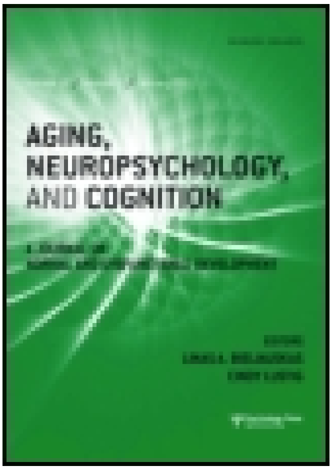

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Verbal learning across the lifespan: an analysis of the components of the learning curve

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ABSTRACT

Previous studies on the acquisition process of verbal material, conducted separately on child and adult populations, reveal that the lifespan is characterized by an inverted-U performance curve with similar achievements at its two poles. To clarify the acquisition mechanism across the entire lifespan, the learning curve for the Rey Auditory Verbal Learning Test was reproduced for participants aged 8–91. The study utilized typical trial summary scores and a more refined analysis of trial-by-trial single-word recalls, including omissions (missed words that were previously recalled), additions (recalled words previously missed), and touched words (a count for the first recall time only, for each word during the five learning trial). A clear age effect was shown for the number of words recalled – symmetrically increases during childhood and decreases in adulthood. Similarly, increased turnover of words omitted and added characterized both incremental and decremental age differences. Measurement patterns differed for the age segments on the two sides of the lifespan, despite the similar total number of words recalled by the two sides. Acquisition pattern in children was characterized by a higher number of touched words and higher turnover than for adult groups. In contrast, older adults achieved fewer touched words and lower turnover than the child groups. This study shows that it is possible to reach the same quantitative results via different cognitive processes. The results are interpreted in terms of specific mechanisms of maturational characteristics.

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Verbal memory; learning curve; Rey AVLT; lifespan

Developmental progress in childhood and performance decrement in ageing adults is well documented in a variety of cognitive domains. Child memory development is assumed to involve parallel maturation of different components including global abilities (i.e., processing speed, working memory, and executive functioning) and specific processes (i.e., language, visual analysis, and facial perception) (Kail, 2004). On the other hand, across the adult lifespan, multiple factors contribute to cognitive deterioration (relating to sensory functioning, mental operation speed, working memory, inhibition

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ability, and processing resources) (Craik & Rose, 2012) and involve compensatory mechanisms and reorganization in processing networks (Reuter-Lorenz & Park, 2014)

Similar to studies of other cognitive domains, verbal learning studies have revealed developmental changes in childhood and adulthood that indicate an inverted-U performance curve over the lifespan. Performance of normative age groups generally improved as a result of trials repetition in learning tasks, and age-related differences in performance persisted across trials; peak performance occurred in the young-adult age groups while poorer performance was shown for younger children (Vakil, Blachstein, & Sheinman, 1998) and older adults (Vakil & Blachstein, 1997). However, in addition to the inverted U-shaped performance curve, it has been suggested that the limitations reflected in the poorer performance displayed by children and the elderly do not mirror one another but, instead, represent different processes and difficulties. Recent studies have shown specific functional differences between the two lower-performing age segments in different tasks (Craik & Bialystok, 2006, for a review). Moreover, there are indications of different mechanisms underlying episodic memory in development and senescence as a result of the combination of differential functioning conditions of the hippocampal structures in their interactions with prefrontal structures (Shing, Werkle-Bergner, Li, & Linderberger, 2008).

Evaluation of verbal learning ability generally involves recording the number of words recalled for each learning trial and generating a learning curve across trials. In multi-trial word-recall tasks that are based on the traditional total number of recalled words per trial, the observed performance profile reflects a change in the total achievements (i.e., a pattern of increase, peak, and decrease) across the life-span. In addition, there are different results for acquisition rates across trials for different age groups. Child populations show greater improvement in performance as age increases (Forrester & Geffen, 1991; Vakil et al., 1998), whereas adult populations show a tendency towards decreased rates as age increases (Bolla-Wilson & Bleecker, 1986; Geffen, Moar, O'Hanlon, Clark, & Geffen, 1990; Mitrushina, Satz, Chervinsky, & D' Elia, 1991; Query & Megran, 1983; Vakil & Blachstein, 1997; Wiens, McMinn, & Crossen, 1988). However, other studies have found similar learning rates in both young adults and elderly populations (Davis et al., 2003; Hultsch, 1974; Keitz & Gounard, 1976). In a recent study that investigated the relationship between subjective organization and verbal learning from childhood to late adulthood, the rate of word acquisition was invariant for all age groups and was lower for children and older adults (Davis et al., 2013).

We sought an analysis that could uncover different acquisition mechanisms across the lifespan that underlies the usual learning curve. Such a tool could help understand the heterogeneous findings related to age-related changes in verbal learning acquisition rates across the lifespan.

A series of recent studies that investigated individual differences in the learning curves for verbal learning and other acquisition tasks found that three elements of learning curves vary independently between individuals: initial performance, asymptote level, and growth rate of the curve. In a study on a positional learning task, age explained 24% of the total variance of the beginning trial but explained only 7% of the asymptotic performance. The element least sensitive to age was the learning rate (Rast & Zimprich, 2010). The issue of the learning rate may be clarified differently by breaking it down into sub-components and focusing on the acquisition process (at the single-word level).

Studies that involve a fine-grained analysis of the learning curve allow the associative and strategic aspects of the consolidation process to be tracked and can characterize the acquisition process. These studies maintain records of the acquisition course of each word on a learned list for each trial (Blachstein, Vakil, & Hoofien, 1993; Davis et al., 2003; Dunlosky & Salthouse, 1996; Tulving, 1964). For each trial, this type of analysis quantifies the single-word recalls and omitted recalls in relation to the words recalled in previous trials. Recall of newly acquired words can be considered to primarily reflect an associative component. In comparison, words that are omitted after having previously been acquired have presumably not been completely stored, or an unsuccessful acquisition strategy was employed to store them. This analysis was used to study patients with closed head injuries (CHI) (Blachstein et al., 1993) and to characterize the pathological acquisition curve displayed by patients with Alzheimer's disease (Woodard, Dunlosky, & Salthouse, 1999). These two studies utilized the additions and gained access measures, respectively, to assess newly recalled words that were not retrieved in previous trials and to assess omissions and loss of access, respectively, to track missed words that were recalled in previous trials.

Gained access represents encoding effectiveness, that is, the degree to which an item is represented in memory during a particular trial (Davis et al., 2003; Woodard et al., 1999). Loss of access, on the other hand, involves an inter-trial consolidation deficit or incomplete storage that leads information to be rapidly forgotten between trials. One study also found that, for delayed trials, lost access was related to forgetting information after acquisition (Davis et al., 2003). A study on ageing used a learning task consisting of lists of related and unrelated words and showed that inter-trial forgetfulness (as reflected by the omissions measure) was associated with an organizational process for related words (Sauzeon, Claverie, & N'Kaoua, 2006). Furthermore, this study and two other studies on verbal memory in normative ageing that used the Rey Auditory Verbal Learning Test (AVLT) and a similar components analysis found that these two measures were distinct and independent (Davis et al., 2003; Dunlosky & Salthouse, 1996). These studies confirmed that the loss of access and gained access measures represent two different and important age-sensitive indices of the learning curve.

The alternation of omitted words and new and old added words generates a pattern referred to as word turnover. During the gradual acquisition process across trials, word turnover may produce a different balance of addition/omission patterns in the learning curve. The different patterns can produce different or similar learning curves (i.e., fewer additions or more omissions can produce an identical decrease in acquisition). In addition, learning curves can vary in the amount of turnover due to total recalls and missed recalls (in case of multiples of the addition/omission ratio). Thus, learning curves can vary in either a single aspect or in both the balance pattern and turnover rates. In our previous study on CHI patients, an overall recall deficit among patients was caused by a particular difference in word turnover, which was the result of a normative amount of additions and more cumulative omissions compared with normal controls (Blachstein et al., 1993). The pattern of these measures throughout the acquisition process can help to empirically reproduce a specific mechanism related to encoding and forgetting processes. For example, more additions would represent better functioning of associative processes, more omissions would represent poorer consolidation, and more turnover patterns would represent less-efficient strategies.

Following the dual-process model, lifespan studies on episodic verbal memory (Shing et al., 2010) have indicated that associative and strategic components and their interactions have an essential function. These associative and strategic components are hypothesized to be based on the activation of the medial temporal lobe and the prefrontal cortex, respectively. According to this framework, lifespan asymmetry in mnemonic performance would be the result of relatively rapid maturation in the medial temporal lobe during early childhood, whereas the prefrontal cortex does not reach maturity until late adolescence, in contrast to the age-related degenerative processes in both structures. Accordingly childhood episodic memory difficulties are associated mainly with immature strategic functioning, whereas the difficulties of adults are related to both strategic and associative components.

In the present study, the developmental courses of acquisition that occur in adults and children are compared within the same framework in order to identify similarities and differences between the maturation and senescence stages and to understand the changes that occur in these two conditions. Previous studies have applied component analysis with these measures for adults, but not for children. The pattern that emerges for the different age segments can contribute to elucidating a verbal acquisition mechanism. In addition, a refined analysis of the learning curve can further clarify the inconsistencies in learning-rate changes based on the summary measures. Thus, based on the results obtained by analyzing the learning curve using global measures (i.e., total number of words recalled for each trial) in the studies by Rast and Zimprich (2010) and Davis et al. (2013), we expect that adults will maintain a similar learning curve though recall abilities will decline with age. Comparisons between the child-development and adult segments for the two indices (i.e., starting point and maximum words reached) are expected to yield an inverted U-shaped function. Furthermore, according to the dual-process model (Shing et al., 2008), we expect that children's performance will be characterized by a combination of the relatively rapid maturation of associative binding functions. At an early age, children are expected to reach the same performance level for the additions as young adults, though they will fail to utilize a mature strategy. As a result, children have difficulty sustaining trace strength and maintaining consistent recall of words because of the lack of fully developed frontal regions and their respective networks and are, therefore, expected to show a higher level of turnover than young adults, with more omissions and more additions. A different mechanism displayed by older adults that is based on decreased function of both the hippocampal and frontal regions should result in a deficit in associative binding and in less effective but experience-based strategy application. Accordingly, it is expected that the number of words added, particularly words added for the first time (the total number of "touched words", i.e., recalled at least once), will decrease with age. It is also expected that the less-effective strategy will be manifested as a higher turnover of words, meaning that the number of words omitted and words added after being omitted would be the same for older adults as it is for young children, but different patterns among the segments would emerge. This phenomenon reflects a different strategy-utilization deficit, typical among older adults as a result of adjustment to and compensation for structural deterioration, which results in more cautious patterns.

Furthermore, correlation analysis can help confirm the distinction between omissions and additions as indicated in previous studies. The first measure is supposed to reflect consolidation failure (forgetfulness), whereas the second is supposed to measure encoding effectiveness. Accordingly, omissions are expected to be inversely related to other measures that represent success in consolidation such as primacy recall (first words in a list), post learning (Trial 7), and delayed recall (Trial 8). In contrast, additions are expected to positively relate to other measures that can be considered more sensitive to encoding factors, such as the recency effect (last words in a list) and new-list recall (Trial 6). Finally, each of the two component measures relate exclusively to the encoding or consolidation measures, or, at least, are less related to those measures expected to relate to the other component.

Methods

The data analyzed in the present study are the normative Rey-AVLT data for children and adults, published by Vakil et al. (1998), Vakil, Blachstein, Sheinman, and Greenstein (2008) and Vakil and Blachstein (1997), which are merged in this study for part of the analyses.

Participants

The children's data were collected from a sample of 943 children (487 boys and 456 girls). The age range of the sample population was from 8 to 17 years. The children's sample was recruited from 14 public schools in central Israel (i.e., the greater Tel Aviv area). Children diagnosed with learning disabilities or attention disorders or those requiring special assistance in school were excluded. Furthermore, teachers were asked not to refer children with exceptionally high or low academic achievements. All children were tested within a range of 3 months before or after their birthdays. An additional 124 children (63 boys and 61 girls) in identical age groups from different parts of the country were tested on a voluntary basis; these children met the identical selection criteria. Based on a preliminary analysis and because this group did not differ from the rest of the sample in any parameters, the two samples were merged. Hebrew was the native language spoken by all the children in the sample.

The adult data were collected from a sample of 528 participants (257 men and 271 women). The age range of the sample population was 21 to 91 years. All adult participants had lived in Israel for at least 10 years (most of them much longer) and spoke Hebrew fluently. The younger participants were volunteers who responded to advertisements placed at Bar Ilan University (Israel) and other public places. The older participants were recruited from students attending a special series for the elderly offered at Bar Ilan University or from several senior citizen community centers. The latter were referred by social workers who judged the participants to be active, independent, cooperative, and communicative. When tested, all of the elderly participants were alert and oriented to time and place. Based on the social workers' reports, participants with a history of learning disabilities, alcohol or drug abuse, or with neurological or psychiatric illness were excluded.

Table 1. Characteristics of the age groups.

Age range	Males/Females	Mean years of education
8–10	158/152	2.85
11–14	184/179	6.23
15–17	145/125	9.76
20–29	72/66	13.78
30–49	66/62	13.63
50–59	34/37	13.01
60–69	47/63	12.46
70–91	38/43	12.51

The age cohorts in the present study were determined by two considerations. The first was the intent to capture the increase and decrease in the learning rate for children and adults, respectively. The second was the intent to determine comparable age segments with similar performance in the children and adult samples. Thus, the cut-off points in the age groups were chosen to capture performance differences. This approach was based on preliminary analyses of the data identifying the age ranges for children and adults in which performance was more stable and the age ranges in which significant differences were observed.

According to these considerations, the children's sample was divided into three age cohorts, and the adults' sample was divided into five age cohorts. The demographic characteristics of the two samples are presented in Table 1.

A significant difference was found between the age groups for the mean years of education ($F[4, 527] = 4.88$, $P < .001$). A follow-up analysis using the Duncan procedure indicated that the two younger groups differed from the two older groups. A large proportion of the Israeli population arrived in the country as immigrants. Many of the older adults immigrated as children, and they had to interrupt their studies and go to work. Thus, for the older groups, formal education did not represent their potential education. The preliminary analysis revealed that the two adult groups (ages 30–49 and 50–59) did not differ in the various scores of learning. Therefore, these groups were combined for the following analyses.

Tests and procedure

The children were tested individually in a room allocated for this purpose in their own schools during school hours and participated voluntarily in the study. They were told that they could stop at any time they wished. This occurred with only a few children, who claimed that they were tired. The examiners in this project were 14 undergraduate psychology majors at Bar-Ilan University, who were trained to administer and score the tests. The adults were tested individually, partly in their senior citizens' home in a room allocated for this purpose and partly in the university. The adults participated voluntarily in the study and were told that they could stop at any time that they wished.

The Rey-AVLT: The Hebrew version of the Rey-AVLT was used (Vakil et al., 1998). Administration was standard, as described by Lezak, Howieson, and Loring (2004). This test measures immediate and delayed recall, cumulative learning, learning rate, recognition, proactive and retroactive interference, primacy and recency effects, and recall of temporal order. It consists of 15 common nouns, which were read to the participants at the rate of one word per second in five consecutive trials (trials 1 through 5). Each reading was followed by a free-recall task. In Trial 6, an interference list of 15 new common nouns was presented, followed by free recall of these new nouns. In Trial 7, without an additional reading, the participants were again asked to recall the first list. Twenty minutes later, and without an additional reading, the participants were again asked to recall the first list (Trial 8). In Trial 9, the participants were given a list of 50 words (15 from the first list, 15 from the second list, and 20 new common nouns) and were asked to identify the 15 first-list words.

In a previous study (Blachstein et al., 1993), we reported on two measures extracted from the learning trials: *omissions* and *additions*. *Omissions* refers to the number of words not recalled (omitted) in a trial in relation to the recalled words in the previous trial. *Additions* refers to the number of words recalled on a trial that were not recalled in the previous trial. For example, if the third word of the list was recalled on the first trial, not recalled on the second and third trials, and then recalled on the fourth trial, it was counted as one omission on the second trial, not counted on the third trial, and counted as an addition on the fourth trial. Unlike the previous study (Blachstein et al., 1993), in the present study, these two measures were computed for each trial in relation to the previous trial. In the previous study, the measures were computed in relation to all previous trials. Thus, in the previous example, an omission was also counted for the third trial in the previous study. Thus, for the present measurements, for each trial (except for the first trial), the number of words recalled in a particular trial was the arithmetical sum of the words recalled in the previous trial plus the additions and omissions. An additional measure, *words touched*, was also computed. This measure referred to the number of the words ever recalled, as counted when a word was recalled for the first time for each trial. In the previous example, the third word on the list was counted as a touched word in the first trial, and not counted in the fourth trial. Each recalled word was counted as "touched" only when recalled for the first time across the learning trials (ranging from 0 to 15). This measure enabled us to track the number of words from the list that the person had actually reached at each trial. Extracting this measure from the additions offers a clearer representation of the associative component because additions are also part of a strategic pattern of turnover interchanges with omissions.

For the follow-up, the data for children and the adults were analyzed separately because of the reverse trajectory of change in the two groups. Though performance improves with age among children, it deteriorates with age in adults, with expected differential changes of the components. The younger adults' group data were used as a reference group representing the common optimal-performance age for the follow-up analyses of both data samples.

Results

To track differences in the verbal learning process as a function of age, several measures of learning were analyzed: the learning rate, as reflected in the number of words recalled in each trial, and the three additional learning measures (i.e., additions, omissions, and touched words). These measures were analyzed for the entire lifespan (i.e., for the child and adult samples). To exclude a possible false advantage of the omission and addition scores for the participants who recalled more words, we also computed two proportional scores relative to the number of words recalled in a particular trial (e.g., in addition to the omissions score for Trial 2, we computed a proportional score: omissions on Trial 2/number of words recalled on Trial 2). Second, a direct comparison was made between specific age groups in the two samples. Lastly, to confirm the difference between the omission and addition measures, correlation analyses were conducted separately for the child and adult samples between the component measures with different list segments: recall (primacy recall, recency recall), new-list recall (Trial 6), and post-acquisition recalls (Trial 7 and delayed Trial 8).

Lifespan comparisons

Four separate mixed analyses of variance ANOVAs were conducted for each of the learning measures: number of words recalled (five levels), words omitted, words added, and words touched (four levels). In all four analyses, the age group was analyzed (seven age cohorts: 8–10, 11–14, 15–17, 20–29, 30–59, 60–69, and 70+ years). The first four measures are within-subjects factors, and age is a between-subjects factor. *Post hoc* analyses for age were conducted using trend analyses for polynomial contrasts followed by the Duncan procedure. To identify the source for trial by age-significant interactions, simple analyses were conducted as a follow-up. In this follow-up, learning (5 for the words recalled, 4 for the component measures) was compared for each pair of age groups two at a time, yielding a total of six 5/4 × 2 mixed ANOVAs for each sample. The acceptable *P*-value was set at $P < .001$, and the effect size was $\eta^2 = .01$. To confirm the results obtained for the number of omission and addition scores, identical analyses were repeated for the two proportional measures and are reported when the results differ from the number of item scores. The learning curves for the number of words recalled are presented in Figure 1a and b.

Words recalled

As Figure 1a shows, the number of words recalled increased from trial to trial ($F[4, 5856] = 3376.14$, $P < .001$, $\eta^2 = .698$) and differed with age ($F[6, 1464] = 76.17$, $P < .001$, $\eta^2 = .24$). The significant learning-by-age interaction implies that the learning rate differs as a function of the age group ($F[24, 5856] = 2.94$, $P < .001$, $\eta^2 = .014$).

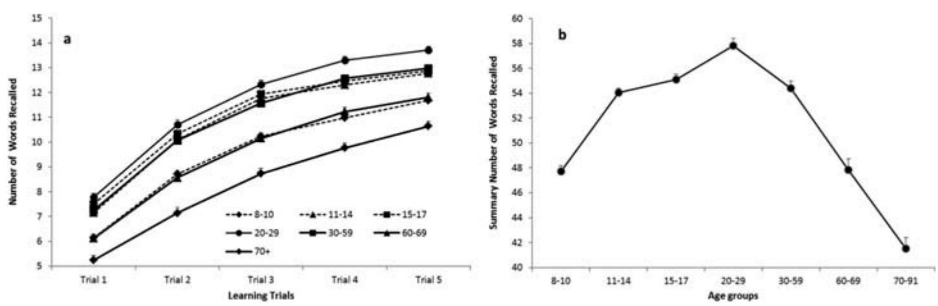

Figure 1. (a) Mean and *SD* of number of words recalled as a function of learning trials across age groups. (b) Mean and *SD* of summary of words recalled as a function of age groups.

The follow-up indicated that the learning rate of the 8- to 10-year-old age group was slower than that of the 11- to 14-year-old age group ($F[4, 2684] = 3.95$, $P < .01$, $\eta^2 = .01$ for the interaction). The 11- to 14-year-old age group and the 15- to 17-year-old age group did not differ, but the first group showed a tendency towards slower learning, and the second group learned more slowly than the young adult reference group ($F[4, 1996] = 2.64$, $P < .05$, $\eta^2 = .01$; $F[4, 1624] = 4.43$, $P < .001$, $\eta^2 = .01$ for the interactions, respectively). In the adult sample, the only difference was a steeper learning rate for the 20- to 29-year-old reference group and the 30- to 59-year-old age group compared with the 70+ age group ($F[4, 868] = 7.24$, $P < .001$, $\eta^2 = .032$; $F[4, 1112] = 5.55$, $P < .001$, $\eta^2 = .02$ for the interactions, respectively). All other interactions were not significant.

A trend analysis across the age groups revealed that, overall, for the summary total learning (trials 1–5), the linear contrast was significant ($CE = -1.198$, $SE = .13$, $P < .001$). The quadratic contrast was also significant ($CE = -2.48$, $SE = .13$, $P < .001$) and better reflected the pattern for the main effect of age. As Figure 1b shows, the 20-year-old reference group achieved the highest number of words recalled; in contrast, the 30- to 59-year-old age group's recall was similar to that of the 11- to 17-year-old age group. Lower achievement was found in the 60- to 69-year-old age group, which was at the same level as the 8- to 10-year-old age group. In contrast with all the other age groups, the lowest achievement was attained by the 70 years and older group.

The age groups were, furthermore, compared with respect to their initial trial performance. A one-way procedure followed by the Duncan procedure conducted on the first trial scores (for each sample) indicated that the number of words recalled increased between 8–10 years and 11–14 years of age. Between 15 and 29 years of age, the participants achieved a similar number of words in the first trial; however, there was a significant and constant decrease in performance between the reference group and the oldest participants in each subsequent age group.

In addition to the learning curve, differences across children development and despite the similarity of the learning curves across the adult age groups (with the exception of a flatter acquisition rate for the oldest age group), the results revealed a different pattern for the three component measures across age groups. The numbers of words omitted, words added, and words touched are presented in Figure 2a–c for the children and in Figure 2d–f for the adults.

Words omitted

The number of words omitted decreased overall across trials though the effect did not met the effect size criterion ($F[3, 4392] = 5.81$, $P < .001$, $\eta^2 = .004$). The main effect for age was significant ($F[6, 1464] = 30.59$, $P < .001$, $\eta^2 = .11$), and the interaction was marginally significant ($F[18, 4392] = 1.59$, $P = .053$, $\eta^2 = .01$). Follow-up indicated that while the number of omitted words among the children decreased overall across trials ($F[3, 3231] = 14.66$, $P < .001$, $\eta^2 = .01$), the adults showed a stable number of omitted words across trials ($F[3, 1572] = 1.01$, $P > .05$).

The quadratic contrasts for age was the representative one ($CE = .61$, $SE = .058$, $P > .001$), with children and older adults showing the highest average levels of omissions (see Figure 3a). As Figure 3a shows, a higher number of omissions was shown for both the 8- to 10-year-old age group and the 70+ age group, which showed a similar number of omissions; these findings differed from those of the 11- to 17-year-old age group and

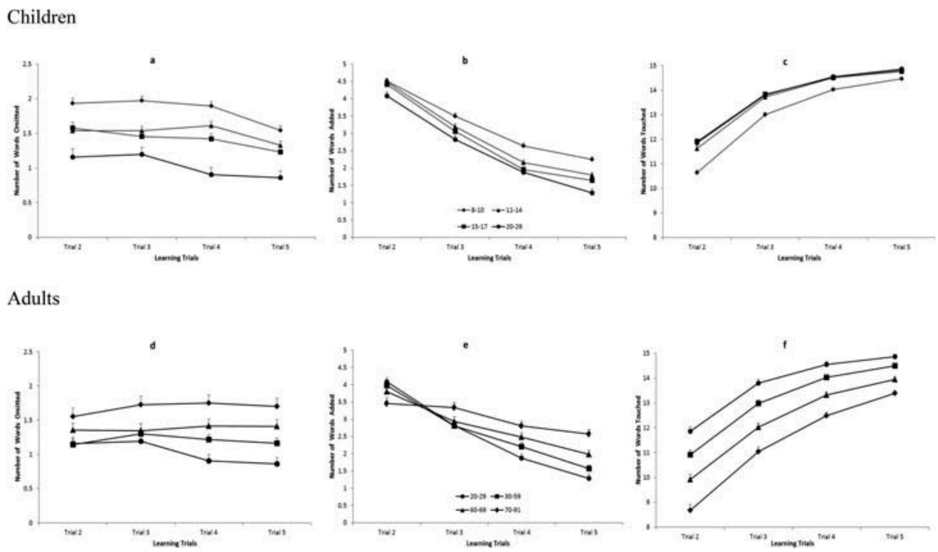

Figure 2. Mean and *SD* of (a and d) number of words omitted, (b and e) number of words added, and (c and f) number of words touched as a function of learning trials across age groups.

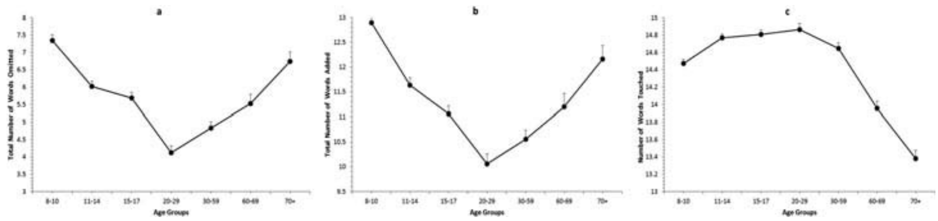

Figure 3. Mean and *SD* of (a) total number of words omitted, (b) words added, and (c) words touched as a function of age groups.

the 60- to 69-year-old age group, which showed a similar number of omissions and differed from the younger adult age groups, which showed the lowest number of omissions. All of the adult groups differed from one another: the older the age group was, the higher the number of omissions was.

The same analysis was conducted for the number of omissions for each trial relative to the words recalled on that trial. Identical results were obtained, except that, among the young adults, the decrease in omissions began one trial earlier than the children's decrease (i.e., on the third trial).

Words added

The number of words added decreased overall across the trials ($F[3, 4392] = 561.17$, $P < .001$, $\eta^2 = .28$). The main effect of age was significant ($F[6, 1464] = 25.67$, $P < .001$, $\eta^2 = .095$), and the age group by trials interaction ($F[18, 4392] = 6.43$, $P < .001$, $\eta^2 = .03$) suggests that the decreasing rate of word addition differs as a function of the age group. A follow-up analysis of the children was conducted to compare the words-added profile for each pair of age groups. A comparison of the 8- to 10-year-old group with the 11- to 14-year-old group showed a marginal interaction that indicated that the 8- to 10-year-old group's rate of word addition decreased more slowly and showed a prolonged course of added words across trials (F[3, 2013] = 3.51, $P < .05$, $\eta^2 = .01$; see Figure 2b). None of the other rate comparisons was significant. Among the adults, word addition showed the inverse of the age pattern that was observed among the children; with increasing age, the adults showed a more gradual decrease in additions from one trial to the next (F[9, 1572] = 7.44, $P < .001$, $\eta^2 = .04$; for the age-by-learning interaction, see Figure 2e).

The quadratic pattern best represented the main effect of age ($CE = .55$, $SE = .057$, $P < .001$), with children and older adults showing the lowest average levels of word additions (see Figure 3b). The highest number of words was added in the 8- to 10-year-old group; the 11- to 14-year-old group had a pattern similar to that of the 70+ age group, which had fewer additions than all of the younger adult groups. The 11- to 17-year-old group was similar to that of the 60- to 69-year-old group, which added fewer words than the younger adult groups. The analysis of the relative scores yielded results similar to the score for the number of additions, with the exception of a similar decrease across trials for all ages.

Words touched

As Figure 1d shows, *the number of words touched* increased across trials (F[3, 4392] = 3560.07, $P < .001$, $\eta^2 = .71$), and the age effect also reached significance (F[6, 1464] = 64.29, $P < .001$, $\eta^2 = .21$). However, this finding should be interpreted cautiously because of the significant interaction (F[19, 4392] = 15.38, $P < .001$, $\eta^2 = .06$). Follow-up analyses of the child groups revealed that, with increasing age, the starting point increased and the rate across trials decreased; this pattern stabilized at 15 years. The 8- to 10-year-old group's rate of words touched increased more rapidly than that of the 11- to 14-year-old group, which had a marginally higher rate of words touched than the 15- to 17-year-old group did. The words touched the rate for the 15- to 17-year-olds stabilized and was similar to that of the young adult reference group (F[3, 2013] = 19.21, $P < .001$, $\eta^2 = .03$; F[3, 1893] = 3.04, $P < .05$, $\eta^2 = .01$, F[3, 1218] = 0.31, $P > .05$, $\eta^2 = .001$ for the interactions, respectively). Among adults, the inverse pattern emerged; the older the age group was, the lower the starting point was and the steeper the increase in the words touched across trials was, as reflected by the interaction (F[9, 1572] = 13.21, $P < .001$, $\eta^2 = .07$; see Figure 2d).

The linear and quadratic contrasts for age were significant ($CE = -1.53$, $SE = .101$, $P < .001$; $CE = -1.55$, $SE = .101$, $P < .001$, respectively); however, the quadratic pattern did not represent the main effect of age better than the linear pattern, and older adults showed the lowest average levels of touched words (see Figure 3c). The highest number of touched words was observed among the 11- to 17-year-old and the 20- to 29-year-old groups. The 8- to 10-year-olds touched a smaller number of words compared with the older children, and adults aged 30 to 59 years and the adult age groups touched fewer words from one age group to the next.

In summary, when we considered the overall patterns of the different acquisition measures, verbal learning appeared to differ with age. The learning pattern gradually differed with age across the age groups. The young adult reference group differed in several aspects from the younger children and the older adults. Overall, the reference group acquired more words than the children and older adults did, they touched most of the new words in the first trials, they omitted a small and constant number of words across trials, and they showed a sharp decrease in added words across trials. In comparison, the children showed a surprisingly high number of words touched in relation to the summary words learned. However, for the younger children, these acquired words were mostly omitted and were frequently added after being omitted. This children's characteristic of a high turnover rate of words recalled and the high number of words touched gradually decreased with maturity.

The older group showed a different profile; they touched fewer new words and showed a distributed profile across the trials. Overall, they omitted more words and also added more words, but with a profile that continued to the final trials. Thus, the word turnover for adults gradually increased with age, but it was more evenly distributed among the trials. The next objective of this study was to further follow-up the two verbal acquisition profiles that characterize the groups at each end of the lifespan. These groups moved in opposite directions but achieved equivalent total learning scores across the learning sessions.

Follow-up with a direct comparison of the child and adult samples

These comparisons reveal whether the underlying learning mechanisms are necessarily the same in the child and adult samples. As Figure 1b shows, according to the summary total learning measure results, the 8- to 10-year-old age group's achievement was similar to the older adults' group (60–69 years), whereas the relatively better-achieving 11- to 17-year-old age group was on par with the 30- to 59-year-old age group of adults. The two pairs of age groups were first analyzed with respect to their traditional learning curves, followed by analyses of the three component measures.

Comparison of the 8- to 10-year-old group and the 60- to 69-year-old group

Words recalled

As Figure 1a and b show, a direct comparison of the learning curves for the words recalled yielded similar results for the 8- to 10-year-old group and the 60- to 69-year-old adult group. Apart from a significant trial increase in words recalled ($F[4, 1672] = 799.78$, $P < .001$, $\eta^2 = .66$), neither age nor the interaction results was significant. Notably, aside from the similar learning curves for the young children and the older adults, a different pattern for the three component measures was found.

Words omitted

For the *number of omissions* measure, the main effect for trial was not significant. In comparison with older adults, the young children omitted more words overall ($F[1, 418] = 30.15$, $P < .001$, $\eta^2 = .07$) and marginally differed in the trial omissions profile across trials. They showed a high number of omissions across the trials with a decrease in the last trials. By contrast, the older adults omitted a small and constant amount of words across trials ($F[3, 1254] = 2.65$, $P < .05$, $\eta^2 = .01$ for the interaction; see Figure 2a and d).

Words added

The number of additions decreased across trials (F[3, 1254] = 112.58, $P < .001$, $\eta^2 = .21$). Similar to the omissions results, young children also added more words across trials relative to older adults (F[1, 418] = 30.02, $P < .001$, $\eta^2 = .07$); however, the interaction did not reach significance (see Figure 2b and e).

Words touched

The *number of words touched* increased across trials (F[3, 1254] = 1158.86, $P < .001$, $\eta^2 = .74$). In comparison with older adults, younger children achieved more words across trials (F[1, 418] = 21.74, $P < .001$, $\eta^2 = .05$) with a marginal steeper rate (F[3, 1254] = 3.58, $P < .05$, $\eta^2 = .01$) for the interaction (see Figure 2c and f).

In summary, for young children and older adults, aside from a similar number of words in the learning curve, the patterns of the profiles of their component measures differed. Young children's word acquisition comprised more touched words, which were also acquired faster when compared to older adults. In comparison with the older adult group, young children's acquisition was also characterized by a higher turnover of words, as expressed by more omissions and more additions.

Comparison of the 11- to 17-year-old group and the 30- to 59-year-old group

The results of the learning process comparison for the 11- to 17-year-old older children and the 30- to 59-year-old middle-aged adults who achieved the same summary learning score (Figure 1b) are presented in Figure 2.

Words recalled

Figure 1a shows a pattern of two close learning curves with a significant trial increase in words recalled (F[4, 3320] = 1968.65, $P < .001$, $\eta^2 = .70$) and a similar number of words recalled overall for children and for adults. A comparison of these two age groups showed only a marginally significant interaction (F[4, 3320] = 3.46, $P < .01$, $\eta^2 = .01$) deriving from a difference in the point of maximal acquisition increase on the third trial for the children and the fourth trial for the adults, (i.e., F[1, 830] = 13.17, $P < .001$, $\eta^2 = .02$, for the interaction of the third and fourth trials). This light curve difference was further clarified by the analysis of the pattern shown for the three component measures.

Words omitted

As Figure 2a and d show, a tendency from one trial to the next, *to omit* fewer words (F[3, 2490] = 3.03, $P < .05$, $\eta^2 = .01$). The older children (similar to the younger children compared with the older adults) omitted more words than the middle-aged adults did (F[1, 830] = 22.16, $P < .001$, $\eta^2 = .03$); The interaction was not significant.

Words added

As Figure 2b and e show, the *number of additions* decreased across trials (F[3, 2490] = 425.41, $P < .001$, $\eta^2 = .34$). Overall, across trials, the older children added more words compared to the middle-aged adults (F[1, 830] = 13.83, $P < .001$, $\eta^2 = .02$), but with a different pattern. Though the children began with more additions in relation to the adults and a sharp decrease across trials, a smoother decrease was shown for the adults ($F[3, 2490] = 5.96$, $P < .001$, $\eta^2 = .01$ for the interaction).

Words touched

As Figure 2c and f show, as in the previous comparison of young children and older adults, *the number of words touched* increased across trials ($F[3, 2490] = 1658.48$, $P < .001$, $\eta^2 = .67$). Again, overall, the children touched more words than the adults did ($F[1, 830] = 20.00$, $P < .001$, $\eta^2 = .02$); both age groups showed a pattern of a decreasing number of new words from one trial to the next, but the children showed a more rapid decrease across trials compared with the adults ($F[3, 2490] = 7.98$, $P < .001$, $\eta^2 = .01$ for the interaction). The slower decrease in newly acquired words across trials for the adult group indicated a prolonged acquisition process distributed over more trials. In summary, as in the previous group comparison of children and adults, a similar number of words were found for the learning curve, but with a different pattern of the component measures. In the initial trials, older children not only touched more words but also omitted and added more words relative to middle-aged adults. In comparison, the middle-aged group of adults consistently omitted words (but less than the children) and distributed their acquisition of touched words across more trials.

Correlational analysis

To confirm the age differences found in the first trial's asymptote point, total learning (sum of the acquisition trials), and component measures, Pearson Product Moment correlations were computed for these measures with age across the two samples. Age was significantly positively related to each of the global measures among children (respectively, $r\,[941] = .30$, $r\,[941] = .29$, $r\,[941] = .37$, $P < .001$, for all), whereas a significantly inverse direction was found among adults ($r\,[526] = -.41$, $r\,[526] = -.54$, $r\,[526] = -.57$, $P < .001$ for all, respectively), which confirms continuous age differences in the opposite direction for these global measures.

The inter-correlation among the three measures across the lifespan reveals that the relationship between omissions and touched words was not significant. Though a strong relationship was shown between additions and omissions ($r\,[941] = .78$, $P < .001$, for the children's sample; $r\,[526] = .66$, $P < .001$, for the adults' sample), a significant but weaker relationship was found between additions and touched words ($r\,[941] = .39$, $P < .001$, for the children's sample; $r\,[526] = .59$, $P < .001$, for the adults' sample).

The strong correlations between additions and omissions are not surprising because they measure components of the same situation, and less consolidated words might involve a turnover of both omissions and additions. However, the two measures showed different profiles across trials in both children and adult samples.

Further indications of a distinction between these two measures was revealed by a tendency shown in the following patterns of correlations: one pattern relates to these measures in respect to primacy and recency words, and the second pattern relates to these measures in respect of the global measures for the new-list recall (Trial 6), post-acquisition recall (Trial 7), and delayed recall (Trial 8). Primacy and recency were computed (for the first three and last three words list, respectively), in the first acquisition trial. The Pearson Product Moment correlations for the

Table 2. Pearson product moment correlations of the component scores with age and global learning scores for the child and adult samples.

	Children (*N* = 941)		Adults (*N* = 528)	
	Omissions	Additions	Omissions	Additions
Primacy	−.18**	−.05	−.20**	.11*
Recency	−.01	.07*	.02	.10*
Age	−.23**	−.07*	.34**	−.07
New-L	-.20**	.03	−.26**	.13**
Post-L	−.47**	−.07*	−.47**	.13**
Delay	−.47**	−.04	−.41**	.19**

Notes: * = $P < .05$; ** = $P < .001$; Primacy = first words recall; Recency = last words recall; New L = number of new list words recalled (Trial 6); Post-L = number of Trial 7 words recalled; Delay = number of words recalled on the delayed trial (Trial 8).

component measures with age, primacy, recency, and the post-acquisition global measures are presented in Table 2.

As shown in Table 2, in general, with age, omissions decreased among children and increased among adults. When more words were recalled overall, fewer words were omitted. However, additions were less related to the global measures and to age. Primacy was inversely related to omissions, but was not related to additions and was positively related amongst adults. By contrast, recency was not related to omissions and was positively related to additions (see Table 2).

A further tendency for a different pattern of correlations between additions and omissions was shown for the correlations of the component measures with the three global post-acquisition measures. The correlations of the additions and omissions with the new list (Trial 6) were lower compared with post-acquisition recall (Trials 7 and 8); these results indicate a stronger relationship between the omissions and additions scores, on the one hand, and retention and forgetting, on the other, with respect to the relationship with the initial acquisition stage (see Table 2).

This inverse relationship, in favor of post-acquisition, delayed recalls, and primacy is in accordance with the previous studies suggesting the omission measure to be associated with consolidation deficit (Dunlosky & Salthouse, 1996) and forgetting, (Davis et al., 2003).

Discussion

The investigation of verbal learning across the lifespan, including childhood, showed the expected superior scores for the total number of words acquired by young adults, whereas children and older adults displayed the poorest performance. In addition, the entire pattern of the acquisition measures employed revealed differences in verbal learning across the lifespan and a gradual difference as both children and adults aged. Moreover, a particular pattern of the component measures emerged, even when the groups were paired for overall recall and learning rates, with differences characterizing the youngest and oldest age groups.

Comparing the data collected for children with that of the adults for the component measures revealed that both ends of the lifespan showed a characteristically high turnover rate of words across trials, consisting of *both* more additions and more omissions compared with the young adult reference group. The particular components pattern that distinguished the two samples is notable; the adult reference group touched most of the new words in the initial trials and omitted only a small and constant number of words across trials, and this group showed a steep decrease in added words. However, the child sample showed a surprisingly high number of touched words (results for the age-11 group was similar to the adult reference group) and the highest turnover of words omitted and added in the entire lifespan. In contrast, the older group showed a lower number of touched words than the adult reference group. They displayed an increase in additions and omissions alongside broader distribution of acquisition across trials that extended until the last trials. It is important to note that these differences in component patterns also appeared in a similar learning curve when comparing the 8- to 10-year-old group and the 60- to 69-year-old group.

Further evaluations of the touched words metric revealed a trend that distinguished the child sample from the adult sample based on the level and rate of acquisition across trials. By the third trial, the 11-year-old child sample had touched more than 90% of the words on the list, which is similar to the rate achieved by the young adults in the same trial (the younger children achieved 93% of the words by the fourth trial). On the other hand, adults just over 40 years of age did not touch 90% of the words on the list until the fourth trial, and adults aged 60–69 did so only on the fifth trial. The 70+ age group gradually touched 89% of the words by the last trials.

In the present study, the different patterns that emerged for acquisition components at the opposite ends of the lifespan are consistent with the dual-process framework of episodic memory introduced by lifespan studies (Shing et al., 2008). The components pattern differences associated with age represent a specific characterization of verbal learning during development and senescence, and represent an indication of different mechanisms employed for acquisition processes displayed by children and older adults. The finding that the additions and touched words measures increased rapidly in children, in accordance with the dual model, can be explained by the efficient associative function of a rapidly developed associative component and the results of a successful binding process, which has previously been found to increase with age among children in a visual working memory task (Cowan, Naveh-Benjamin, Kilb, & Saults, 2006). Accordingly, the difference between the 8–10 year group and the 11–15 year group, particularly for the number of touched words, implies development of associative processes during the transition to adolescence. Additions are also accompanied by a high number of omissions in childhood. This study found that the highest word turnover-rate throughout the lifespan occurred among children aged 8–11, which may reflect the use of an immature strategic component, as was also predicted by the dual model. Childhood associative efficiency is related to the support of the hippocampal-limbic system, which is supposed to automatically bind information for storage, whereas frontal lobe areas are used to process information strategically. Poor subjective organization was found to be one cause of childhood recall deficits in a study on subjective organization in verbal learning and has also been linked to poor recall in senescence (Davis et al., 2013). It should be noted that the hippocampal structures do not develop uniformly and, recently, evidence was found for different development rates for subfields related to verbal memory and delayed retention among adolescents (Tamnes et al., 2014). That study, however, assessed memory by measuring total scores for the CVLT learning trials, while the present study decomposed the acquisition process *across* trials.

Unlike the children's pattern of acquisition, older individuals were characterized by the lowest rates of touched words throughout the lifespan and a high addition/omission turnover (compared to the adult reference group). This finding may be the result of an associative deficit of decreased binding ability (Naveh-Benjamin, 2000) and less-effective strategy application. It is also consistent with the dual-process model (Shing et al., 2008), which describes an expected decrease in function of both the associative and strategic components of the model. Associative memory is also believed to rely on self-initiated memory searches (Craik, 2002). Because the recall task used in this study required memorizing a list of unrelated common words, the strategic support requested is even more incisive. This suggestion may explain the higher number of omissions. Davis et al.'s (2013) findings offer further evidence of a strategic deficit in older adults by linking poor subjective organization to poor recall in senescence. However, the higher word-turnover rates across trials in older adult groups compared to the adult reference group represents a lower but more gradual (i.e., more evenly distributed across trials) acquisition process during ageing. The particular pattern profile of distribution of touched words and additions across trials can also be interpreted with an explanation of a biased nature: older adults may have a more conscientious approach to acquisition. In two lifespan studies, a biased explanation was suggested for older adult performance. A cautious bias characterized the visual search of older adults (Hommel, Li, & Li, 2004), and cautious judgment bias displayed by older adults was shown in a visual working-memory task performance (Cowan et al., 2006). The approaches to acquisition taken by older adults can also be interpreted as a cautious strategy that involves focusing on particular items, and may be an expression of a type of wisdom or reflection of expertise accumulated throughout the lifetime that applies a specific pattern of action when coping with a task (prospective memory) (Goldberg, 2005).

Furthermore, distribution is compatible with compensative cerebral functioning, as indicated in older adult populations (Cabeza, Anderson, Locantore, & McIntosh, 2002; Mattay et al., 2006; for compensative reorganization relative to the prefrontal cortex). This suggestion was identified by Craik and Bialystok (2006) as an adaptive function that is related to the neural degradation found in older adults.

Steeper learning-rates in children as they grow older are consistent with certain previous studies (Forrester & Geffen, 1991), but are not consistent with Davis et al. (2013). The number of words achieved by the adult groups gradually decreased with age from the first trial, but the learning curve remained relatively consistent with age. The initial performance and the asymptote achievement, which both show inverted U-shaped differences across the lifespan, are consistent with studies by Rast and Zimprich (2010) and extend the two learning curve index results that they presented to incorporate children's developmental changes. Furthermore, the invariance of the rate as age increases among adults up to nearly 70 years old that was found in the present study is also consistent with studies by Rast and Zimprich (2010). The large adult age cohorts used in the present study may also have favored a stable adult age curve up to the 70+ age group. A future meta-analysis study that considers demographic and procedural factors could shed light on the inconsistencies in relation to the adult acquisition rate.

A comparison of the curve component results for adults could be compared with the results of previous studies; however, these measures were not previously applied to children. The measures of both omissions and additions, termed "loss of access" and "gained access", respectively (Davis et al., 2003; Dunlosky & Salthouse, 1996), are age sensitive, which is consistent with the present results. Furthermore, consistent with Davis et al. (2003), the results of both measures increased with age. Dunlosky and Salthouse (1996) also found increasing omissions with increased age, though additions were shown to decrease with age. The measure used by Dunlosky and Salthouse (1996) was a ratio score; thus, the results were calculated differently from the present study and from Davis et al. (see Davis et al., 2003) who used a summative score (the authors explained that they preferred the proportion measure to avoid a ceiling effect for the younger group). The proportion measures that were computed in the present study (additions and omissions related to the words recalled) reproduced a pattern of results similar to that of the absolute count measures. Furthermore, in the study by Dunlosky and Salthouse, additions were more significant than omissions for explaining changes in acquisition with age. The present study does not focus on comparing measures because the distinctive pattern of the three components across the lifespan is more relevant to our hypotheses. The studies that utilized the two component measures both indicated that they represent different aspects of the acquisition process (a point that was also confirmed in a recent study on gender differences by Krueger & Salthouse, 2010; in an Alzheimer's study by Moulin, James, Freeman, & Jones, 2004). The correlational findings in the present study further support this distinction.

The two measures have been found to be distinct and independent; however, it remains unclear how the two acquisition components interact during the acquisition process. A turnover mechanism that involves acquisition and forgetting elements in a list-learning process, in other terms, is likely to mediate encoding, maintenance, and interplay between short-term and long-term memory, both of which are thought to be activated by the same task (Unsworth & Engle, 2007). The possibility of interplay between short-term and long-term memory across trials is consistent with findings reported by Krueger and Salthouse (2011) in an adult study of a multi-trial recall task. The authors found that, in older populations, recency words were saved only for the first trial, but any advantage for recency words in older ages was shown for subsequent trials or after a retention trial. The authors explained that the recency words in the initial trial were still expected to rely on a short-term buffer, but not to remain in the short-term store at later trials.

The composite pattern differs with age and across the lifespan, which is consistent with evidence that demonstrates that older adults find different ways of elaborating information compared to young adults, even when actual performance is similar (Dennis et al., 2008). Different word turnover rates, rather than different additions and omissions ratios, are what distinguished young children from older adults.

The continuous ages sampled in this study enabled the use of component measures to detect differences between subgroups of adult aged population. In spite of stable acquisition rates found for age groups up to 69 years of age, the three component measures showed gradual differences between different age groups, that is, over 29, over 59, and over 69. These differences involved more omissions, more additions, and fewer touched words with age. These results are consistent with the findings reported by Davis et al. (2003) on declining performance in a group of adults aged 46 and above for lost-access and clusters.

Several limitations in the results observed should be considered. The component measures used were developed using clinical memory assessments and suffers because it is not theoretically designed to distinguish basic factors that interact in the acquisition process over the lifespan. Future research is required to better understand the mechanisms underlying the turnover of incompletely recalled words in verbal learning across the lifespan.

Further limitations in the present finding include the potential contribution of cohort differences other than age, such as bilingualism, educational practices, and variability in testing conditions. Furthermore, since this study was based on the Hebrew version of the Rey- AVLT, a replication of a fine-grained analysis of the learning curve in other languages is recommended.

In conclusion, according to Li and Baltes's (2006) review, which noted the complexity of the cognitive changes across the lifespan, performance depends on the function measured and the size of the measurement unit. Though the conventional total number of words recalled measures are important, this study also showed that it is possible to reach the same quantitative result using different cognitive processes. It is worth considering component measures when evaluating the quality of the acquisition and characterizing the learning process of different populations. These measures can be informative even when the learning curves seem similar. When the learning curves differ, they provide even more information by highlighting the source of the differences.

Disclosure statement

No potential conflict of interest was reported by the authors.

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