dropout schedules, a smaller amount of attention required, and a more consistent context of study and test context due to less time between studying and testing (Kinnell & Dennis, 2011). One may assume that persons differ regarding these cognitive correlates. Thus, persons might also differ regarding criterion-based dropout learning trajectories. These differences might be even more pronounced in old age, after a life-long history of individual differences in cognitive development. In line with a position advocated by Hofer and Sliwinski (2001), the goal of our study was thus not to demonstrate age-related differences in dropout learning between, e.g., young and old adults. Rather, our focus was on individual differences and possible predictor variables that might account for these individual differences with respect to dropout learning in one age group---that of older individuals.

Individual Differences in Criterion-Based Dropout Learning in Old Age

In order to investigate individual differences in criterion-based dropout learning, the present study focused on processing speed and verbal knowledge as possible predictors. In line with the processing speed theory by Salthouse (1996), there are two different cognitive mechanisms of how processing speed may influence learning, the limited time and the simultaneity mechanism. According to the limited time mechanism, lower processing speed results in cancelling ongoing elementary cognitive operations because of an internal lack of time. Thus, lower processing speed impedes the availability of previous executed operations

and their products. The simultaneity mechanism posits that slower processing speed leads to less information activated simultaneously that is requested for other processes. According to these two mechanisms, high processing speed may facilitate the ongoing processes required for retrieval.

Regarding possible mechanisms of how verbal knowledge affects individual differences in learning, there are some studies that provided evidence for a positive relation between verbal knowledge and verbal learning (Jones et al., 2005; Kyllonen et al., 1991; Rast, 2011). Rast (2011) emphasized, in particular, the role of verbal knowledge for learning rates in old age. One possible mechanism of these relations might be that the larger the pool of words in memory and the greater the experience in searching for words, that is, the higher verbal knowledge, the less individuals would need to rely on, for example, speed of retrieval in the performance of verbal learning tasks (cf. Salthouse, 1993). To sum up, there is theoretical and empirical evidence to assume that both processing speed and verbal knowledge may be predictors for individual differences in verbal learning in old age because higher processing speed and verbal knowledge may facilitate learning. However, note that these relations have not yet been investigated with a criterion-based dropout learning schedule. The aim of the present study was to investigate the role of processing speed and verbal knowledge as explanatory variables of individual differences in criterion-based dropout learning.

Learning based on a criterion-based dropout schedule also entails the possibility to investigate a possible relation between individual differences in this type of learning and the amount retained after a certain time. Whereas previous studies provided findings that there are individual differences in the amount of verbal material retained (MacDonald et al., 2006; Zimprich & Kurtz, 2013), to the best of our knowledge, there is no study, which investigates individual differences in a delayed recall test by using a criterion-based dropout approach. The present study aimed at closing this gap. In doing so, it was possible to quantify the

amount persons retain after a short retention interval and to analyze the relation between individual differences in criterion-based dropout learning and performance in a delayed recall test.

Aims of the Present Study

Summing up, the present study focused mainly on three different aims: Analyzing 1) individual differences in criterion-based dropout learning, 2) predictors of individual differences in criterion-based learning, and 3) the influence of individual differences in learning on a delayed recall test. In doing so, we referred to individual differences in initial level, speed of learning, and quadratic growth as individual differences in criterion-based dropout learning. Regarding the third aim, we assumed that processing speed and verbal knowledge may have a positive effect on the initial level, speed of learning, and quadratic growth by adjusting for age-related effects on learning.

Methods

Sample

The original sample comprised $N = 52$ older adults. Of these, five persons did not complete the whole session due to technical problems or lack of motivation. Of the remaining $N = 47$ older adults, 18 were male (38%) and 29 were female (62%). On average, participants were 69.3 years old (SD 6.4), with age ranging from 59 to 83 years. On a scale ranging from 1 = "excellent" to 5 = "poor", participants judged their subjective health on average as 2.34 (SD 0.85). All participants were recruited during a semiannual event organized by the Centre for General Scientific Continuing Education at the University of Ulm. Because the senior audience of these semiannual events is typically more educated than the general population of older adults, the sample of the present study also had a strong educational background, with 27 participants (54%) reporting to have a high-school graduation.

Measures

Learning and Memory.

Paired Associates. For the paired associates task comprising 40 word pairs, 80 German words were selected from the Berlin Affective Word List Reloaded (BAWL-R; Vö et al., 2009). Half of the words, which functioned as the cues in word pairs, were two-syllable words (e.g., "Hafer" [oat]). The other half of the words, which functioned as the targets in word pairs, were one-syllable words (e.g., "Kamm" [comb]). All words selected were relatively high in frequency, with the cue words having an average frequency of 17 per million and the target words showing an average frequency of 121 per million. Both cue and target words were emotionally neutral (the average emotionality of cue words was 0.08 and the average emotionality of target words was 0.46 on a scale ranging from -3 = "emotionally very negative" to 3 = "emotionally very positive") and high in imageability (the average imageability of cue words was 4.37, the average imageability of target words was 5.06 on a scale ranging 1 (low imageability) to 7 (high imageability)). Cue and target words were randomly combined to pairs and these word pairs were the same for all participants. Subsequently, the 40 word pairs were randomly assigned to five lists of eight word pairs each. These five lists were the same for all participants. Order of presentation of word pairs within lists was randomized both across participants and, across study-test cycles, within participants. Participants were asked to associate cue and target stimuli and to recall the target stimuli when prompted with the cue and the first letter of the target word. The additional cueing with the first letter of the target word was done because a pilot study had shown that otherwise the learning of 40 word pairs in total would be too difficult.

Learning Performance. Learning performance in the paired associate task was measured using the *cumulative* number of target words successfully remembered after each study-test cycle. That is, for every participant learning performance ranged between the number of target words successfully recalled after the first study-test cycle and the

cumulative number of target words successfully recalled after each study-test cycle until reaching the learning criterion of all 40 target words. What differed between participants, then, is the number of study-test cycles needed to reach the learning criterion, that is, the speed of learning.

Delayed Recall. After reaching the 100% learning criterion of the 40 word pairs, participants were asked to recall as many of the 40 target words as possible when prompted with the cue word and the first letter of the target. The number of target words recalled correctly represented the delayed recall task. Note that the delayed recall test started by asking for the target words of the first list of word pairs. Subsequently, delayed recall of targets from word pairs of the second, the third, the fourth, and the fifth list was required.

Processing Speed

Identical Pictures. This task comprised 60 items taken from the Identical Pictures Test from the Educational Testing Service (ETS; Ekstrom et al., 1976). For each item, participants were asked to select as rapidly as possible the one out of five pictures that was identical to a target picture. Each item consisted of a row of six simple pictures; the target picture was presented to the left of five numbered pictures. Participants indicated their decision about which of the five numbered pictures was identical to the target picture by typing the corresponding number on the computer keyboard. The number of correctly answered items was scored (possible range: 0-60). After two practice items during the instruction phase, participants had 90 s time to work on the task.

Verbal Knowledge

Spot-a-word. This task is comprised of 37 items taken from Version A of a widely used German vocabulary test (MWT; Lehrl, 1999). For each item, one word and four pronounceable nonwords, which were similarly spelled or similarly sounding, were presented on the computer screen. Participants were asked to select the word from the nonwords by

pressing designated keys on the computer keyboard. The number of correct responses was scored (possible range: 0-37). Participants were given up to 7 minutes to complete the task.

Procedure

Participants were tested individually. After having given their informed consent, the experimental procedure started with the presentation of the eight word pairs from the first list on a computer screen (study phase). Each word pair was presented separately for 3 seconds. After presentation of all eight word pairs of the first list, participants read the instruction of how to enter target words using the keyboard when prompted with the according cue word and the first letter of the target. Next, the cue words of the eight word pairs were presented consecutively and participants were asked to enter the according target words (test phase). When a target word was correctly recalled, it was, together with its cue word, removed from the list of word pairs. Thus, the second presentation of the first list contained only those word pairs which had not been successfully recalled. When a target word was correctly recalled, it was, together with its cue word, removed from the list of word pairs. Thus, the second presentation of the first list contained only those word pairs which had not been successfully recalled. Participants were informed about this dropout schedule and thus the removing of a word pair served as an implicit feedback for participants regarding which target words were recalled correctly. Note that the removing of successfully recalled word pairs also meant that the number of study-test cycles a word pair was presented was different for different word pairs. The second presentation of the remaining word pairs was followed by a second recall phase, which included only cues of previously not successfully recalled targets. The second presentation of the remaining word pairs was followed by a second recall phase, which included only cues of previously not successfully recalled targets. These study-test cycles were repeated maximally six times or until all targets were successfully recalled. Thus, the learning criterion was 100% but under a dropout procedure in that word pairs the target word

of which was successfully recalled did not appear again---neither during the study phase nor during the recall phase.

Subsequently, participants were required to work on the Identical Pictures task (see measures section above). Next, presentation of the second list of eight word pairs started. Like for the first list, a dropout procedure of word pairs was used. Afterwards, participants were required to work on a Number Backwards task (similar to that of the WAIS-R; Tewes, 1991) for three minutes. Participants saw a series of numbers ranging from 2 to maximally 7 numbers. After the presentation of these series participants were asked to type in backwards these numbers. The data of this task will not be used in the present study, because due to the theoretical background mentioned in the introduction, the aim of the present study was to analyze processing speed and verbal knowledge as predictors of learning. Hence, the Number Backwards as well as the Letter Sets task is not described in detail here. Next, the third list of eight word pairs was presented analogously to the way the first and second word lists were presented. The third list of word pairs was followed by the Spot-A-Word task (see measures section above).

Following this, participants learned and recalled the fourth list of word pairs analogously to the previous lists. Next, participants worked for four and a half minutes on a Letter Sets task. Four groups of letters, each group containing four letters, were presented. Participants were asked to decide which group of letters was the only group not following a rule that was reflected in the other three groups. Finally, the fifth list of word pairs was learned and recalled in the same way as the previous lists. Directly afterwards, participants were given a delayed recall task (see measures section above). Note that the delay between learning the five different lists and the final delayed recall differed between persons. The individual delay depended on the time, respectively, the number of study-test cycles needed for reaching the learning criterion.

Results

Descriptive Statistics of Study Variables

Table 5 shows descriptive statistics of the variables used in the present study. As can be seen from Table 5, participants needed approximately 17 study-test cycles to achieve the criterion of having recalled each of the 40 target words successfully exactly once. This number, however, differed considerably between participants, with the fastest participant requiring only seven study-recall phase cycles and the slowest participant requiring 25 cycles (of 30 cycles maximally possible) to reach the criterion of 100%. Thus, in terms of numbers of study-test cycles to criterion, there were pronounced individual differences between participants. Note that there were three participants who recalled only seven instead of eight target words each in one of the five cue-target word pair lists. Thus, these participants only narrowly missed the learning criterion and were therefore included in the analyses.

Table 5: Descriptive Statistics of Study Variables

	Mean	SD	Min	Max
Identical Pictures	9.73	4.66	1	14
Spot-A-Word	33.84	1.71	30	37
Total Number of Study-Test Cycles Needed	14.16	4.58	7	25
Delayed Recall Performance	30.58%	21.70%	2.5%	80%

Note. $N = 47$.

If the total number of study-test cycles needed is broken down into study-test cycles needed for each of the five word lists (see Figure 5), it appears that participants became, on average, somewhat faster in learning, that is, they needed less study-test cycles across the five lists of word pairs. These mean differences between number of study-test cycles needed for

the five lists were statistically significant in a repeated measures analysis of variance with number of study-test cycles needed for the five lists as within-person factor ($F = 4.82$, $df = 4$, 46 , $p < .01$). The Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(9) = 10.85$, $p = .28$. Multiple comparisons using Fisher's LSD test indicate that the average number of study-test cycles needed for the fourth and fifth lists was smaller than the average number of study-test cycles needed for the first and the second lists. What can also be seen from Figure 5 is that, across word lists, individual learning differences were comparatively consistent as is expressed by the correlations between numbers of trials needed for adjacent word lists.¹⁰ This implies that those who were faster in learning of the first word list needed fewer study-test cycles and were also faster in learning the following word lists. Individual differences in learning speed were, thus, relatively stable. The relatively high stability can also be seen from Figure 6, which depicts the cumulative number of successfully recalled words across study-test cycles for every participant. As Figure 6 shows, the increase in the cumulative number of recalled words appeared to be almost linear for most participants, again implying relative high stability of learning performance across the five word lists.

On average, participants recalled 30% of the 40 word pairs studied in the delayed recall test. The average performance of processing speed measured by the Identical Picture test was 16.48. With regard to verbal knowledge, participants chose correctly 33.88 words in the Spot-a-Word task of maximal possible 37 words.

¹⁰ One has to keep in mind that a restriction of range is present regarding the number of study-test cycles per word list because no participant could have less than one or more than six study-test cycles per word list. This restriction of range attenuates the correlations between the number of study-test cycles needed for adjacent word lists. If one calculates the correlations between the cumulative number of study-test cycles needed instead, correlations are much higher ($> .90$).

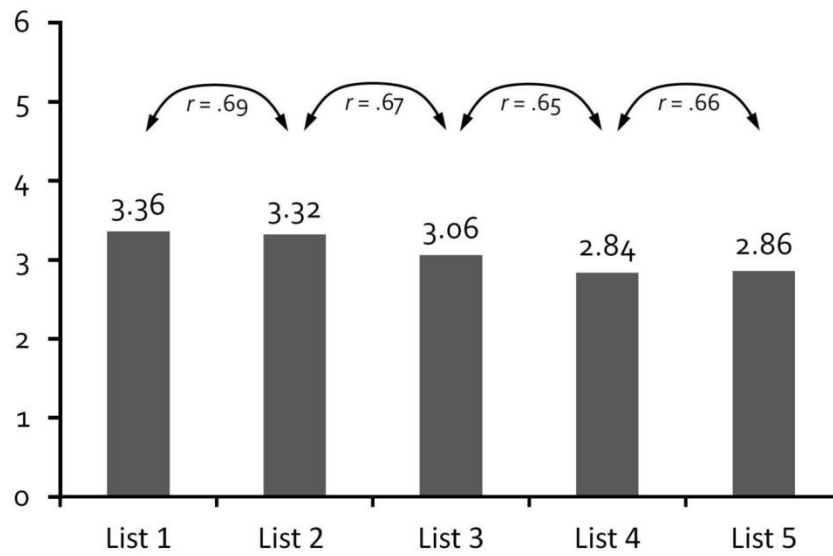


Figure 5: Mean Number of Trials Needed per Word List and Correlations between Numbers of Trials Needed for Adjacent Word Lists.

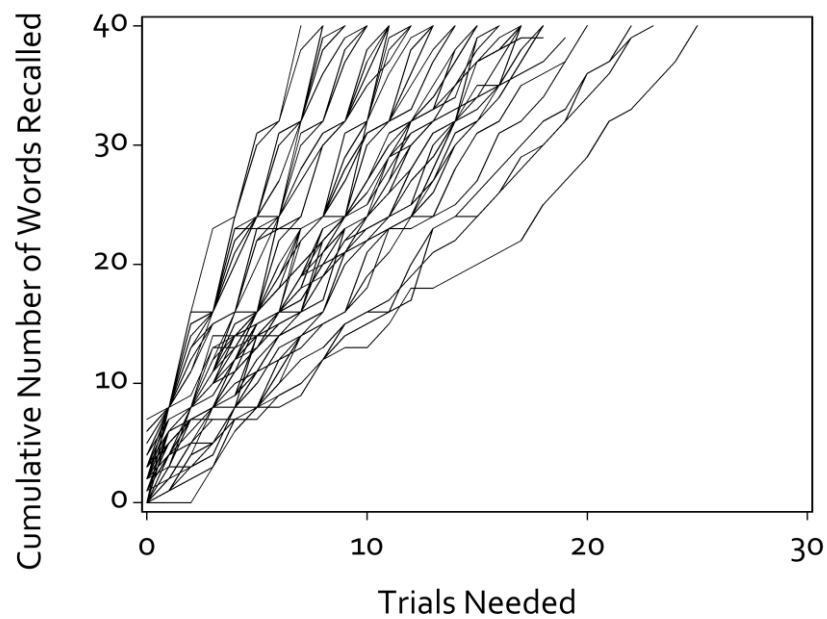


Figure 6: Observed Cumulative Number of Successfully Recalled Target Words Across Trials (Study-Test Cycles).

*Multilevel Models**Growth Curve Model.*

In line with the aims of the present study, a multilevel approach was implemented (Raudenbush & Bryk, 2002), with number study-test cycles at Level 1 and individuals at Level 2 using MPLUS version 6.12 (Muthén & Muthén, 2004), type = twolevel.¹¹

In a first model (Model 1), we modeled within-person changes in cumulative recall performance across study-test cycles with a linear slope, which represents speed of learning. Table 6 shows the corresponding fixed effect and random effects estimates for Model 1. On average, participants started with a recall performance of 2.46 correctly recalled word pairs after the first study-test cycle. The significant linear slope indicates that recall performance linearly increased by 2.84 words with every study-test cycle, on average. Note that there are two random effects indicating that there are individual differences in the initial level and in speed of learning. Furthermore, the positive correlation between random intercept and linear slope ($r = .55$) indicates that persons with a higher performance after the first study-test cycle tended to reach the learning criterion faster.

In order to take into account possible non-linear trajectories, in Model 2, a quadratic slope was added to the model, which represents quadratic growth of learning. Note that the fixed effect of the quadratic slope was not statistically significant, however, the random effect of the quadratic slope was, indicating that there were reliable individual differences in quadratic growth. Therefore, in the following models the linear and quadratic slope both remained as Level-2 predictors. In Model 2, all random effects were statistically significant indicating that there were reliable individual differences still in the initial level and speed of learning, but also in quadratic growth. Furthermore, the correlation between individual differences in the initial level and the linear slope as well as the correlation between

¹¹ Our design of criterion-based learning inevitably leads to unbalanced data. We assumed that the missing data are missing at random (MAR) because the amount of missingness directly depends on the observed data, that is, the trials needed to achieve the criterion (see, e.g., Graham, 2009). Of course, the results of the present study and thus the number of trials needed to achieve the criterion refer to the chosen learning criterion of 40 word pairs.

individual differences in the linear slope and quadratic slope indicates that persons with a higher initial level tended to have a higher speed of learning, and persons with a higher speed of learning tended to have a less pronounced quadratic growth (see Figure 7).

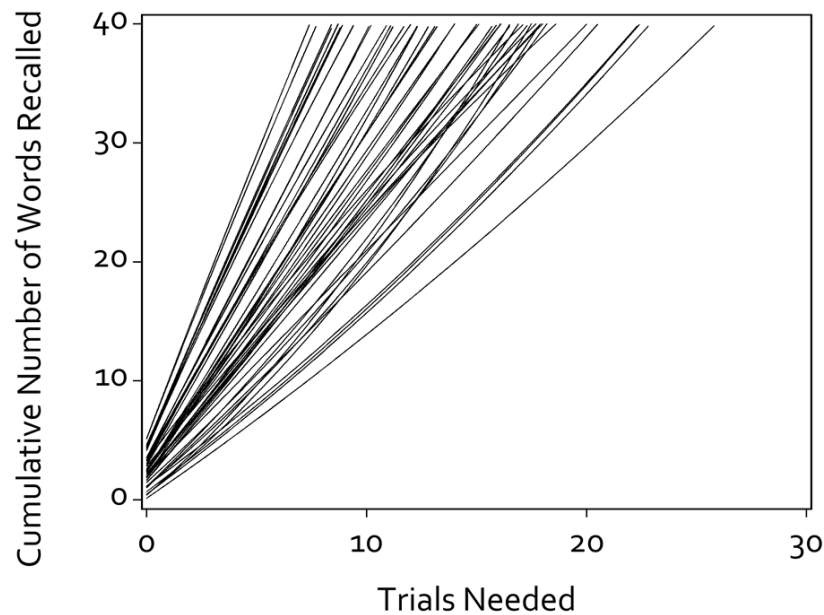


Figure 7: Predicted Cumulative Number of Successfully Recalled Target Words Across Trials (Study-Test Cycles) based on Model 2.

Conditional Models.

The second aim of the present study was to investigate the predictive role of processing speed and verbal knowledge for individual differences in criterion-based dropout learning by adjusting for age-related effects on learning. To do so, in a first step, in Model 3, within-person changes in cumulative recall performance were modeled by including age as a 2-Level predictor (grand-mean centered). Model 3 indicates that age did not have a statistically significant effect on the initial level, but there was a statistically significant effect of age on speed of learning, which was negative, and one on quadratic growth, which was positive. This result means that older persons tended to have a lower speed of learning, respectively, needed more study-test cycles in order to achieve the learning criterion. At the

same time, older persons tended to have a stronger quadratic growth across study-test cycles, implying that they increased their recall performance faster towards the end of the learning phase. All random effects and the correlation between individual differences in speed of learning and quadratic growth remained statistically significant in this model. Note that we also test a quadratic age effect in order to take into account the assumption that the effect of age on learning may not be linear. However, the quadratic age effect was not significant. Thus, we omitted this effect for the subsequent analyses.

Table 6: Parameter Estimates and Fit Statistics

	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed effects					
Initial Level (Intercept)	2.46*	2.65*	2.63*	2.56*	2.58*
Trial (Linear Slope)	2.84*	2.81*	2.81*	2.77*	2.75*
Trial \times Trial (Quadratic Slope)		-0.01	-0.01	-0.01	0.00
Age			-0.03	-0.02	-0.02
Age \times Trial			-0.07*	-0.06*	-0.05*
Age \times Trial \times Trial			0.01*	0.01*	0.01*
Spot-A-Word				0.44*	0.37*
Spot-A-Word \times Trial				0.25*	0.28*
Spot-A-Word \times Trial \times Trial				-0.01	-0.01*
Identical Pictures				0.03	0.06
Identical Pictures \times Trial				0.11*	0.09*
Identical Pictures \times Trial \times Trial				0.01	0.01
Intercept \rightarrow Delayed Recall					0.05
Trial \rightarrow Delayed Recall					0.16*
Trial \times Trial \rightarrow Delayed Recall					4.19*

Table 6

Continued

Random effects					
Residual Variance	3.37*	2.84*	2.85*	2.85*	2.82*
Intercept Variance	5.32*	2.62*	2.55*	1.99*	2.21*
Trial (linear) Variance	0.76*	1.17*	1.03*	0.82*	0.79*
Trial (quadratic) Variance		0.01*	0.01*	0.01*	0.01*
Corr. Intercept with Trial	0.55*	0.69*	0.71*	0.65*	0.59*
Corr. Intercept with Trial \times Trial		-0.53	-0.59	-0.56	-0.30
Corr. Trial with Trial \times Trial		-0.63*	-0.59*	-0.67	-0.58
Goodness of fit					
-2 LL	1685.282	1643.950	1496.466	2503.718	1674.661
AIC	3382.563	3307.899	3018.933	5045.436	3399.322
Number of free parameters	6	10	16	19	25

Note. $N = 47$. * $p < .05$ (two-tailed).

In a second step, we included verbal knowledge and processing speed (grand-mean centered) as predictors for the initial level, speed of learning and quadratic growth (Model 4). Table 6 shows that verbal knowledge had a positive effect on the initial level and speed of learning. Thus, persons who recalled more word pairs correctly after the first trial and who reached the learning criterion faster were also those persons, who tended to have a higher verbal knowledge. Regarding the role of processing speed for criterion-based dropout learning, results of Model 4 indicate that persons with higher processing speed tended to have a higher speed of learning. The random effects remained similar after the inclusion of predictors compared with the previous model. This was also true for the correlations between random effects, except for the correlation between individual differences in speed of learning and quadratic growth. This correlation decreased to a non-significant level.

In order to investigate the role of individual differences in learning for delayed recall performance by adjusting for effects of processing speed and verbal knowledge on learning,

in a final model, delayed recall performance was included as a dependent variable (Model 5). Initial level, speed of learning, and quadratic growth were now predictors for between-person differences in delayed recall performance. As can be seen from Table 6, speed of learning and quadratic growth had a positive effect on delayed recall performance. Thus, persons who reached the learning criterion earlier were also those persons, who retained more word pairs on the delayed recall test. Model 5 explained about 78% of between-person variance in delayed recall performance indicating the role of the predictors introduced in this model for retaining verbal material. All fixed effects remained the same regarding their size and significance, except the effect of verbal knowledge on quadratic growth. This effect was negative and now statistically significant. This result means that persons who tended to have a higher verbal knowledge tended to have a higher speed of learning and did not show quadratic growth towards the end of the learning phase.

Discussion

The present study focused on individual differences in criterion-based dropout learning in old age. As mentioned in the introduction, the criterion-based dropout learning approach is the most economic one, because this approach usually implies the least number of study-test cycles needed for the individual by avoiding overlearning (cf. Rohrer, Taylor, Pashler, Wixted, & Cepeda, 2005). The present study implemented this economic learning approach for persons in old age and investigated predictors of individual differences in this type of learning.

First of all, results of the present study indicate that there are reliable individual differences in this type of learning, more precisely, in the initial level, speed of learning and quadratic growth of learning. This is in line with previous studies using a fixed-trial approach, which showed that persons in old age differ regarding their verbal learning trajectories (Rast, 2011; Zimprich & Rast, 2009; Zimprich et al., 2008b). In order to compare the degree of individual differences of the present study with the corresponding fixed effects, we calculated

the coefficient of variation (CV) as a normalized measure. The CV is defined as the SD divided by the mean, thus leading to a standardized measure of variability independent of the scale of a variable (Reed, Lynn, & Meade, 2002). The CV for initial level was .61, for speed of learning .38, and for quadratic growth .32. To illustrate these individual differences, e.g., in speed of learning, consider the fastest learner, who only needed seven study-test cycles to learn 40 word pairs, vs. the slowest learner, who needed 25 study-test cycles.¹² In order to explain these individual differences, the present study investigated whether processing speed and verbal knowledge are reliable predictors for criterion-based dropout learning. To do so, we first analyzed age-related effects on learning. In a second step, the role of processing speed and verbal knowledge was analyzed.

Regarding age-related effects, the present study showed that older persons needed more study-test cycles to reach the learning criterion as indicated by a lower speed of learning. This is in line with previous results showing that, on average, learning and recall performance declines in old age (Kausler, 1994). The present study showed, in addition, that older persons also accelerated their performance more pronounced towards the end of the learning phase as compared to younger counterparts. What might be possible cognitive mechanisms of this finding? The paired associate task of the present study was based on five word lists each containing eight cue-target word pairs. Following this, participants were exposed to changing to-be-learned material across study-test cycles. This characteristic of the task is also reflected in task-specific learning, or learning-to-learn studies (cf. Hultsch, 1974; Schwenn & Postman, 1967). Task-specific learning refers to learning of task demands that can increase recall performance regardless of the particular to-be-learned material. Recently, it was demonstrated that older persons showed task-specific learning by learning different sets of verbal material (Kurtz, Mogle, Sliwinski, & Hofer, 2013). The finding of the present study

¹² A previous study on verbal learning found a CV of .64 for individual differences in rate of learning (Zimprich et al., 2008b). However, this study used a fixed-trial whole list approach. Thus, differences in CVs of the present study and this previous study are reflected in differences of the learning process itself making a comparison of CVs difficult.

that older persons showed quadratic growth in performance could refer to a related task-specific learning process in these persons. Older persons needed more study-test cycles and therefore, were more often exposed to the task procedure and demands. With increasing exposure to task demands, older persons may benefit from learning the procedure of the paired associate task, which, in turn, resulted in ever bigger changes in recall performance towards the end of the learning phase, respectively, in quadratic growth. The effect of age on quadratic growth was 0.01 in the present study. This result implies that besides the fact that older persons required more study-test cycles in order to achieve the learning criterion, they also showed bigger recall increases at the end of the learning phase. To illustrate, an age difference of ten years would lead to a learning performance difference of 0.2 word pairs favoring the younger person after trial 1, of 1.2 word pairs favoring the older person after trial 10, and of approximately 5 word pairs favoring the older person after trial 20---if one ignores the other predictor variables.

After taking into account these age-related effects, the present study investigated whether processing speed and verbal knowledge predict individual differences in criterion-based dropout learning. The present study showed that persons with higher processing speed and verbal knowledge needed fewer study-test cycles in order to achieve the learning criterion. They had a relatively high speed of learning. As mentioned in the introduction, higher processing speed and verbal knowledge might have a positive influence on the retrieval process (Salthouse, 1993, 1996). The present study provided results consistent with these assumptions. In line with this, there was an additional effect of verbal knowledge on quadratic growth, which was negative. Persons with a higher verbal knowledge tended to have a higher speed of learning and smaller quadratic growth. Similar to younger persons, persons with higher verbal knowledge needed fewer study-test cycles, implying less quadratic growth.

In addition to these retrieval-based accounts, it is also possible that a relation between processing speed, verbal knowledge and learning is reflected in individual differences in

encoding. A person higher in processing speed and higher in verbal knowledge may use a more elaborative and deeper encoding in terms of the level-of-processing approach (Craik & Lockhart, 1972). Similarly, Salthouse (1994) argued that higher processing speed is related to a more elaborate encoding because with more time available the quality of encoding of the to-be-learned material will be higher, which, in turn, should result in better recall performance.

According to the associative binding approach (Naveh-Benjamin, 2000; Shing, Werkle-Bergner, Li, & Lindenberger, 2008), older persons show, on average, a disadvantage with regard to paired-associative learning. The present study showed that there are individual differences in paired-associative learning implying that some persons in old age may have bigger associative binding difficulties than others. In order to gain more insights into the question of why persons in old age differ in their recall performance future studies should focus on further predictors of individual differences in criterion-based dropout learning.

Regarding individual differences in criterion-based dropout learning and a possible relation of these with delayed recall performance, the present study implies that persons with a higher speed of learning were also those persons who retained most in the delayed recall test after adjusting for effects of processing speed and verbal knowledge on learning. These are the persons who benefitted the most from the economic learning schedule used in the present study. Hence, they had a relatively high recall performance in the delayed recall test by having reached a predetermined learning criterion with only few study-test cycles. This finding is in line with studies on forgetting and speed of learning suggesting that fast learning persons are also those persons who retain more, respectively, forget less (Underwood, 1954; Zimprich & Kurtz, 2013). Regarding the effect of speed of learning on delayed recall performance the question is of why fast learners might forget less material. As argued elsewhere (Zimprich & Kurtz, 2013), forgetting may refer to the absence of adequate retrieval cues (Tulving & Madigan, 1970). Relating these theoretical assumptions to the results of the present study it follows that fast learners might possess more adequate retrieval cues. A

further explanation for the effect of speed of learning on delayed recall performance may be with regard to the measures of these two variables. Both, speed of learning and delayed recall performance, were measured with the same type of task and based on the same indicators, i.e., recall performance. Following this, it may not be surprising that persons with a higher recall performance during the learning phase may also show higher recall performance in the delayed recall task, because the demand of recalling verbal material during the learning session and in the delayed recall may refer --- at least to some degree --- to the same underlying cognitive mechanism.

Besides speed of learning, quadratic growth also had an effect on delayed recall performance. Persons with a more pronounced quadratic growth retained more word pairs in the delayed recall test. As mentioned above, quadratic growth may refer to task-specific learning. Following this assumption, task demands are learned with more study-test cycles that might result in better retention as reflected in a higher recall performance in a delayed recall test. A commonality analysis showed that the unique effect of the three learning parameters was about 64%. This means that individual differences in delayed recall performance were strongly related to individual differences in initial level, learning speed, and quadratic growth.

To sum up, the present study showed there are reliable individual differences in criterion-based dropout learning. Processing speed and verbal knowledge explain these individual differences in part. Note that the approach used in the present study refers to a relatively parsimonious approach by implementing a polynomial learning curve with a linear and quadratic slope. Future studies that are able to model criterion-based dropout learning in a more elaborative way, e.g., structured latent growth curves (Browne, 1993), as done in other studies on verbal learning (Rast & Zimprich, 2010; Zimprich et al., 2008a, b), would be important in order to obtain learning parameters that are interpretable more easily regarding their meaning for the learning process. Future research should also focus on further predictors

of individual differences in this very economic type of learning in order to design optimal learning schedules for persons in old age. Participants of the present study were able to learn 40 word pairs and to retain 30% of these. Fixed-trial approaches using a whole list procedure provided findings that about 73% of material learned is retained by older persons in a delayed recall test (Zimprich & Kurtz, 2013). This is in line with findings showing that a drawback of the economic dropout schedule might be a reduced recall performance across long retention intervals (cf. MacLeod, 1985; Karpicke & Roediger, 2008; Pyc & Rawson, 2011). Note that these studies, including the present one, all differ regarding the precise learning conditions, for example, list length, degree of support during recall tests. Future studies, which compare a fixed-trial vs. a criterion-based approach by controlling for such effects of different learning conditions, might be promising regarding benefits of different learning approaches for persons in old age. However, note that if the aim of a person in old age is to learn a particular amount of verbal material in a very economical way with only a relatively short retention interval needed, this person should rely on the typical learning strategy of students described above: Learning every single item successively until it is once retrieved successfully, then leave this item out and concentrate on the remaining to-be-learned items.

2.4 Individual Differences and Predictors of Forgetting in Old Age: The Role of Processing Speed and Working Memory*

Abstract

The goal of the present study was to examine whether individual differences in basic cognitive abilities, processing speed and working memory, are reliable predictors of individual differences in forgetting rates in old age. The sample for the present study comprised 364 participants aged between 65 to 80 years from the Zurich Longitudinal Study on Cognitive Aging. The impact of basic cognitive abilities on forgetting was analyzed by modeling working memory and processing speed as predictors of the amount forgetting of 27 words which had been learned across five trials. Forgetting was measured over a 30-min. interval by using parceling and a latent change model, in which the latent difference between recall performance after five learning trials and a delayed recall was modeled. Results implied reliable individual differences in forgetting. These individual differences in forgetting were strongly related to processing speed and working memory. Moreover, an age-related effect, which was significantly stronger for forgetting than for learning, emerged even after controlling effects of processing speed and working memory.

Key Words: Forgetting – Individual differences – Latent change model – Working memory – Processing Speed.

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Introduction

Put simply, forgetting refers to a loss of information that was already encoded and stored in an individual's long-term memory. As straightforward as such a definition may appear, the phenomenon of forgetting has defied an equivocal theoretical underpinning. There is a variety of different theoretical approaches, which, for example, consider forgetting a natural decay process (Brown, 1958), a weakening of associations formed during acquisition (Underwood, 1957), or caused by interference because of similarities among items in memory (Anderson & Neely, 1996). From another theoretical perspective, forgetting is explained by the absence of adequate retrieval cues (Tulving & Madigan, 1970). According to this theoretical account, forgetting occurs because information is no longer accessible due to a lack of retrieval cues, although, in principle, it would be available. The number of both classic and contemporary theories of forgetting (e.g., Crowder, 1976; Lansdale & Baguley, 2008) may be taken as an indication of the complexity of phenomena in conjunction with forgetting and the difficulty to empirically examine mechanisms that underlie forgetting.

Individual Differences in Forgetting

In the present study, we used a different, non-experimental approach to gain insights into forgetting. In lieu of searching for general mechanisms underlying forgetting, we focused on individual differences in forgetting in old age. Our basic premise was simple: The fundamental mechanisms underlying forgetting may be the same for all older persons. At the same time, however, we expected individual differences in the amount or rate of forgetting which may be accounted for by explanatory variables that amplify or lessen individual rates of forgetting. Elsewhere, we have argued similarly with respect to the converse of forgetting, learning (Rast, 2011; Zimprich, Rast, & Martin, 2008).

The question of whether there are individual differences in the rate of forgetting is still under debate. Starting with Underwood (1954), who posited that individual differences in forgetting are negligible if forgetting starts from the same initial level of learning, there have

been a number of studies failing to find individual differences in forgetting. Slamecka and McElree (1983), for example, found forgetting rates to be virtually unrelated to the number of learning trials. Similarly, Meeter, Murre, and Janssen (2005) did not find an association between initial learning and forgetting rates in a large sample of more than 4000 individuals. By contrast, Kyllonen and Tirre (1988) reported that in a sample of 685 military recruits fast learners forgot fewer paired associates across time than slower learners.

One reason for these controversial findings regarding individual differences in forgetting rates is that in different studies forgetting rates have been measured and compared in different ways. In addition, the failure to find individual differences in forgetting may be due to insufficient statistical power, which may be particularly low in small samples. As Raudenbush and Liu (2000) demonstrated, sample size was the biggest determinant of power to detect significant variance in the slope in growth curve models. Power may also be low if unreliable measures of forgetting or brief measures of forgetting are used (e.g., only a few words), and if the retention interval is short (that is, when the amount of forgetting and, thus, effect size is small). Moreover, the number of measurements of forgetting and whether the forgetting curve is adequately captured by a model describing the data is relevant for statistical power. As seen from a statistical power perspective, it would be ideal to have as many measurements of forgetting as possible. But this ideal collides with the fact that successful retrieval attempts can function like additional learning trials (for a recent review, see Roediger & Karpicke, 2006). The same appears to happen in conjunction with forgetting of autobiographical events (Linton, 1975). Another problem with respect to finding individual differences in forgetting rates using many measurements is that forgetting usually is most pronounced immediately after acquisition and decelerates at longer time intervals (see, for example, MacDonald et al., 2006). That is, individual differences in forgetting tend to become smaller and smaller over time, thus rendering it more difficult to find differences in forgetting between persons at longer time intervals.

In the present study, we planned to overcome some of the methodological limitations mentioned. First, we used data from a relatively large sample of older adults. Second, by using a parceled measure of memory performance and forgetting (cf. Bandalos & Finney, 2001) and by applying latent change models (McArdle & Nesselroade, 1994), we aimed at considerably increasing the reliability of our measure of forgetting. Third, we focused on the first phase of forgetting immediately after acquisition, that is, when forgetting is most pronounced.

Basic Cognitive Abilities as Predictors of Forgetting

The successful retrieval of learned information requires search processes in long-term memory. The relevance of such search processes at retrieval has, for example, been emphasized by random search models (Bousfield, Sedgewick, & Cohen, 1954; Kaplan, Carvellas, & Metlay, 1969; Wixted & Rohrer, 1994). In random search models, forgetting may occur when the search process is either cancelled too early or when it is not performed successively. As will be outlined in the following, basic cognitive abilities, such as working memory capacity and processing speed, may influence the dynamics of a search process at retrieval.

First, on a very general level, working memory capacity (e.g., Baddeley & Logie, 1999) and processing speed (Salthouse, 1996) are considered basic or elementary cognitive abilities that limit higher-order cognitive processes, for example, retrieval from memory. In that sense, individual differences in basic cognitive abilities could be associated with individual differences in forgetting. A recent study by MacDonald et al. (2006) provided evidence for reliable individual differences in forgetting rates. These individual differences were associated with individual differences in working memory. Applying a multilevel approach, results of this study indicated that for forgetting within a short time delay (< 24 hr), working memory emerged as the most powerful predictor of individually differing forgetting rates.

Apart from these general considerations, there are, second, several possible mechanisms of how working memory and processing speed may affect forgetting. Recently, Unsworth and Engle (2007) suggested a framework in which individual differences in working memory were divided into primary and secondary memory, thus containing a dynamic attention component of working memory as well as a cue-dependent search component. The authors argued that depending on the successful use of cues, which delimit the size of the search set, the search set might be larger or smaller. A large search set may lead to an impeded search because of a higher amount of irrelevant information that is included in the search set (Unsworth, 2007). In turn, if the search set is smaller and contains only or mainly relevant information, retrieval may be facilitated. Precisely at this point, individual differences in working memory capacity may become a critical factor. Individuals with lower working memory capacity may execute the search process less effectively because of a poorer use of cues or because they rely on noisier context cues. Such a less effective search process can result in a larger set size including more irrelevant information, which may lower recall performance, and, in consequence, lead to higher forgetting rates (Unsworth, 2007; Unsworth & Engle, 2007; Unsworth et al., 2011).

With regard to processing speed, Salthouse (1996) proposed two mechanisms, the limited time and the simultaneity mechanism, which may help explain individual differences in forgetting due to lower processing speed. According to the limited mechanism, lower processing speed results in cancelling ongoing elementary operations because of an internal lack of time. Moreover, lower processing speed may impede the availability of previous executed operations and their products (Salthouse, 1996). This simultaneity mechanism indicates that slower processing speed leads to less information activated that is requested for other processes. Transferring these two mechanisms to the field of retrieval and forgetting, one might assume that high processing speed may influence the search process because of a longer search interval and because of a higher amount of simultaneously available

information. This may facilitate the ongoing processes of retrieval and thus, in turn, reduce forgetting.

To summarize, to broaden existing research on forgetting and the processes underlying it, the present study addressed the question of how basic cognitive abilities, processing speed and working memory, are related to individual differences in forgetting rates in old age. We hypothesized that higher basic cognitive abilities, that is, a larger working memory capacity as well as faster processing speed, are associated with less forgetting, because basic cognitive abilities should facilitate the long-term memory search process during retrieval.

Forgetting in Old Age

Whereas many studies have demonstrated a decline in verbal learning performances in old age compared to younger adults (for an overview, see Kausler, 1994), with regard to age-related effects in forgetting the majority of studies has found that forgetting rates are virtually the same for younger and older adults (Kausler, 1991; Maylor, 1993; Salthouse, 1991). This invariance of forgetting rates across age has been demonstrated using a variety of different materials, for example, line drawings (Rybarczyk, Hart, & Harkins, 1987), name-face associations (Hulicka, 1965), stories (Hultsch, Hertzog, & Dixon, 1984), or words (Bäckman & Mäntylä, 1988).

A more detailed analysis of forgetting, however, shows that there may be some age-related differences in the rate of forgetting. Fisk and Warr (1998), for example, have shown that older adults tend to more often forget little-learned material. One reason for this may be that the representation of little-learned in long-term memory is more fragile and, hence, more easily disrupted. That is, memory traces may be less consolidated for little-learned material. In line with this assumption, Wheeler (2000) found that older adults forgot more words across a one-hour interval than younger adults. Similarly, Giambra and Arenberg (1993) reported age-related differences in the rate of forgetting of sentences across retention intervals between ten minutes and seven hours. Interestingly, age became a predictor of different forgetting rates

after the data from a larger sample were analyzed, thus increasing statistical power. In line with McGaugh (1989), one might argue that these findings are consistent with a short-term modulation of memory storage by endogenous processes activated by the learning process. That is, older adults may experience quantum-like consolidation difficulties for several minutes after initial acquisition of the to-be-learned material.

As before, we see one reason for different results regarding age-related differences in forgetting rates in the fact that some previous studies may have suffered from insufficient statistical power. Of course, statistical power alone is but one important issue for forgetting research, denoting the precision with which parameters (e.g., individual differences in forgetting rates) can be estimated. Equally important from a theoretical perspective is the question of how large individual differences in forgetting rates are, thus addressing issues of effect size. Because in old age at least subjective complaints about memory problems and increased forgetting are common (e.g., Zimprich, Kliegel, & Rast, 2011), we expected forgetting in general to be stronger and, in addition, individual differences in forgetting to be more pronounced in old age than in younger age groups. Based on this assumption, the effect size of individual differences should be larger and, hence, easier to detect in old age.

The present study

The present study offers a new and unique perspective on forgetting in old age due to the following reasons. Compared to many previous studies, we used a larger sample in order to increase statistical power. Also, as will be detailed in the methods section, by maximizing performance across five learning trials, average performance was boosted with the effect that, at the same time, individual differences in the acquisition of the to-be-learned material were amplified. Moreover, by applying latent change model (see methods section), we modeled forgetting on the latent level, thereby increasing reliability. An old sample, like in the present study, may increase the effect size both of average forgetting per se but also with respect to individual differences in forgetting. In addition, the benefit of an individual differences

perspective on forgetting is the possibility to include individual differences explanatory variables (here: basic cognitive abilities). The leading question of the present study thus was not why persons in old age forget, but rather whether different persons in old age differ in their amount of forgetting and, if so, whether basic cognitive abilities may account for these individual differences.

Methods

Sample

The data used in the present study stem from the Zurich Longitudinal Study on Cognitive Aging (ZULU), an ongoing longitudinal study on cognitive and learning abilities of elderly persons in Switzerland (Zimprich et al., 2008a). At first measurement occasion (T1: 2005), the sample comprised $N = 364$ participants who were between 65 to 80 years of age (Mean age: 73 years, $SD = 4.4$ years; 46% women). The majority of the sample was married and resided with others. On average, participants reported about 13 years of formal education. For the sample, there were no signs of cognitive impairments (all participants scored 25 or higher on the MMSE; Folstein, Folstein, & McHugh, 1975) or pronounced depressive affect (all participants scored 6 or lower on the Geriatric Depression Scale; Yesavage et al. 1983). The majority of participants judged their health as “good” (on a five point Likert-type scale ranging from “very good” to “bad”) and, in addition, no participant reported any severe hearing or vision difficulties. Part of the cognitive testing protocol in ZULU were three measures of working memory (Reading Span, Counting Span, Operation Span), processing speed (Number Comparison, Identical Pictures, Letter Digit Substitution), and a verbal learning measure that comprised five trials of a word list recall and, after a 30-minutes interval, a delayed recall.

Measures

Working Memory Tasks.

Reading Span. This task was a modified version of a task used by Daneman and Carpenter (1980). Simple sentences consisting of seven to nine words were successively presented on the computer screen. Participants were asked to decide if the sentence was meaningful or not, and, additionally, were supposed to memorize the last word. After several sentences, participants were supposed to name the memorized words in the same order as presented. The dependent variable was the average percentage of words recalled in correct order. In the present sample, Cronbach's alpha was .71.

Counting Span. This task was based on a task used by Engle et al. (1999). A varying number of targets and distractors was displayed on the computer screen. Participants were instructed to count aloud the number of targets and enter the final tally into the computer. In addition, participants were asked to memorize the result. After several displays, participants were asked to recall their counting results of the previous displays in the same order as presented. The dependent variable was the average percentage of counting results recalled in correct order. In the present sample, Cronbach's alpha was .68.

Operation Span. This task was a modified version of a task used by Turner and Engle (1989). Simple arithmetic decision problems were successively presented on the computer screen. Concurrently with the decision task, participants were instructed to read aloud and memorize the last digit of each arithmetic problem. After several problems, participants were supposed to recall the memorized digits in the same order as presented. The dependent variable was the average percentage of items recalled in correct order. In the present sample, Cronbach's alpha was .80.

Processing Speed Tasks.

Number Comparison. This task consisted of 60 items taken from the Number Comparison Test (Ekstrom, French, Harman, & Dermen, 1976). For each item, participants

were asked to compare as rapidly as possible whether two numbers presented on the computer screen were identical or not. Scored was the number of correct answers within 90 seconds. According to Ekstrom et al., the test-retest reliability of the Number Comparison Test ranges from .70 to .82 in adult samples.

Identical Pictures. This task comprised 60 items taken from the test of the same name from the Educational Testing Service (Ekstrom et al., 1976). For each item, participants were asked to choose one out of five pictures, one of which was identical to a reference picture as rapidly as possible. Scored was the number of correctly answered items within 90 seconds. The test-retest reliability of the Identical Pictures Test is .87 for males and .81 for females as reported by Ekstrom et al. (1976).

Letter Digit Substitution. This task was similar to the Digit Symbol Substitution task, except that participants had to assign digits to letters instead of symbols to digits. The test consisted of 75 items. For each item, a table that assigned five different letters to the numbers one to five was displayed on the computer screen. Below the table, a single cue letter was presented together with a question mark. Participants were supposed to press the target number that belonged to the letter according to the coding table. Scored was the number of correctly answered items within 90 seconds. In a sample of several thousand elderly participants, the test-retest reliability of a similar letter digit substitution task was .88 (Houx et al., 2002).

Verbal Learning and Delayed Recall

Verbal learning was assessed by five consecutive trials of a word list recall task. The task was comprised of 27 meaningful, but unrelated two- to three-syllable German words taken from the Manual of German word norms (Hager & Hasselhorn, 1994). Words were selected on the basis of their imageability, meaningfulness, and concreteness. In addition, words were chosen in a way that inter-item-associations were as unlikely as possible and typicality was low. The 27 words appeared on a computer screen at a rate of 2 s each, and

participants were asked to read them aloud. After all 27 words had been presented, participants were to recall as many words as possible in any order. This procedure was repeated five times, with the order of word presentation being randomized for each trial. On each trial, the number of correctly recalled words was scored. After half an hour (filled with other cognitive tasks), participants were asked to again recall as many of the 27 words in any order. The number of words recalled correctly represented the delayed recall task.

Measurement of Forgetting

Aiming at analyzing individual differences in forgetting, the measurement of forgetting might be a crucial step. In line with several other researchers, forgetting in a verbal memory task can be operationalized as the difference between the number of words recalled during immediate recall and the number of words recalled during delayed recall (MacDonald et al., 2006; Slamecka & McElree, 1983). One problem, however, is that in old age the average level of recall after one learning trial is comparatively low, which would make it difficult to find individual differences in forgetting. A related problem is that simple difference scores are flawed by methodological shortcomings like, e.g., unreliability. With regard to both issues, our study offers unique possibilities. First, by using the difference between recall after the fifth learning trial and delayed recall, performance level in both recall tasks was raised and individual differences were amplified, which does also imply that individual differences in forgetting were enlarged. Second, because of the relatively high performance levels in both recall after the fifth learning trial and delayed recall, we decided to use parceling to model verbal recall performance (cf. Bandalos & Finney, 2001). Forgetting can then be modeled on the level of latent variables and the issue of potential unreliability is mended.

In the present study, of the 27 words presented at the fifth learning trial we selected words number 1, 4, 7, ..., 25 to form the first parcel. For the second parcel, words number 2, 5, 8, ..., 26 were selected. Finally, for the third parcel, we selected words number 3, 6, 9, ...,

27. Thus, each of the three parcels consisted of the recall performance of nine words. The three parcels represented three manifest indicators of recall performance after five learning trials. Note that because the order of word presentation was random at the fifth learning trial (but equal for all participants), the assignment of words to parcels was random (cf. Little, Cunningham, Shahar, & Widaman, 2002). In order to build three manifest indicators for delayed recall, we used the same assignment of words to parcels as before, but now using the performance in delayed recall.

To model forgetting on the latent level, we used a latent change model (McArdle & Nesselrode, 1994). In latent change models, the level of a latent construct and the change of this latent construct over time are estimated. If the indicators at T1 (Recall performance after the fifth learning trial) and T2 (Delayed recall) load on one latent variable and the unstandardized factor loadings of the indicators are invariant over time, and a second latent variable with equal factor loadings is introduced for the indicators at T2, the variance of this second latent variable captures interindividual differences in latent variable change over time. Thus, the second latent variable may be called a latent change or latent difference factor, which, in our case, represented forgetting. It follows that if the variance of the second latent variable is significantly different from zero, the amount of change differs across persons, i.e., there are interindividual differences in forgetting. A necessary prerequisite of modeling differences on the latent factor level is that the measurement of the latent factors is comparable.

Measurement invariance. In order to ensure that the same latent factor is modeled at different measurement occasions in the sense that the latent factor has equivalent measurement properties, longitudinal measurement invariance (MI) has to be established (cf. Meredith & Horn, 2001). One might distinguish four forms of longitudinal MI (cf. Meredith, 1993): (1) Configural invariance entails that the number of factors and according salient and non-salient loadings are equal over time, which ensures that the dimensionality of the

measured constructs is longitudinally equivalent. (2) Weak MI requires that pattern matrices (factor loadings) be fully invariant across measurement occasions. This form of MI ensures that the same indicators on different measurement occasions do relate to constructs (latent variables) in the same way. Because this implies that latent variables are scaled in the same way, weak MI allows for comparing (co)variances across measurements. (3) Strong MI requires that pattern matrices (factor loadings) and intercepts of the manifest indicators be invariant over time. Establishing this form of MI allows for meaningfully comparing means across measurement occasions. It is for this reason why strong MI is of special importance in the present study: The modeling of a latent mean difference (i.e., forgetting) requires that the same latent variable has been measured. (4) Finally, strict MI requires that pattern matrices, intercepts, and unique variances be invariant over time. This strictest form of invariance implies that all of the differences in means, covariances, and variances of the observed indicators across measurements arise from differences in latent variables. Examining different degrees of MI is typically accomplished by employing confirmatory factor models with increasingly severe across-time restrictions on parameters (e.g., Zimprich, Allemand, & Hornung, 2006; Zimprich & Mascherek, 2010).

All analyses were conducted using MPLUS version 3.0 and Maximum Likelihood parameter estimation (Muthén & Muthén, 2004). The goodness-of-fit of models was evaluated using the χ^2 -test and two additional criteria, the Comparative Fit Index (CFI) and the Root Mean Square Error of Approximation (RMSEA). Values of the CFI above .95 are considered to be adequate, whereas for the RMSEA values less than .08 indicate an acceptable model fit (cf. Browne & Cudeck, 1993). In comparing the relative fit of nested models, we used the χ^2 -difference test, which was complemented by the 90% confidence interval of the RMSEA (MacCallum, Browne, & Sugawara, 1996).

Results

Table 7 shows relevant descriptive statistics of the variables analyzed in the present study. As can be seen from Table 7, except for age, most intercorrelations were positive and statistically significant. The median correlation was .20. Raw data were checked for departures from normality and the skewness and kurtosis estimates of the cognitive variables did not exceed 1 or -1 . The estimate of Mardia's coefficient of multivariate kurtosis was 363.76 and not significant. Hence, the distributional properties of the manifest variables warranted the use of maximum likelihood parameter estimation.

Structural equation modeling started with testing different degrees of measurement invariance for the fifth trial and delayed recall parcels. The first model tested was one of configural invariance. As Table 8 shows, this model achieved an excellent fit, implying that configural invariance held across the two measurements of recall (fifth trial and delayed). Next, weak MI was examined by adding the constraint of equal factor loadings at both measurements. Doing so did not lead to a significant decrement in fit, which indicated that weak MI held in the data. Because words were assigned to parcels randomly, we examined the additional constraint of factor loadings being equal also across parcels, that is, within measurements. Combined with the weak MI model across measurements already tested and accepted, this required all factor loadings to be equal. This model, which goes under the name of "Strict MI II" in Table 8, achieved an excellent fit, implying that both within and across measurements weak MI held—as one would expect because of the random way parcels were built. Afterwards, strong MI was investigated by constraining manifest intercepts to be equal across the two measurements. According to Table 8, the loss of fit that resulted from this constraint did hardly alter model fit, from which we concluded that strong MI held. Eventually, strict MI was imposed by requiring residual variances to be equal at both measurements. Again, this did not produce a decrement of fit. Because we had used randomly composed word parcels as indicators, we again added an additional constraint by requiring all

residual variances to be equal. This model, which is labeled “Strict MI II” in Table 8, also achieved an excellent fit, implying that the strictest form of measurement invariance, strict MI within and across measurements, held in the ZULU memory and recall data. To summarize, we modeled memory performance after the fifth learning trial and after a 30-minutes delay.

Based on the strict MI II model, several change-related parameters were estimated. First, the difference in variance of memory performance between the fifth trial ($\hat{\sigma}^2 = 1.60$) and the delayed recall ($\hat{\sigma}^2 = 2.32$) was statistically significant ($\chi^2 = 22.06$, $df = 1$, $p < .01$), implying that memory performance of the sample was more heterogeneous at delayed recall than after the fifth learning trial. On the latent level, memory performance was correlated .87 across measurements, implying relatively high stability. Finally, compared to the fifth trial, during delayed recall participants had a factor mean that was 1.43 less, on average. Because this difference between performance is based on three parcels, it can be transformed back to the number of words recalled metric by multiplying it by three, i.e., $1.43 \times 3 = 4.3$. Thus, on average, 4.3 words were lost during the retention interval of half an hour.

Table 7: Descriptive Statistics of the Manifest Variables

	Mean	<i>SD</i>	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Age	73.0	4.43	-											
2. Trial 5, Parcel 1	5.50	1.80	-.13	-										
3. Trial 5, Parcel 2	5.37	1.87	-.04	.47	-									
4. Trial 5, Parcel 3	5.14	1.93	-.11	.43	.47	-								
5. Delayed Recall, Parcel 1	4.07	1.96	-.22	.63	.49	.53	-							
6. Delayed Recall, Parcel 2	4.11	2.06	-.12	.50	.69	.53	.60	-						
7. Delayed Recall, Parcel 3	3.54	2.06	-.16	.44	.49	.71	.60	.53	-					
8. Identical Pictures	21.4	4.54	-.35	.20	.21	.20	.26	.26	.23	-				
9. Number Comparison	17.1	4.30	-.25	.14	.16	.25	.22	.21	.30	.49	-			
10. Letter-Digit-Substitution	31.9	6.62	-.37	.28	.22	.33	.31	.29	.39	.63	.64	-		
11. Reading Span	21.9	3.38	-.08	.28	.21	.31	.30	.27	.30	.18	.16	.25	-	
12. Counting Span	22.9	3.51	-.12	.20	.20	.28	.20	.20	.30	.22	.26	.34	.51	-
13. Operation Span	22.6	4.28	-.16	.19	.21	.23	.27	.27	.28	.33	.25	.39	.47	.42

Note. $N = 364$. Correlations larger than $r = .11$ in absolute value are statistically significant at $p < .05$ (two-tailed).

Table 8: Model fit statistics

Model	χ^2	df	$\Delta \chi^2$	Δdf	CFI	RMSEA	RMSEA 90% CI
Configural MI	9.135	5			0.996	0.048	0.000 - 0.096
Weak MI	11.997	7	2.862	2	0.995	0.044	0.000 - 0.086
Weak MI II	12.034	9	0.037	2	0.997	0.030	0.000 - 0.070
Strong MI	17.807	11	5.773	2	0.990	0.041	0.000 - 0.075
Strict MI	24.697	14	6.890	3	0.990	0.046	0.011 - 0.075
Strict MI II	28.051	16	3.354	2	0.990	0.045	0.014 - 0.073
Model 1	87.709	56			0.983	0.039	0.022 - 0.055
Model 2	89.185	58	1.476	2	0.983	0.038	0.021 - 0.054
Model 3	100.116	66			0.982	0.038	0.021 - 0.052

Note: CFI = Comparative Fit Index; RMSEA = Root Mean Square Error of Approximation. Model 1 = Model with Processing Speed and Working Memory as Predictors of Learning and Forgetting; Model 2 = Model with a second-order factor of Processing Speed and Working Memory a Predictor of Learning and Forgetting; Model 3 = Model 2 with Age included (see Figure 8).

The strict MI model was re-parameterized as a latent change model and re-estimated in order to directly model the difference between performance after the fifth trial and delayed recall on the latent level, that is, the measure of forgetting. There were two new parameters, the variance of the performance difference, i.e., the variance of forgetting, and the covariance between fifth trial performance and forgetting. The variance of forgetting was 0.171 and statistically significant, implying that there were reliable individual differences in the amount of forgetting during the 30-minutes interval. The covariance between fifth trial performance and forgetting was 0.275 ($p < .01$), corresponding to a correlation of $r = .53$. Because forgetting had a negative mean, this implied that those with a higher recall performance at the

fifth trial tended to forget less. To briefly summarize, the latent mean difference reflecting forgetting was 1.43, corresponding to about 4.3 words that were forgotten. Importantly, there were reliable individual differences in forgetting during the retention interval of half an hour. Moreover, those who recalled more words at the fifth learning trial tended to forget less. Figure 8 shows a scatter plot of fifth learning trial performance and the amount of forgetting as based on Model Strict MI II transformed back to the original metric of number of words.¹³ In order to get a better understanding of the amount of individual differences in forgetting, we computed the coefficient of variation as a normalized measure for both fifth learning trial recall performance and forgetting. These coefficients were $c_v = .24$ (fifth learning trial) and $c_v = .28$ (forgetting), implying that the amount of individual differences was even somewhat larger in forgetting compared to fifth learning trial performance.

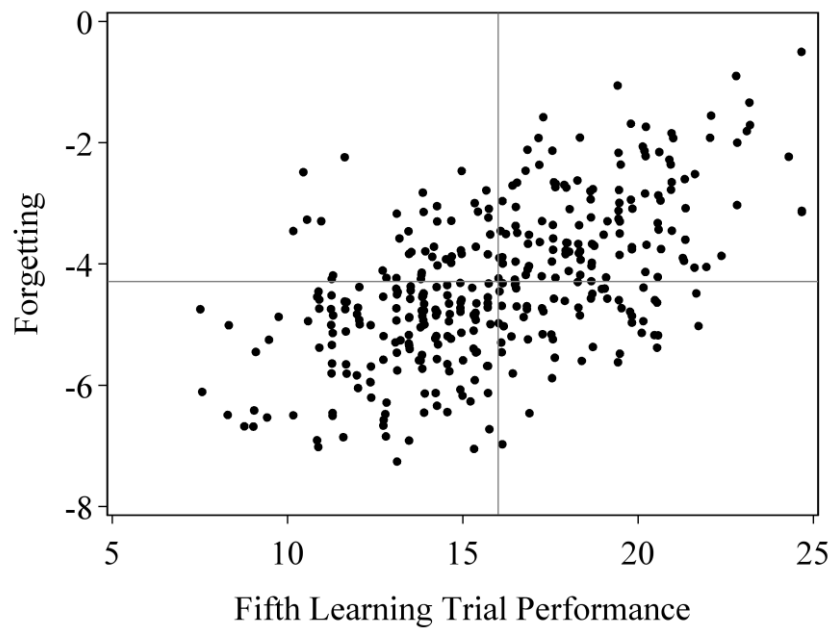


Figure 8: Scatter plot of number of words recalled during fifth learning trial performance and number of words forgotten ($r = .53$). Note that for forgetting, more negative values denote more forgetting. Estimates are based on Model Strict MI II. The horizontal and vertical gray lines denote the respective means of fifth learning trial performance and forgetting.

¹³ For reasons of comparison, we also estimated the correlation between the manifest variables number of words recalled during fifth learning trial and number of words forgotten (calculated as a simple difference score between fifth learning trial and delayed recall), which was $r = .08$ (compared to $.53$ in our Model Strict MI II). This, in our view, demonstrates the benefits of modeling forgetting on the latent level using parcels.

Predictors of Forgetting in Old Age

In order to investigate the effect of basic cognitive abilities on individual differences in forgetting rates, in a first model (Model 1) we included processing speed and working memory, both measured as latent variables with their respective indicators, as predictors of fifth trial performance and forgetting. This model achieved an excellent fit (see Table 8). The standardized effects of both processing speed and working memory on fifth trial performance were statistically significant and positive (speed: $\beta = .23$, working memory: $\beta = .39$). Thus, persons with higher processing speed and working memory tended to recall more words after a 5-trial learning episode. With regard to the effects of the two basic cognitive abilities on forgetting, only processing speed emerged as a statistically significant predictor (speed: $\beta = .35$, working memory: $\beta = .17$). Hence, only a higher level of processing speed was significantly associated with less forgetting. Because working memory and processing speed were strongly correlated ($r = .51$), we conducted a commonality analysis in order to decompose the variance accounted for in forgetting into portions attributable to the unique and common portions of processing speed and working memory (Pedhazur, 1982). The unique contribution of processing speed in accounting for individual differences in forgetting was $R^2 = 2\%$ while the unique contribution of working memory was $R^2 = 5\%$. The common contribution was $R^2 = 14\%$, implying that in predicting forgetting both processing speed and working memory had stronger common than unique effects.

To take into account that processing speed and working memory had a common effect on forgetting, in Model 2 we introduced a second order latent variable, a combination of processing speed and working memory, with the factors processing speed and working memory as indicators (loadings were fixed at 1 for both processing speed and working memory for reasons of identification). The new latent variable, which may be labeled basic cognitive abilities, captured the shared effect of the two basic cognitive abilities on fifth trial performance and on forgetting by pooling the shared variance of processing speed and

working memory. This model (Model 2) also achieved an excellent fit (see Table 8). The standardized effect of the second order latent variable, basic cognitive abilities, on fifth trial performance was estimated as $\beta = .66$, while the effect on forgetting was $\beta = .55$, accounting for 43% and 31% of variance, respectively. When processing speed and working memory were modeled as a common latent variable, there were strong effects on recall performance after five trials and on forgetting. Persons with higher basic cognitive abilities retrieved more successfully words after five learning trials and forgot fewer words after a 30 minutes delay than persons with lower basic cognitive abilities. Note that the relation between fifth learning trial performance and forgetting decreased to a correlation of $r = .16$, which was no longer statistically significant. After taking into account the effects of processing speed and working memory, the association between acquisition and forgetting was considerably reduced, thus highlighting the effect of basic cognitive abilities.

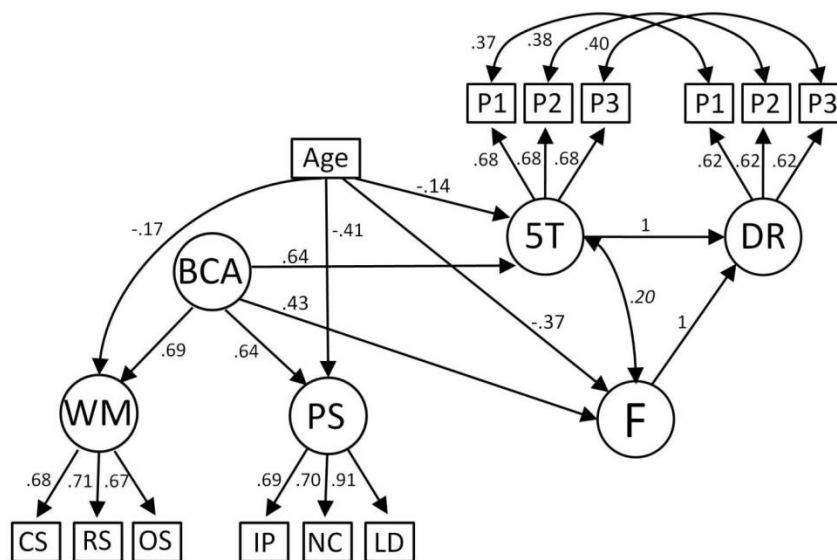


Figure 9: Structural Equation Model of Forgetting in Old Age predicted by Age and Basic Cognitive Abilities (Model 3). $N = 364$. All parameters are standardized. Non-significant paths are in italics. CS = Counting Span; RS = Reading Span; OS = Operation Span; IP = Identical Pictures; NC = Number Comparison; LD = Letter Digit Substitution, P1-P3 = Parcels of Recalled Words, WM = Working Memory, PS = Processing Speed, BCA = Basic Cognitive Abilities, 5T = Recall Performance after Five Learning Trials, DR = Delayed Recall, F = Forgetting.

In a third step, Model 2 was extended by entering age into the model. Note that compared to the hitherto common approach of modeling the amount of age-effects that are mediated via explanatory variables, due to the interpretational problems inherent to age-meditational models in cross-sectional data (see Hofer & Sliwinski, 2001) we decided to separate the effects of age and basic cognitive abilities. The model (Model 3), which is depicted in Figure 9, also achieved an excellent fit (see Table 8). Age exerted a statistically significant effect on working memory ($\beta = -.17$) and processing speed ($\beta = -.41$). Thus, older persons tended to exhibit lower working memory capacity and, mainly, slower processing speed. Age also had a statistically significant effect on fifth trial performance ($\beta = -.16$) and on forgetting ($\beta = -.37$). Notably, the standardized effect of age on forgetting was significantly stronger than the age effect on fifth learning trial performance, because when both standardized effects were constrained to be equal, model fit decreased significantly ($\Delta\chi^2 = 4.42$, $\Delta df = 1$, $p < .05$). The age-related effect on both fifth trial learning performance and forgetting implies that old age is accompanied by a decrease in acquisition, but an even stronger increase in forgetting. After controlling for age, the shared effects of processing speed and working memory (basic cognitive abilities) on fifth trial performance and forgetting remained statistically significant and strong, although they were slightly reduced (fifth trial performance: $\beta = .64$, forgetting: $\beta = .43$). To summarize, both age and basic cognitive abilities contributed to the prediction of acquisition and forgetting. However, because the amount of explained variance (fifth trial performance: 44%; forgetting: 32%) did hardly change with the inclusion of age as a predictor, one might conclude that age and basic cognitive abilities share a substantial amount of variance in predicting acquisition and forgetting.¹⁴

¹⁴ Upon request of an anonymous reviewer and in order to gauge our main findings, Model 3 was re-estimated as a multiple-groups model with the sample split in two halves. We split the sample in two groups according to chronological age: The young-old group ($n = 182$, mean age: 69.2 years) and the old-old group ($n = 182$, mean age: 76.9 years). A model where only the structural parameters were allowed to be different across the two age groups fit the data well ($\chi^2 = 181.7$, $df = 145$, RMSEA = .037). Next, we also constrained the unstandardized

Discussion

The main result of our study is that, in old age, there are individual differences in forgetting across 30 minutes retention interval. Moreover, individual differences in forgetting were strongly related to individual differences in basic cognitive abilities (processing speed and working memory), also after controlling for age. In what follows, these main findings of our study shall be discussed from four different perspectives. First, we will focus on the measurement of forgetting. Second, we will consider possible mechanisms that may underlie the effect of basic cognitive abilities on forgetting. Third, we will discuss the connection between forgetting and its converse, learning. Finally, we will address the effect of age-related differences on forgetting.

Measurement of forgetting

We followed a new approach to measure forgetting by building three parcels of remembered words to measure forgetting on the latent level (cf. Bandalos & Finney, 2001). Due to our design with five learning trials, it was ensured that older adults remembered a quantity of words large enough (about 16 words, on average) for splitting the total score in three parcels. The assignment of words to parcels was random (Little et al., 2002), indicated also by the extremely stringent form of strict measurement invariance we established. Factor loadings were equal across both measurements, but also within measurements. In addition, the residual variances of the three parcels were equal across measurements and within

effects of BCA on fifth learning trial performance and forgetting to be equal across the two subsamples, which did hardly alter model fit ($\chi^2 = 182.2$, $df = 147$, $RMSEA = .036$), from which we concluded that these parameters were not statistically different. The standardized effects of BCA on 5T were $\beta = .57$ (young-old) and $\beta = .73$ (old-old), whereas the standardized effects of BCA on F were $\beta = .52$ (young-old) and $\beta = .58$ (old-old). Subsequently, we also constrained the unstandardized effects of age on fifth learning trial performance and forgetting to be equal. Again, doing so only marginally changed model fit ($\chi^2 = 182.8$, $df = 149$, $RMSEA = .035$), which implied that these effects were not statistically different in the two age groups. The standardized effects of age on 5T were $\beta = -.08$ (young-old) and $\beta = -.07$ (old-old), while the standardized effects of age on F were $\beta = -.44$ (young-old) and $\beta = -.37$ (old-old). The amount of explained variance in fifth trial performance was 33% (young-old) and 52% (old-old), whereas in forgetting it was 25% (young-old) and 43% (old-old). Although these additional analyses show that there were no statistically significant differences in the unstandardized effects of interest across the two age groups, which, in principle, would strengthen our main findings, two things have to be kept in mind. First, splitting the sample into subsamples post hoc is not a full cross-validation. Second, statistical power (and, thus, sample size) becomes an issue in comparing parameter estimates across subsamples.

measurements.

At first glance, it seems unusual to examine measurement invariance in word parcels that were built randomly. For dichotomous items, factor analysis on the item level would normally represent a viable alternative to parceling (Bandalos, 2008). However, although whether an individual word is recalled or not can be considered a dichotomous item, to-be-remembered words are not items. Because *which* specific words a person remembers is mostly idiosyncratic, implying that the recall of individual words is uncorrelated across words and persons. This would render factor analysis of individual words a useless endeavor. At the same time, three randomly built quantitative indicators of recall, i.e., the parcels, can and do correlate across persons and measurements (see Table 7). For reasons of comparison, we mention here that in a separate analysis where forgetting was modeled using a simple difference score (instead of using parcels and the latent difference score that was captured by the variable F in Figure 9), only 8% of variance were explained in forgetting---as opposed to the 31% of variance found in the present study. This, in our view, indicates the superiority of modeling forgetting on the latent level using parcels.

One may object that in our study we measured only the first phase of a forgetting process, that is, short-term forgetting. Related to this objection would be the argument that forgetting curves covering longer time periods could differ in many ways from the latent difference model we applied. Although we fully acknowledge these objections as possible limitations of our study, there are two empirical observations that may help to validate our approach of modeling forgetting across a 30 minutes retention interval. First, the forgetting curve is inherently non-linear with an exponential, but decelerating decline of remembered words. As a consequence, most forgetting occurs between the last learning trial and the first recall trial (see Mac Donald et al., 2006). This implies that individual differences in forgetting should be largest during this first phase of forgetting. Similarly, the longer the time period of forgetting, the smaller and more and more affected by random influences possible individual

differences in forgetting become. In addition, others (Giambra & Arenberg, 1993; Wheeler, 2000) have also used relatively short retention intervals and, like in the present study, were successful in detecting age-related differences. This does not mean that short-term and long-term processes of forgetting are necessarily the same. Rather, this is to say that in order to model individual differences in forgetting, short-term forgetting may be more powerful.

The Nature of the Effect of Basic Cognitive Abilities on Forgetting

If, as we have demonstrated, basic cognitive abilities affect the amount of forgetting to a considerable extent, which mechanisms can be thought to underlie this effect? As outlined in the introduction, trying to recall as many words from a previously learned list necessarily involves a search process. In free recall tasks, participants repeatedly try to recall further words from the presented list. Selection of words is with replacement so that, as words are recalled, an increasing number of retrievals are found to have been recalled already, thus representing irrelevant information in the search set that has to be suppressed (Wixted & Rohrer, 1994). The successful recall of a word decreases its likelihood of further recall due to suppression, but a prior recall does not automatically inhibit a further retrieval from long-term memory—in fact, the contrary (Bjork, 1988). Thus, during recall, the number of retrievals that have to be suppressed increases because an increasing number of words retrieved from long-term memory had already been recalled. In that sense, recall becomes progressively more resource-demanding because more suppression is needed to govern the search process, which decreases the probability of access of unrecalled words (cf. Laming, 2009).

This is where the simultaneity mechanism proposed by Salthouse (1996) could set in. Free recall consists of two tasks, a suppression of successfully retrieved words and a continuing search for unrecalled words. The longer the set of words that has to be suppressed gets, the more information has to be kept available simultaneously, thus limiting the search for unrecalled words. A person high in processing speed, however, is assumed to more rapidly execute elementary operations of, e.g., comparing the set of already recalled words with a

word retrieved from long-term memory. Similarly, individual differences in working memory capacity might shape forgetting rates because lower working memory capacity may result in a higher amount of irrelevant information in an individual's search set size (Unsworth & Engle, 2007; Unsworth et al., 2011). Thus, it is argued that persons with lower working memory capacity are hampered at retrieval because of a broader search set that includes more interfering information. This broader search set might result in retrieving fewer items and, hence, higher forgetting rates.

Of course, if suppression is relevant in forgetting, inhibition as proposed by Hasher and Zacks (1988) could be considered as another basic cognitive abilities that merits examination. Indeed, there are empirical findings that demonstrate that lack of inhibition leads to increased forgetting (Anderson & Neely, 1996), although the effect has not been tested on the level of individual differences. The relevance of inhibition in forgetting was further elaborated upon by Anderson (2003), who suggested that inhibition in form of executive control may be the critical factor in forgetting due to interferences as deficits in executive control processes may lead to higher retrieval competition.

Learning and Forgetting

Forgetting necessarily requires previous learning. A straightforward question that has extensively been debated in the literature then is: Do persons who learn better forget less? There is, indeed, evidence that learning is related to lower forgetting rates (cf. Wixted, 2004a)—although there is a large bulk of studies reporting the contrary (e.g., Meeter et al., 2005; Underwood, 1954). In a sense, learning and forgetting might be considered two memory phenomena that represent two sides of the same coin—learning and unlearning.¹⁵ This assumption also implies that learning and forgetting may be opposite ends of a continuum, both being highly correlated (McGeoch, 1942). Our results show, however, that although

¹⁵ Interestingly, the Greek philosopher Plato held the opposite view. In the Socratic dialogue *Meno*, he developed the idea of *anamnesis* (recollection), which considers all learning as un-forgetting. According to this explication, the acquisition of knowledge is not a discovery of the previously unknown, but a recovery of what was once known but then forgotten.

learning and forgetting are correlated ($r = .53$), this correlation is far from perfect in old age. Learning and forgetting share a substantial amount of variance (ca. 25%), but, as indicated by their unshared variance (ca. 75%), are more different than equal. This implies that learning and forgetting may tap different aspects of memory.¹⁶

Apart from the question whether learning and forgetting represent opposite sides of a continuum, one may ask whether both are driven (in part) by the same mechanisms. Previous research demonstrated that factors influencing learning not necessarily influence forgetting, too (cf. MacDonald et al., 2006). By contrast, the results of the present study suggest that basic cognitive abilities are related to both learning and to forgetting. This finding shows that both have an overlap in underlying processes, which, after statistically controlling for basic cognitive abilities, led to a decrease in the correlation between learning and forgetting. Considering the small, but still existent correlation between fifth trial performance and forgetting and the fact that there remained reliable individual differences in learning and forgetting, there may be further variables that account for their (shared) variance. Whether additional variables, for example, cognitive inhibition, executive functioning, or subjective ratings concerning changes in memory, will turn out to be predictive of both learning and forgetting represents an open empirical question, however.

Age and Forgetting

We found that older persons forgot more words after a 30-minute delay. Note that this age-related effect remained after statistically controlling for basic cognitive abilities (processing speed, working memory). At the same time the low correlation between fifth trial performance and forgetting shows that higher forgetting rates of older persons can not be due to only a lower level of acquisition. From that we conclude that age may have an effect on forgetting due to other age-sensitive variables. Li, Lindenberger, and Sikström (2001), for

¹⁶ One has to keep in mind, however, that forgetting is a dynamic process, implying that items not recalled after a certain delay may be recalled at a later occasion. In that sense, the overlap of learning and forgetting also depends on the timing of measurements.

example, have argued that deficient neuromodulation combined with noisy processing might result in less distinctive cortical representations of information. This implies that mental representation of events and the context within which events occurred become more confusable with each other, which complicates later reinstatements of these events (recall). Similarly, Welford (1981) suggested that older people have a reduced signal-to-noise ratio in the brain. Because performance results from decisions made on the basis of data, which are confused to a greater or lesser extent by momentary random disturbances or “noise” in the central nervous system, the accuracy of decisions based on the signal-to-noise ratio decreases into old age. Likewise, the dilution model of forgetting (Lansdale & Baguley, 2008) assumes that the probability of retrieval after a delay is predicted by the proportion of memory traces of a stimulus that are defined as correct if sampled and that traces are diluted over time by null traces that, if accessed, block retrieval. If one is willing to assume that dilution becomes more rapid in aging, the problem of increasing “noise” (null traces) with delay may explain higher forgetting rates in old age.

Besides the question of which age-sensitive variables may cause an effect of age on forgetting, we repeat here that in the present study the effect of age on learning was smaller than the effect of age on forgetting. This result indicates that individual differences in learning performance after five trials may be less affected by age rather than by other individual characteristics. Interestingly, with forgetting as the outcome, age becomes a more reliable predictor of forgetting meaning that older persons forget more of the material learned.

Why may this be the case? As others have argued (cf. Fisk & Warr, 1998), it may be that the representation of little-learned in long-term memory is more fragile in old age and, hence, more easily disrupted. That is, memory traces may be less consolidated for little-learned material. One reason for this might be that the ability to build associations between items is, in general, weakened in old age (Naveh-Benjamin, 2000). In particular, persons in old age appear to use strategies (at encoding) that help building up associations less

spontaneously (Richardson, 1998). If associations are either not build successfully during learning or, which appears more important from our perspective, do not last over time due to their more fragile nature in old age, age may have a stronger effect on forgetting than on learning performance after five trials. As McGaugh (1989) has conjectured, older adults may have difficulties to consolidate newly-learned associations for several minutes after initial acquisition of the to-be-learned material. Hence, after 30 minutes of not repeating the to-be-learned material, old age and age-sensitive variables may become more powerful predictors of forgetting than for learning.

Conclusions

The question of which mechanisms underlie forgetting remains an open issue. As stated by various forgetting theories, reasons of forgetting may contribute to interference (unlearning), decay or fading traces, inadequate cues, or even a combination of fading traces and interference (Laming, 2009). However, we have shown that the issue of which processes underlie forgetting can be addressed not only by experimentally demonstrating the influence of design factors, but also by focusing on individual differences in forgetting. Specifically, we found that basic cognitive abilities affect learning and, more important from the perspective of the present study, forgetting to a considerable extent in old age. In that sense, further research may focus on additional predictors that are believed to be related to individual differences in forgetting in old age, thus broadening our knowledge of why different persons differ with regard to both phenomena: Learning and forgetting.

3 GENERAL DISCUSSION

The overarching aim of the present thesis was to analyze whether basic cognitive abilities and subjective organization are predictors of individual differences in learning and forgetting in old age. The rationale for this was in line with an individual-differences cognitive aging perspective which aims at analyzing mechanisms of cognitive aging within the individual in order to understand cognitive aging. Basic cognitive abilities and subjective organization were chosen as predictors of individual differences in learning and forgetting in old age, because previous research suggests that these variables cross-sectionally account for age-related differences in episodic memory (e.g., Davis et al., 2003; Salthouse, 1993). However, these studies do not match with an individual-differences cognitive aging perspective, because relations at the individual level were neglected. By not questioning, but rather acknowledging the underlying theoretical assumptions of these studies (Salthouse, 1996; Tulving, 1962; Unsworth, 2007), the present thesis investigated whether the suggested relations also exist at the individual level in old age. In terms of the present thesis, the question was whether basic cognitive abilities and subjective organization are predictors of individual differences in learning and forgetting in old age. If so, these variables may be considered as relevant explanatory variables of cognitive aging (see Hofer & Sliwinski, 2001), at least regarding episodic memory. The present thesis investigated this issue in four different studies. The following discussion will first focus on the results and implications including limitations of the four studies. In line with the two leading research questions of the present thesis, this first part of the discussion will be divided into two parts: 1) Are there individual differences in learning and forgetting in old age (Chapter 3.1) and if so, how large are they, and 2) are basic cognitive abilities and subjective organization predictors of these individual differences (Chapter 3.2)? Following this, open issues that are, in particular, relevant from an individual-differences cognitive aging perspective, are addressed in an outlook (Chapter 3.3). Finally, a conclusion is presented.

3.1 Individual Differences in Learning and Forgetting in Old Age

As stated above, the overarching aim of this thesis was to analyze whether basic cognitive abilities and subjective organization are predictors of individual differences in learning and forgetting in old age. A logical prerequisite of analyzing these relations is to examine the degree of individual differences in learning and forgetting in old age. Are there reliable, significant, individual differences in learning and forgetting in old age? Overall, the four studies of the present thesis indicated that there are individual differences in learning and forgetting in old age. In the following, implications and the relevance of this result will be discussed.

Learning and forgetting in the present thesis were both measured as a process. Regarding learning, Study 1 and Study 2 analyzed three parameters: initial level, rate of learning, and asymptotic performance, respectively, the amount of learning. This modeling approach was in accordance with Zimprich et al. (2008b). Zimprich et al. suggested to model non-linear learning curves by using these parameters, because they represent parameters that are interpretable in the context of learning. Study 3 focused on a specific kind of learning: criterion-based dropout learning. Learning was modeled by a polynomial function focusing on speed of learning – the linear slope of recall performance. Regarding the process of forgetting, two parameters were captured: the initial level, that is, the degree of learning, and the amount of forgetting as reflected in a change parameter.

Before discussing the relation between individual differences in these learning and forgetting parameters, individual differences in learning and forgetting in old age will be discussed separately. Overall, Study 1, Study 2, and Study 3 showed that there are individual differences in learning in old age. Older individuals differ regarding their initial performance, their increase in recall performance over trials, and regarding asymptotic performance, respectively, the amount of learning. This result is in line with previous studies showing that there are individual differences with regard to verbal learning in old age (Rast, 2011;

Zimprich et al., 2008a, b). However, the present study extended this existing body of research by indicating that individual differences in learning in old age are a robust finding. Individual differences in learning in old age emerged if learning was designed as a multi-trial free recall verbal learning task (Study 1), if learning referred to task-specific spaced paired-associates learning in a natural context (Study 2), and if learning referred to paired-associates criterion-based dropout learning (Study 3). Overall, this result implies that theories on learning that describe such different characteristics of learning as influential variables of learning (see Chapter 1.1.2) should incorporate predictions regarding individual differences. This point will be highlighted below.

In line with previous studies (e.g., Zimprich et al., 2008b), verbal learning in old age in Study 1 and Study 2 was best represented by a hyperbolic function. Note that a more precise differentiation between different functions that may capture learning, for example, power, exponential, or hyperbolic function, requires a high precision of parameters. A high precision of parameters is reached by implementing more study-recall trials than done in the present thesis. As suggested by Rast and Zimprich (2010), experiments with more than 10 learning trials are required in order to differentiate between different functions of learning. This represents a challenge for future research in the field of cognitive aging, because motivational issues with regard to such a design (e.g., fatigue) might limit a realization of a learning approach including 10 learning trials or more.

The degree of individual differences in learning in old age varied both regarding the parameter and regarding the way learning was designed. The coefficient of variation (CV), which is a standardized measure of the variability (Reed et al., 2002), ranged from .24 (recall performance after five study-test cycles in Study 4), .32 (quadratic growth in Study 3) to .61 (speed of learning in Study 3). These values indicate that the degree of individual differences depends on both the design of how learning is implemented and the learning parameter under consideration. Individual differences in learning are, thus, multidimensional. A further

dimension of individual differences in learning in old age was suggested by the present thesis regarding different time scales. The results of Study 1, Study 2, and Study 3 indicated that individual differences in learning in old age were evident in at least two different time frames: over a short-term, that is, over minutes (Study 1 and Study 3), and over a spaced learning condition across days (Study 2). A comparison of the degree of individual differences in learning in old age should therefore always mention which parameter of learning and what kind of learning individual differences refer to. One might assume that individual differences in old age become more pronounced towards the end of a verbal learning task, when participants reach their personal upper asymptotic performance and unsystematic influences become less important (see Zimprich et al., 2008b). Furthermore, learning tasks that require more effortful processes such as free-recall instead of recognition (see Wingfield & Kahana, 2002, for a discussion) may show bigger individual differences. However, due to broadly varying learning conditions in the laboratory empirical results may contradict with these predictions. The supportive role of the experimenter during learning with persons of older age, which may differ across studies, may influence the degree of individual differences in learning among persons of older age.

As mentioned in Chapter 1.1.1, learning and forgetting are not two sides of one coin, but rather represent distinct, but related cognitive processes. Because of this, individual differences in learning do not automatically include information regarding individual differences in forgetting in old age. Individual differences in forgetting in old age were addressed in Study 3 and Study 4. Whereas Study 3 analyzed individual differences in retention (i.e., the amount of material retained over a short-term delay), Study 4 addressed individual differences in forgetting by considering forgetting as a change in recall performance over 30 minutes. Both studies showed that individuals differed regarding the amount of retained and forgotten material.

Furthermore, Study 3 and Study 4 indicated a close relation between learning and forgetting. In Study 3 it was shown that persons with a higher speed of learning were also those persons retaining target words most in a final delayed recall task. A similar relation is reflected in findings by Kyllonen and Tirre (1988). Speed of learning explained about 14% of variance in retention. Kyllonen and Tirre (1988) implemented a dropout schedule as done in Study 3 of the present thesis. However, in the study by Kyllonen and Tirre (1988) as well as by Study 3, the underlying mechanism of a relation between individual differences in speed of learning and individual differences in retention remains unclear. Possible underlying mechanisms may refer to mechanisms that occur during retention, for example, consolidation (see Wixted, 2004b, for a review), or individual differences in interference (Underwood, 1957). Hence, it might be that persons in Study 3 differed regarding the amount of proactive interference. Due to the design of Study 3, some persons may have recalled word pairs that were not presented in the corresponding study trial of that cycle, but in a previous one. In order to understand mechanisms of retention more precisely, experiments, which systematically control for such design effects, could be the focus of future research.

Study 4 showed that the correlation between individual differences in recall performance after the fifth trial correlated .53 with the amount of forgetting. This result indicates that persons who learned a high amount of the to-be-learned material were also those persons who forgot less material over a period of 30 minutes. Note that the measure of forgetting in Study 4 was based on a whole-list learning schedule with number of study-test trials fixed. Because of this, the degree of learning was not controlled in an absolute sense. Thus, the relation between individual differences in learning and forgetting may result from individual differences in associative strength. In order to shed light on the question of how individual differences in learning are related to individual differences in forgetting, future research could examine relations of different types of learning schedules (dropout vs. whole-list learning schedule) with individual differences in forgetting. The approach of modeling

forgetting used in the present study might represent one way of reliably modeling forgetting at the individual level. The issue of different learning schedules will be discussed in more detail in Chapter 3.3. Summing up, regarding research question 1) there are individual differences in learning, retention and forgetting. These are overall highly pronounced, and there is a relation between individual differences in learning, retention, and forgetting in old age.

Implications of this result derive from two different perspectives: 1) a more general theoretical scientific perspective and 2) a cognitive aging perspective. Regarding the general theoretical scientific perspective, it can be noted that existing theories on learning and forgetting as presented in Chapter 1.1.2 and Chapter 1.1.3 do not include predictions regarding individual differences in learning and forgetting. Explanations of why individuals may learn differently and show different effect sizes of influential variables of learning and forgetting are not taken into account. This lack in theory represents the need to extend existing theories of learning and forgetting, because results of the present thesis indicate that there are individual differences in learning and forgetting. As stated by Cohen (1994) “the consideration of individual differences within the framework of a theory (or model) could result in a more precise and more comprehensible formulation” (p. 11). As described below in detail, the present thesis suggests taking into account basic cognitive abilities and subjective organization as relevant individual-differences variables regarding episodic memory in old age. Existing general theories on learning and forgetting could be extended by these relations. The approach used in the present thesis (i.e., analyzing the process of learning and forgetting and relations of individual differences therein with characteristics of the individual) may represent a general approach, which could be used for evaluating and extending theories.

From a cognitive aging perspective, the result of the present thesis that there are individual differences in learning and forgetting in old age raises the question of *why* these differences exist. Of course, it is intuitively clear that individuals differ regarding any performance, being in young or older age. Newell, Mayer-Kress, Hong, and Liu (2010) stated

that “learning curves are the product of multiple processes, that in addition to memory strength, include constructs such as warm-up, inhibition, noise, and fatigue” (p. 72). As mentioned in Chapter 1.1.1, learning refers to memory strength. However, the other variables such as inhibition and fatigue may also influence recall performance, or more precisely, the learning curve. More importantly, the weightings of each contribution of these variables to the learning curve might differ between individuals and consequently, individuals differ regarding their learning curve as indicated by the present studies. Accordingly, individual differences in learning and forgetting may refer to individual differences regarding encoding and retrieval and related influential variables of learning and forgetting as reviewed in Chapter 1.1.2 und 1.1.3. What is the relevance of this regarding cognitive aging?

From a life-span perspective (Baltes, Staudinger, & Lindenberger, 1999), individual differences are relevant in particular in older age, because as mentioned briefly in the introduction of the thesis and in Study 3, older persons show a relatively long history of development. Every person encounters individual situations across the life-span with which individuals cope in individual ways and in different contexts (Fischer & Silvern, 1985; Hess, 2005). Furthermore, due to individual biological and cultural influences across the life-span, development of a single person is highly individual and represents a differential process (Baltes, Staudinger, & Lindenberger, 1999). Following this, any older person possesses a relatively long history of individual influences. Accordingly, individual differences in learning and forgetting in old age may be one result of these diverse and individual influences across the life-span.

In addition, individual differences in learning and forgetting among persons of similar old age that were evident in the present thesis may also be the result of individual differences in current activities. They may not necessarily represent only the result of an individual history. For example, the current participation in a memory strategy intervention program may also result in individual differences in learning and forgetting in old age. This idea will

be discussed in terms of training, plasticity and a possible relation with individual differences in learning and forgetting in old age in Chapter 3.3.

The fact that the present study indicates that there are individual differences in learning and forgetting in old age indicates in the first place that these should be taken into account. The conclusion that there is a general age-related decline in episodic memory (e.g., Kausler, 1994) does not seem to be adequate. A decline in episodic memory may refer to some, however, not all aging individuals. Note that individual differences in learning and forgetting in old age as indicated by the present studies may not only imply that an age-related decline in episodic may not be correct for the individual, but also that individuals differ regarding their stabilization of cognitive functioning (Martin, Jäncke, & Röcke, 2012). According to such a functional life-span approach, individuals may differ in orchestrating their abilities, for example, episodic memory. Regardless of whether change or stability processes are the focus, in both kinds of processes there might be individual differences. In turn, these differences may result in individual differences in learning and forgetting in old age as indicated by the results of the present thesis.

3.2 Predictors of Individual Differences in Learning and Forgetting in Old Age

In order to explain individual differences in learning and forgetting in old age and thus understanding cognitive aging at the individual level, the second research question of the present thesis asked whether basic cognitive abilities and subjective organization predict individual differences in learning and forgetting in old age. This chapter will summarize results and implications with regard to basic cognitive abilities and subjective organization separately. After doing so, in Chapter 3.3 both kinds of predictors will be incorporated.

3.2.1 Basic Cognitive Abilities

The question of whether basic cognitive abilities are explanatory variables of individual differences in learning and forgetting in old age was addressed in Study 2, Study 3, and Study 4. In all three studies, processing speed and/or working memory accounted for

individual differences in learning (Study 2 and 3) and forgetting (Study 4). Overall, results of the studies indicated that working memory and processing speed influenced learning positively and forgetting negatively. This is in line with theoretical assumptions suggesting that processing speed and working memory may influence episodic memory (Salthouse, 1996; Unsworth & Engle, 2007).

With regard to the relation between working memory, processing speed, and learning, there was a positive effect of processing speed on the speed of learning as indicated by Study 3. A positive effect of working memory and processing speed on asymptotic performance, initial level, and learning rate was demonstrated in Study 2. In conclusion, basic cognitive abilities positively influenced learning, more precisely, task-specific learning as well as criterion-based dropout learning. This is in line with the suggested mechanisms by Salthouse (1991, 1996). A higher working memory and processing speed ability may facilitate ongoing retrieval processes. Furthermore, encoding may be deeper in terms of the level-of-processing approach (Craik & Lockhart, 1972), because more time is available for encoding to-be-learned material in a deeper way (Salthouse, 1994). The positive effects of basic cognitive abilities on task-specific learning indicate that basic cognitive abilities are required for both the learning of task demands and learning of actual items.

Regarding forgetting, persons with relatively higher basic cognitive abilities in processing speed and working memory showed less forgetting. Basic cognitive abilities explained about 32% of variance in forgetting. These differential relations of basic cognitive abilities with learning and forgetting indicate that learning and forgetting are 1) differential processes as argued in Chapter 1.1.1 and that 2) both represent cognitive processes with different characteristics that are related differently to basic cognitive abilities. Note that future studies could shed light on whether the effect of working memory and processing speed on episodic memory represents unique or shared effects. Hence, as Study 4 showed, processing speed and working memory showed more shared than unique effects regarding their

predictive role for individual differences in forgetting. Whether such a relation also emerges regarding learning remains an open research question up to date. However, working memory and processing speed may interact and should consequently be considered as related basic cognitive abilities. As argued by Danthiir, Roberts, Schulze, and Wilhelm (2005), the measurement of working memory often includes aspects of processing speed. Persons with higher processing speed may be able to rehearse material more often resulting in better performance in, for example, complex span tasks that were also implemented in the present thesis as measures of working memory.

What do these results imply from a cognitive aging perspective? As stated in the introduction, in line with an individual-differences approach of cognitive aging (Hofer & Sliwinski, 2001), a suggested explanatory variable for age-related differences in any cognitive variable of interest may be considered as relevant if the suggested relation is evident at the individual level. In line with this argumentation, the results of the present thesis indicate that working memory and processing speed both represent relevant explanatory variables of cognitive aging, at least regarding episodic memory. Against this background, predictions regarding how basic cognitive abilities may influence episodic memory (Salthouse, 1996; Unsworth, 2007) were supported by the present thesis. Basic cognitive abilities were predictors of individual differences in learning and forgetting in old age. The idea that processing speed may affect learning and forgetting due to a simultaneous and limited time mechanism (Salthouse, 1994) and that working memory affect learning and forgetting due to effects in set search during retrieval (Unsworth, 2007) may represent underlying mechanisms of the present results. However, these mechanisms and thus the theoretical models themselves formulated by Salthouse (1994) and Unsworth (2007) could not be examined in the present thesis. Whether an effect of a simultaneous and limited time mechanism on episodic memory (Salthouse, 1996), or an effect in set search during retrieval (Unsworth, 2007) actually occurs remains an open issue at present.

A limitation of the present results refers to the fact that in Study 2 and Study 3, predictors were analyzed as manifest variables. Processing speed and working memory were modeled as latent variables in Study 4 only. The benefit of latent variables is based on the fact that measurement errors are modeled explicitly (Brown, 2006). Furthermore, measures of working memory and processing speed referred to different material. Whereas in Study 2, processing speed referred to a symbol search and working memory to a span task including numbers, in Study 3 processing speed was measured by pictorial material, and in Study 4 processing speed was measured by a number comparison, letter-digit substitution, and identical picture test. Study 4 measured working memory by a reading, counting, and operation span task. Thus, whereas only Study 4 incorporated different material for measures of basic cognitive abilities, the other studies only used one kind of material. This represents a limitation of the present thesis and should be taken into account when interpreting the results of the present thesis. Future research should investigate the reported relations systematically with different material by using latent variables in order to examine whether the relations found in the present studies represent domain-specific relations or not. Such analysis may be, in particular, relevant for working memory measures, because the construct of working memory represents a broad system including domain-specific mechanisms, that is, a phonological loop and a visuospatial sketchpad, that are characterized by individual differences (see Engle, Kane, & Tuholski, 1999).

The aim of the present thesis was not to examine within-person changes of basic cognitive abilities and relations of these with changes in episodic memory. However, in line with a life-span perspective (Baltes et al., 1999), such an analysis is worthwhile and represents a further issue for future research. A study by Hertzog, Dixon, Hultsch (2003), for example, indicated that changes in working memory and processing speed are related to changes in episodic memory. Correlations of changes in processing speed and working memory with changes in episodic memory ranged from .41 to .49. If the aim is to analyze the

relations that were evident in the present study from a life-span perspective, analyzing correlated changes of basic cognitive abilities and episodic memory represents a topic for future research.

Overall, the results of the present thesis indicate that basic cognitive abilities contribute to learning and forgetting in old age at the individual level. However, they also indicate that there is a need for examining further predictors because of the unexplained variance remaining in learning and forgetting. Chapter 3.3 discusses this issue in more detail by incorporating results regarding subjective organization, the second kind of predictors of the present thesis.

3.2.2 Subjective Organization

Based on the same rationale as described above concerning basic cognitive abilities, subjective organization may be considered as a relevant explanatory variable of cognitive aging regarding episodic memory if the variable predicts individual differences in episodic memory in old age. Study 1 indicated that this is the case: Growth parameters of subjective organization were related to parameters of learning. This is in line with Tulving (1962), who suggested that the associative structure (i.e., the organization of the material) among words and the increase of such organization across trials is positively related to recall performance.

The effect mentioned of repetition on recall (see Chapter 1.1.2) may thus be mediated by organization. Repetition implies subsequent occasions in which to-be-learned material may be organized and thereby facilitates recall (see Crowder, 1976). However, the present study could not reveal which processes exactly take place in effective subjective organization. This problem is also related to an issue regarding subjective organization: the measurement of subjective organization itself. The measure used in the present study, that is, paired frequency (PF), is rather limited, because as mentioned in the discussion in Chapter 2.1 the PF measure only considers two items. The measure of PF does not take into account the organization of bigger units. How to measure subjective organization more accurately represents an important

future research issue. In line with Tulving (1962), subjective organization refers to the organization due to individual higher order units. Depending on individual associations of single words into units, these higher order units may be smaller or bigger. Against this background, a more accurate measure of subjective organization should be more flexible regarding the unit it measures. The PF measure is limited to organize only two items. If a measure of subjective organization could reflect individual sizes of units above the size of two items, mechanisms of subjective organization could be analyzed in a way that may be more appropriate to actual ongoing cognitive processes during learning and therefore subjective organization. Furthermore, the PF measure used in the present dissertation depends per definition on the individual recall performance. Due to this dependency between learning and subjective organization, at present an open issue remains whether effective learning may also be possible without subjective organization because of other individual strategies used. Future research could therefore aim at developing a measure of subjective organization that is not depending on the individual recall performance. These methodological considerations may be in particular relevant regarding cognitive aging, because as will be mentioned in the next paragraph, memory strategies (e.g., the method of loci) are conceptually related to subjective organization in some aspects. A more precise measurement of subjective organization could thus be implemented in order to measure mechanisms of effective memory strategies.

One question emerging from Study 1 is why there are individual differences in subjective organization in old age. A possible explanation might be that individuals in old age differ regarding their use of mnemonic strategies. Hence, mnemonic strategies such as the method of loci (Yesavage & Rose, 1984) imply some conceptual similarities with subjective organization: To-be-learned material is organized. In the case of the method of loci this is realized by structuring the material according to a self-determined way. In the case of subjective organization this is realized by structuring to-be-learned material according to individual higher order units. In both cases, internal cues are generated to work as retrieval

cues for to-be-learned material. As indicated by testing-the-limit studies, older adults are able to learn a mnemonic strategy such as the method of loci and thereby to increase their recall performance (Kliegl, Smith, & Baltes, 1989). Testing-the-limits studies investigate the latent performance potential, or the limit persons achieve even after training (Lindenberger & Baltes, 1995). With regard to cognitive aging, a common finding is that younger adults outperform older adults: Older adults do not reach the potential performance of younger adults, but are able to learn a memory strategy (e.g., Baltes & Kliegl, 1992). However, testing-the-limit results refer to cross-sectional data. Individual differences regarding limits within the younger and older age-group are not taken into account, except by one study by Kliegl (as cited in Baltes & Kliegl, 1988). Kliegl analyzed individual testing-the-limit trajectories of six younger and six older adults. Results indicated that even after 120 training sessions of 15 minutes, the best older adult regarding recall performance did not reach the recall performance of that of a younger adult after 15 training sessions.¹⁷

Individual differences in subjective organization in old age as indicated by the present thesis suggest that there also might be individual differences in further memory strategies. Because of the mentioned conceptual relation between subjective organization and the method of loci technique, it might be interesting for future research to investigate whether training the method of loci is reflected in higher subjective organization.

One step back, in order to examine the relation between subjective organization and episodic memory in old age more precisely, a further extension of the present thesis is to include forgetting apart from learning as a variable of interest. Hence, subjective organization may influence both processes of episodic memory, that is, encoding and retrieval. During encoding subjective organization may facilitate the formation of association, during retrieval subjective organization may facilitate retrieval because of using single to-be-learned items as retrieval cues. Hence, according to Tulving and Osler (1968), a failure in retrieval (i.e.,

¹⁷ Asymptotic performance as measured in Study 1 and Study 2 may be related to aspects of limits as formulated by testing-the-limit studies (see Zimprich et al., 2008b).

forgetting) is related to inadequate retrieval cues (Chapter 1.1.3). Accordingly, subjective organization – using items as cues for other items – should minimize forgetting. Such a qualitative conceptualization of forgetting may reveal individual patterns of forgetting in old age. While this issue remains an open one up to date, the present thesis showed that subjective organization may be considered as a relevant explanatory variable of cognitive aging, because individual differences in learning in old age were predicted by subjective organization. Of course, if the aim is to analyze these relations from a life-span perspective, analyzing correlated changes of subjective organization and episodic memory represents a promising approach for future research as stated above regarding basic cognitive abilities.

3.3 Outlook

The present thesis indicated 1) that there are individual differences in learning and forgetting in old age and 2) that basic cognitive abilities and subjective organization predict these individual differences. In line with an individual-differences cognitive aging perspective (Hofer & Sliwinski, 2001), these variables may in turn be considered as relevant explanatory variables of cognitive aging. In the following this result will be incorporated and discussed by focusing on 1) possible interactions of predictors, 2) dedifferentiation, and 3) trainings.

Possible Interactions of Predictors

How might subjective organization interact with basic cognitive abilities regarding individual differences in learning and forgetting in old age? In order to answer this question, the testing effect mentioned in Chapter 1.1.3 should be taken into account. The testing effect states that testing has a positive effect on recall performance, both in immediate and delayed recall (Roediger & Smith, 2012). Roediger and Smith suggested that testing might work as a feedback insofar as testing helps to concentrate better on encoding items that were not recalled in previous test trials. Regarding paired-associative learning, Pyc and Rawson (2010) suggested that persons build up mediators between cues and targets. Testing may help to evaluate whether mediators are good mediators. Such benefits of feedback due to testing

might be influenced by basic cognitive abilities. Higher basic cognitive abilities may facilitate the beneficial testing processes of focusing on not yet recalled items and of evaluating mediators. This in turn could result in better learning and less forgetting. Note that the present thesis provided evidence for an association between basic cognitive abilities and learning and forgetting. Whether this association is due to mechanisms of testing and feedback remains an open research question.

Furthermore, subjective organization may also be influenced positively by increasing test occasions. Zaromb and Roediger (2010) showed that higher subjective organization was related to more test occasions. In conclusion, higher basic cognitive abilities and subjective organization may both moderate the testing effect. The crucial question is whether subjective organization is also influenced by basic cognitive abilities. Is a higher working memory and processing speed ability related to higher subjective organization? To the best of my knowledge, there is no study that has investigated this question. Without relying on any theoretical account (there is none), a person who processes faster and more because of higher working memory and processing speed abilities may be advantaged regarding the use of strategies and regarding the organization to-be-learned material.

This interaction of basic cognitive abilities and subjective organization may also be influenced by the kind of learning and forgetting. Hence, Roediger and Smith (2012) also suggested that testing has a beneficial effect on learning, because with more test occasions persons will become more familiar with task demands. This describes task-specific learning as implemented in Study 2 of the present thesis. Study 2 showed that older persons are able to learn task demands and that this task-specific learning is related to basic cognitive abilities. However, whether subjective organization occurs in task-specific learning remains an open issue up to date, and so does the question whether subjective organization interacts with basic cognitive abilities in old age.

Forgetting may be related to lower subjective organization during learning and lower basic cognitive abilities in general. However, as stated above, no study has investigated whether subjective organization is related to forgetting. In line with the theoretical account suggested by Tulving and Osler (1968) as presented in Chapter 1.1.3, effective retrieval cues should minimize forgetting. A higher subjective organization implies more effective retrieval cues. Study 4 showed that basic cognitive abilities influence forgetting, in line with Tulving and Osler (1968) possible due to more effective retrieval cues. Therefore, higher basic cognitive abilities should be related to higher organization. Thus, an interesting research question is whether forgetting could be minimized if additional retrieval cues are presented and if this in turn would be reflected in higher subjective organization. Is it possible to compensate deficits in basic cognitive abilities? Note that these suggested relations should be evident for younger as well as for older persons. However, analyzing these relations in old age may be in particular worthwhile, because the question why some individuals in old age show better episodic memory performance than other individuals of similar old age could be addressed. Investigating whether learning and forgetting in old age are positively influenced, for example, by providing retrieval cues, may help to develop interventions for older persons. This issue will be highlighted below.

Apart from possible interactions of subjective organization and basic cognitive abilities, the issue of further possible predictors of individual differences in learning and forgetting should be discussed in this context. As mentioned in the studies in Chapter 2, subjective organization and basic cognitive abilities both explained a considerable extent of between-person variance in learning and forgetting among persons of old age. However, a considerable amount of variance remained unexplained. This indicates that further variables may predict individual differences in learning and forgetting in old age. Possible candidate variables in this context may be non-cognitive variables such as personality and motivation (Ackerman, 1987) or memory complaints (Mascherek & Zimprich, 2011). In addition, more

state-dependent variables such as fatigue or test anxiety (Fisk & Warr, 1996) may also be relevant predictors of individual differences in learning and forgetting in old age. Of course, it might be that individual differences in these non-cognitive variables are in turn influenced by basic cognitive abilities. According to Ackerman (1996) and his PPIK theory, personality and interest are related to so-called intelligence-as-process facets to which belong working memory and (perceptual) speed. Ackerman (1996) argued that depending on the ability level, a person may be more or less successful in performing a particular task. However, the choice of kind of task is influenced by the individual motivation and interest. Depending on individual abilities, some tasks might be more or less attractive to the individual. However, if, regardless of abilities, the individual may have a specific interest in these tasks, low abilities may be compensated, at least regarding the first step of attempting to perform the task. If these hypothesized relations are also evident for basic cognitive abilities, episodic memory, and the non-cognitive variables such as motivation and interest remains an open issue at present. However, if this issue would be addressed in future research, mechanisms of episodic memory of the individual could be analyzed by taking into account the variety of variables that characterizes an individual.

A further cognitive variable that may also be relevant for predicting individual differences in learning and forgetting in old age, which, therefore, should be taken into account in further studies, is verbal knowledge. Note that in Study 3 verbal knowledge was, apart from processing speed, included as a predictor of individual differences in learning and retention. Results of this study indicated that verbal knowledge had a positive effect on learning. According to Zelinski et al. (1993), persons with higher verbal knowledge may show more activities in daily life that practice their abilities for episodic memory. Summing up, there are studies and theoretical accounts suggesting that basic cognitive abilities and subjective organization may interact regarding learning and forgetting and that further variables may predict individual differences in learning and forgetting in old age. Examining

these possible relations represents a broad research issue and, in particular, implies that more theories are required that explain why variables may actually influence individual differences in learning and forgetting in old age.

Note that any analysis of a possible interaction of basic cognitive abilities and subjective organization should take into account that basic cognitive abilities and subjective organization refer to different kinds of individual difference variables. Whereas basic cognitive abilities refer to characteristics of the person that may be measured in different contexts, subjective organization represents an individual difference variable that occurs only during the context of learning itself. Hence, it is a related process of learning and represents a measure of learning that includes information of the learning process. This issue refers to the methodological problem of measuring subjective organization as mentioned above: Subjective organization measured by PF is *not* an independent measure of learning.

Dedifferentiation

By incorporating results of the four studies of the present thesis, the issue of dedifferentiation in older age implies further possible extensions of the studies conducted in the present thesis. The dedifferentiation hypothesis states that a general factor of different cognitive domains dominates in older age in contrast to childhood, when cognitive abilities are more differentiated from each other (Baltes & Lindenberger, 1997). The dedifferentiation hypothesis has been analyzed by cross-sectional (e.g., Lindenberger & Baltes, 1997) as well as by longitudinal (e.g., Anstey et al., 2003) studies. Overall, there are inconsistent findings regarding dedifferentiation in old age (see Anstey et al., 2003, for a discussion). Apart from this, results on dedifferentiation should take into account the different study design used. Hence, cross-sectional studies are in general, and therefore also regarding dedifferentiation (see Chapter 1.2.2) biased by mean trends of age-sensitive variables. Individual change is analyzed only indirectly by comparing age-heterogeneous samples. Individual rates of change are not analyzed, more importantly, intraindividual covariation are only *indirectly* captured by

cross-sectional studies (see Hofer et al., 2006). In the context of dedifferentiation, the analysis of intraindividual covariation of different cognitive abilities is the core aim. Thus, cross-sectional studies regarding dedifferentiation do not imply inferences about dedifferentiation at the individual level. Hofer and Sliwinski's (2001) idea of using narrow-age cohorts at cross-section does not only have the common advantage of not providing results with average mean trends regarding age-sensitive variables (see Chapter 1.2.2), but also provides an analytical approach of how to examine dedifferentiation.

Using multiple age-homogenous samples (i.e., a sequential narrow-age cohort design) offers the possibility to analyze intraindividual covariation of variables of interest without a bias of mean trends. Is there an increase of the covariance between age-related cognitive processes, because rates of aging are related to each other (see Hofer et al., 2006)? An increase in within-group correlations, that is, within narrow-age cohorts, across sequential narrow-age cohorts would indicate dedifferentiation. Hence, by analyzing interactions of narrow-age cohorts and cognitive variables of interest, it is possible to analyze if correlations between different cognitive variables of interests increases over time. Hofer et al. (2006) showed analytically and by conducting simulation studies that such correlations with time indeed reflect correlations between rates of change. This highlights the benefit of using NACs instead of age-heterogeneous cross-sectional studies, because rates of change could be observed *directly* across cohort.

For example, Frias, Lövdén, Lindenberger, and Nilsson (2007) investigated dedifferentiation regarding four abilities longitudinally over ten years (three points in time): episodic recall, semantic knowledge, semantic fluency, and visuospatial ability by using narrow-age cohorts separated by five years of age. Their results indicated that in older age levels of performance in the four cognitive abilities are more pronounced correlated than in younger age. This result is a first indication of dedifferentiation in old age.

The present thesis indicates that basic cognitive abilities and subjective organization are related to a substantial degree to episodic memory in old age. According to the dedifferentiation hypothesis, relations between basic cognitive abilities, subjective organization and episodic memory should become more pronounced, respectively, the amount of shared variance should increase in older age. Up to date, no study has examined dedifferentiation regarding basic cognitive abilities, subjective organization and episodic memory. In order to understand mechanisms of episodic memory across the life-span, future research may use the NAC approach in order to analyze possible different degrees of correlations of basic cognitive abilities, subjective organization, and episodic memory across the life-span.

Training

The present thesis indicated that basic cognitive abilities and subjective organization are related to individual differences in learning and forgetting in old age. In line with the societal and individual aim of preserving the ability of episodic memory also in older age, one question that may be raised in this context is how to optimize learning and how to minimize forgetting in old age.

In line with the results of the present thesis, one might first suggest enhancing basic cognitive abilities and the ability to organize to-be-learned material. However, working memory and processing speed refer to more content-free basic cognitive abilities. Individual capacities in these abilities may be partly biological determined as indicated by neural correlates of working memory (D'Esposito, 2007) and of processing speed (Rypma et al., 2006). Taking this into consideration, trainings aiming at enhancing working memory and processing speed do have to match the behavioral and neural level of the individual.

Against this background and by considering results of the present thesis, training memory strategies might be more adequate, respectively, more practicable. Hence, as shown in Study 1, subjective organization was related to learning. In this study participants were not

explicitly asked to use subjective organization. However, a training of using individual higher order units consciously may enhance learning. Participants could be explicitly asked to think about associations between single to-be-learned items. Similarly, learning a memory strategy such as the method-of-loci technique may influence individual differences in learning and forgetting in old age. Both approaches, using subjective organization consciously or using the method-of-loci technique, may compensate for low basic cognitive abilities. As mentioned above, testing-the-limit studies indicate that, on average, training to use a memory strategy is possible and effective in old age (Baltes & Kliegl, 1992). In line with this, Gross et al. (2012) showed that over a five-year period memory training was related to better memory performance. However, a meta-analysis by Zehnder, Martin, Altgassen, and Clare (2009) indicated that memory trainings effects may refer to unspecific interventions effects. Effect sizes of memory trainings were in a similar range as effect sizes of an active control condition (see also Martin, Clare, Altgassen, Cameron, & Zehnder, 2011). The effectiveness of training regarding individual differences in episodic memory should therefore be investigated more systematically at the individual level: Which memory strategy is effective for whom? When is a training of strategy use effective for an individual?

Effects of training or interventions, and their relations with individual differences in learning and forgetting in old age are also reflected in research on plasticity (Baltes & Lindenberger, 1988). Plasticity describes that behavior changes due to environmental demands. Behavior may refer to episodic memory performance and environmental demands to a cognitive intervention aiming at enhancing episodic performance (see e.g., Verhaeghen, Marcoen, & Goossens, 1992, for a meta-analysis). Verhaeghen et al. (1992) indicated that persons are able to enhance memory performance due to strategy training. However, as indicated by testing-the-limit studies, on general, older adults do not reach performance of younger adults (Baltes & Kliegl, 1988). In conclusion, the ability to use preserved capacities in a specific context, such as a training context, is preserved in old age, but is, on average,

diminished in older age. The general diminished ability to benefit from trainings is, however, from an individual-differences perspective not as relevant as the fact that older adults are able to train a specific domain and that this might be influenced by individual-differences variables.

As shown in a study by Singer, Lindenberger, and Baltes (2003), processing speed was a predictor of individual differences in training. The present thesis indicated a relation of processing speed with individual differences in learning and forgetting in old age. The question that remains open at this moment is whether these individual differences in learning and forgetting are related to individual differences in plasticity in old age. Of course, depending on the ability being trained within a plasticity study, these trained abilities may facilitate episodic memory. Consequently, individual differences in learning might be related to individual differences in plasticity. An investigation of this issue (i.e., relating individual differences in plasticity to individual differences in learning) seems to be promising: In particular, regarding cognitive aging, because both processes (learning and training) may refer to similar underlying cognitive processes. These related processes may be predicted differently by basic cognitive abilities, for example. If such mechanisms were known, individualized interventions that aim at enhancing episodic memory of an individual could be developed, or at least, as a first step, knowledge regarding the process of episodic memory in old age and correlates of this could be enhanced.

Apart from memory strategy trainings, the use of different learning schedules might offer a further effective opportunity to improve episodic memory. The present thesis showed that relations between basic cognitive abilities and episodic memory were evident when learning was implemented by different learning schedules. The finding that there are individual differences in these different learning schedules implies that individuals may benefit differently from different learning schedules. For example, the person who needed 27 study-test cycles in Study 3 and, thus, was the slowest person, may benefit from a different

learning schedule than the chosen criterion-based dropout schedule of Study 3. Furthermore, as stated above, individuals may differ regarding a positive effect of influential variables of learning and forgetting (Chapter 1.1.2, 1.1.3). These influential variables may in turn interact with the learning schedule. Thus, one aim from a more applied cognitive aging psychology perspective would be to analyze optimal learning schedules for persons more systematically and to develop optimal learning conditions for persons in old age that differ regarding basic cognitive abilities.

Both, strategy use due to training and the implementation of different learning schedules, may have different effects for different individuals. In order to investigate mechanisms of why individuals differ regarding these effects, future research should analyze homogeneous samples regarding basic cognitive abilities, subjective organization, or training responding (see Martin et al., 2012). Does episodic memory still differ between individuals if persons of similar basic cognitive abilities and subjective organization are compared to each other? Is there still an effect of different learning schedules or different strategy use?¹⁸ Note that a statistical control for any influential variable of learning and forgetting may offer an alternative approach to the use of homogenous samples that investigates the relations described above. Regardless of the chosen analytical approach – may this be the use of homogeneous samples or statistical control of variables on learning and forgetting – the evaluation of the interaction between individual differences in basic cognitive abilities and learning schedules is promising regarding possible interventions for persons in old age. If it was known which characteristics of a person best match with what kind of learning, individualized interventions that may facilitate learning and minimize forgetting in old age may be practicable.

¹⁸ Note that it might also be worth matching functional age (Wohlwill, 1970) rather than chronological age in order to examine mechanisms of episodic memory and possible memory enhancers for persons in old age.

3.4 Conclusion

Nesselroade (2010) argued that the individual is the critical unit of modern analysis of scientific psychology. In line with this statement, Hofer and Sliwinski (2001) argued that possible mechanisms of cognitive aging should be analyzed at the individual level. Regarding episodic memory in old age and predictors therein, the present thesis extended existing research by indicating 1) that there are pronounced individual differences in learning and forgetting in old age across different kinds of learning and forgetting, and 2) that basic cognitive abilities and subjective organization predict these individual differences. Cross-sectional findings suggesting that these relations are relevant from a cognitive aging perspective were thus extended. Note that cross-sectional studies should not be questioned completely. They focus on different research questions by analyzing the average age regarding a developmental phenomenon (cf. Kraemer, Yesavage, Taylor, & Kupfer, 2000). However, if the aim is to analyze mechanisms of cognitive aging regarding cognitive processes such as learning and forgetting, an individual-differences perspective is essential, which is not reflected in cross-sectional study designs.

Implications of the present results primarily involve investigating further relations of episodic memory and both cognitive characteristics of the individual and the related process of learning, for example, memory strategy use. If these mechanisms become clearer, individualized learning programs that aim at enhancing episodic memory of older persons who differ regarding their current episodic memory could be developed.

In line with a life-span perspective, one extension of the present thesis is to analyze the relations found in this thesis longitudinally. Are changes in basic cognitive abilities and subjective organization related to changes in episodic memory in older age? Whereas this question remains open at present, results of the thesis clearly demonstrated that aging is a highly individual process. The present thesis suggested one analytical approach that takes individual aging into account and thereby offers the possibility to analyze directly the role of

individual-differences variables for episodic memory in old age that is reflected in both processes of episodic memory: learning and forgetting.

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ZUSAMMENFASSUNG

Das übergeordnete Ziel der vorliegenden Dissertation war, Prädiktoren für individuelle Unterschiede im Lernen und Vergessen älterer Personen zu analysieren. Auf Grundlage theoretischer Ansätze und empirischer Befunde wurde die prädiktive Rolle von basalen kognitiven Fähigkeiten und dem subjektiven Organisationsgrad für individuelle Unterschiede im Lernen und Vergessen älterer Personen untersucht. Sowohl basale kognitive Fähigkeiten als auch der subjektive Organisationsgrad haben sich in Querschnittstudien als erklärende Variablen für Unterschiede im episodischen Gedächtnis verschiedener Altersgruppen erwiesen. Eine Einschränkung von diesen Querschnittstudien ist jedoch, dass individuelle Unterschiede innerhalb einer Altersgruppe vernachlässigt worden sind. Zusammenhänge von basalen kognitiven Fähigkeiten, dem subjektiven Organisationsgrad und dem episodischen Gedächtnis innerhalb von Individuen wurden in diesen Studien nicht erfasst. Mit dem Ziel, Mechanismen *individueller* kognitiven Alterns zu analysieren und den empirischen Forschungsstand diesbezüglich zu erweitern, untersuchte die vorliegende Dissertation die Fragestellung, ob basale kognitive Fähigkeiten und der subjektive Organisationsgrad individuelle Unterschiede im Lernen und Vergessen älterer Personen erklären können. Dieses analytische Vorgehen entspricht dem Argument einer Perspektive individuellen kognitiven Alterns: Mögliche erklärende Variablen kognitiven Alterns sind dann als relevante Variablen zu betrachten, wenn diese individuelle Unterschiede von Personen gleichen Alters erklären können. Vor diesem theoretischen und empirischen Hintergrund wurden in der vorliegenden Dissertation vier Studien präsentiert. Bei Berücksichtigung von bekannten, robusten Design-Variablen, die Lernen und Vergessen beeinflussen, konzeptualisierten die vier Studien Lernen und Vergessen mit unterschiedlichen Designs. Studie 1, Studie 2 und Studie 3 thematisierten individuelle Unterschiede im Lernen älterer Personen. Studie 1 analysierte Lernen im Rahmen einer *fixed-trial free-recall* Lernaufgabe. Studie 2 untersuchte das Erlernen von Aufgabenanforderungen einer Paar-Assoziationsaufgabe. In Studie 3 wurde kriteriums-

basiertes Dropoutlernen analysiert. Außerdem wurde in Studie 3 die Rolle von individuellen Unterschieden in dieser Art von Lernen für individuelle Unterschiede in der Erinnerungsleistung nach einem kurzen Behaltensintervall analysiert. Studie 4 analysierte individuelle Unterschiede im Vergessen von verbalem Material, das in einer *fixed-trial free-recall* Lernaufgabe erlernt wurde. Insgesamt zeigen die Ergebnisse der vier Studien, dass individuelle Unterschiede im Lernen und Vergessen älterer Personen vorhanden sind und dass es sich dabei um bedeutsame Unterschiede handelt. Des Weiteren erwiesen sich basale kognitive Fähigkeiten und der subjektive Organisationsgrad als relevante Prädiktoren für diese individuellen Unterschiede. Diese Ergebnisse zeigen sich konform mit theoretischen Ansätzen, die vorhersagen, dass das episodische Gedächtnis durch die oben genannten Variablen positiv beeinflusst wird. Aus einer Perspektive individuellen kognitiven Alterns können damit basale kognitive Fähigkeiten und der subjektive Organisationsgrad als relevante erklärende Variablen kognitiven Alterns für das episodische Gedächtnis angesehen werden. Diese Ergebnisse werden in Hinblick auf Grenzen der Studien sowie auf theoretische und praktische Implikationen an Hand von entwicklungspsychologischen Ansätzen der Lebensspanne diskutiert. Ein Fokus hierbei liegt auf der Entwicklung möglicher individueller kognitiver Interventionen, die darauf abzielen, das episodische Gedächtnis älterer Personen zu verbessern. Es werden außerdem Ideen für zukünftige Forschungsarbeiten diskutiert, die wie die vorliegende Dissertation das Ziel haben, Mechanismen *individuellen* kognitiven Alterns zu analysieren und dadurch die Möglichkeit zu eröffnen, Prozesse des episodischen Gedächtnisses älterer Personen zu optimieren.

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