Individual differences in criterion-based dropout learning in old age: the role of processing speed and verbal knowledge

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Published online: 10 October 2013
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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 multilevel 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 six 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.

Keywords Individual differences · Dropout schedule · Processing speed · Verbal knowledge · Paired associate learning · Multi-level

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 and Roediger 2008; Pyc and 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 and Rast 2009; Zimprich et al. 2008), is characterized by a constant number of study–test cycles (cf. Pyc and 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 and Zimprich 2009; Zimprich et al. 2008).

Responsible Editor: H.-W. Wahl.

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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 and 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 and Katsaiti 1988). Due to repeated encoding and repeated retrieval, memory performance regarding these overlearned items is assumed to be better (cf. Karpicke and Roediger 2008). Indeed, according to a meta-analysis conducted by Driskell et al. (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 and Roediger 2008; Kyllonen and 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 and 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 and 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 and

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 and 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 canceling 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 for 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 and 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 second 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; Võ 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 non-words, which were similarly spelled or similarly sounding, were presented on the computer screen. Participants were asked to select the word from the non-words 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 min 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 s. 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. Afterward, participants were required to work on a Number Backward task (similar to that of the WAIS-R; Tewes 1991) for 3 min. 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 backward 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 Backward 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 afterward, 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 1 shows descriptive statistics of the variables used in the present study. As can be seen from Table 1, 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.

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 Fig. 1), 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 ($F = 4.82$, $df = 4, 46$, $p < 0.01$). The Mauchly’s Test of Sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(9) = 10.85$, $p = 0.28$. 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 Fig. 1 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.¹ 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 Fig. 2, which depicts the cumulative number of successfully recalled words across study–test cycles for every participant. As Fig. 2 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.

Multilevel models

Growth curve model

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

Table 1 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

$N = 47$

¹ 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 (>0.90).

² 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.

Fig. 1 Mean number of trials needed per word list and correlations between numbers of trials needed for adjacent word lists

Fig. 2 Observed cumulative number of successfully recalled target words across trials (study–test cycles)

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 2 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 ($r = 0.55$) 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 nonlinear 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 not only 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 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 Fig. 3).

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 toward 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.

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 2 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

Table 2 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*
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

 $N = 47$ * $p < 0.05$ (two-tailed) **Fig. 3** Predicted cumulative number of successfully recalled target words across trials (study–test cycles) based on Model 2

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 2, 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 toward 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 et al. 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 and Rast 2009; Zimprich et al. 2008). 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 et al. 2002). The CV for initial level was 0.61, for speed of learning 0.38, and for quadratic growth 0.32. 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, versus the slowest learner, who needed 25 study–test cycles.³ 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 toward 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 and 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 et al. 2013). The finding of the present study 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 toward 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 10 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

³ A previous study on verbal learning found a CV of 0.64 for individual differences in rate of learning (Zimprich et al. 2008). 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.

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 and 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 et al. 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 benefited 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 and 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 and Kurtz 2013), forgetting may refer to the absence of adequate retrieval cues (Tulving and 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 and Zimprich 2010; Zimprich et al. 2008), 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 and 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 and Roediger 2008; Pyc and Rawson 2011). Note that these studies, including the present one, all differ regarding the precise learning conditions, e.g., list length, degree of support during recall tests. Future studies, which compare a fixed-trial versus 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.

Acknowledgments Parts of the preparation of this article were supported by the Swiss National Science Foundation, Grants SNSF-100013-103525 and SNSF-100014-122613/1.

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