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Life span strategy implementation in verbal learning: size and type of cluster adoption

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ABSTRACT

Temporal and semantic associative processes during the acquisition of new verbal information undergo various changes across the life span. Temporal order clusters and subjective clusters were monitored during verbal learning trials using the Rey (Auditory Verbal Learning Task) for 1471 participants aged 8–91. Pairs, three-word, and four-word clusters were measured. Subjective clusters were generated at similar frequency across the whole life span. By contrast, a clear inverted-U curve across life span was indicated for temporal clusters. More words were subjectively clustered than clustered by temporal presentation order. The number of words clustered increased across trials, and cluster types showed a different increase profile across trials. The subjective cluster increment was faster and steeper than the temporal cluster increment in most of the age segments. Life span trajectory tendencies in the formation of temporal and semantic associations in recall were interpreted in relation to different frameworks of cognitive life span changes.

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Verbal memory; temporal clustering; semantic clustering; subjective organization

Introduction

Episodic memory, and specifically the acquisition of new information and its retrieval, shows dramatic changes across the life span. A group of studies that analyzed the learning process using multi-trial word lists and focused on performance from a qualitative perspective, delved into some of the underlying processes and indicated increases in seriation and subjective organization across trials (Davis et al., 2003; Pellegrino & Battig, 1974); differential increases in serial position components; increases in serial and semantic clustering (Griffin et al., 2017); and changes in components of the learning curve, such as words added and words omitted over trials, and in their patterns across the life span (Blachstein & Vakil, 2016).

The order of words recalled during the learning of a word list is not arbitrary, but rather follows a specific order from which various learning strategies can be measured. An individual memorizes unorganized information reproducing a sequential structure when instructed to simply recall a list. Even when a studied list consists of "unrelated" words, subjective organization can be observed when two or more items are closely

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positioned during recall across test recalls (Davis et al., 2013; Kurtz & Zimprich, 2014; Tulving, 1962). For example, if an individual recalls the word *garden* next to the word *parent* consistently in two or more sequent recalls, even if these two words do not seem overtly related, this pair is conceptualized as a *subjective organized* cluster. This holds even when the sources of organization cannot be specified by an external criterion (associative grouping, conceptual categories, phonetic grouping, or grouping in terms of familiarity of items). Furthermore, sequential patterns in retrieval indicated the degree of organization independently of quantity of recall (Tulving, 1962). Similarly, semantic clustering can be observed when a studied list is categorized according to conceptual categories, and participants recall words in juxtaposition from the same category even though the words were presented randomly (Bousfield, 1953; Delis et al., 1988).

We found the need to better clarify what is assumed or interpreted about the nature of the subjective organization independently of the kind of measure or experimental paradigm used. Howard and Kahana (2002) approached subjective organization units as a subjective response of semantic similarity between items, assuming a natural tendency to associate semantically similar items. This is not only due to an all-or-none semantic category attribution, but relative to words that are recalled together, since they are *more semantically related* (in word lists lacking categorical structure). Particularly regarding the formation of word clusters which are longer than two words and those formed after repeated trials (with practice), Pellegrino and Battig (1974) interpreted subjective organization in terms of associative elaboration in storage and retrieval. There are also indications in a children's study that the subjective organization units (clusters) generated in a condition with a high associated word list as well as with an unrelated word list were based substantially on the words' semantic properties, rather than orthographic or other properties. This was revealed by post-recall questioning about the basis on which participants sorted the words before recall (Rankin & Battig, 1977). For these reasons, subjective organization clusters are approached in the present study as partly of a semantic association nature. In other words, some subjective organization words can be regarded as subjective associations as well as other forms of associative groupings, and we termed the use of these clusters "subjective clustering" (SC).

Individuals have also been commonly seen to recall parts of the order in which words were presented and to adopt additional strategies such as first word strategy (first recalling a word not recalled previously) and other order effects in recall such as primacy and recency (Pellegrino & Battig, 1974). Temporal associations, like semantic associations, were indicated to be an important factor contributing to free recall performance (Kahana, 1996). To create associations between units of information in a paired association task, temporal organization was considered critical to structure a recalled list (Naveh-Benjamin, 2000). In two previous studies using the Rey – Auditory Verbal Learning Task (AVLT), word order at list presentation was compared with the order at retrieval, and the participants reproduced the order well above chance when order was required at retrieval but not required at acquisition (Vakil & Blachstein, 1994). This compares with the serial recall procedure, in which an explicit retrieval of the order is requested at list presentation. Temporal order was implicitly retrieved above chance in recall protocols, even when not required in both acquisition and retrieval (Blachstein et al., 2012).

During the verbal learning process, both temporal associations, semantic associations, and subjective organization are expected to increase across trials. In a subjective organization study on old age, Kurtz and Zimprich (2014) found that it increased through learning trials. Monitoring changes in subjective organization over trials, the relation of this increase to performance increases throughout recall trials was also confirmed at the individual level. Indices of learning were related to the initial subjective organization level and to its linear slope across trials (with 27 unrelated words, randomly presented over 5 trials) (Kurtz & Zimprich, 2014). Discussing the various strategies that participants developed during learning trials including temporal and semantic factors, Pellegrino and Battig (1974) pointed out the dynamic nature of the use of different organizational strategies across recall trials, and with *changes and shifts over trials* in the adopted strategy. Participants were observed beginning with a temporal order strategy and then shifting over trials to higher-order semantic organization at an advanced stage of practice.

The present study is meant to record temporal clustering (TC) and SC in recall across the life span, in their interactions across trials. First, in the present exposition, temporal organization, semantic associations, and subjective organization changes across life span are revealed. Furthermore, a description is provided of the differences between temporal and semantic strategies, and reported studies which compared the engagement of the two in verbal learning tasks. Finally, a proposal is made for the extraction of separate measures for analysis of temporal associations and subjective clusters from the Rey AVLT data bank on an entire life span age range, from childhood to older adult ages. Subjective organization, semantic clustering, and the adoption of temporal order strategies in word list acquisition undergo various changes throughout the life span trajectory from childhood to senescence. Semantic strategies have been found to improve recall in list learning, and increase with age in children (Bjorklund et al., 1992; Davis et al., 2013). As children grow up, they develop a tendency to spontaneously sort information by meaning (Best & Ornstein, 1986), and spontaneously generate retrieval plans (Hasselhorn, 1990). Just as in childhood, people in adulthood who use clustering showed improved recall (Bower, 1970) as well as subjective organization (Davis et al., 2013). Furthermore, in symmetry with childhood's increasing use of a semantic strategy with age, it was found to decrease in older adults (Griffin et al., 2017; Husa et al., 2017; Sunderaraman et al., 2013; Wingfield & Kahana, 2002).

A life span trajectory of increase in childhood and decline in old age was also found in studies on serial clustering, as the ability to adopt temporal order associations increases during childhood (Healey et al., 2019, for review) within a variety of additional strategies (Bjorklund et al., 2009). On the other end of the life span, in the adult population, both temporal organization and subjective organization were found to decrease across the life span (Sunderaraman et al., 2013). Temporal order, memory of source, context, and spatial position were found to be sensitive to age among adults in verbal and nonverbal modalities as well, in a meta-analysis study (Old & Naveh-Benjamin, 2008). Difficulties older adults experienced with order information were attributed to reduced item-context binding (Howard et al., 2006), and related to the associative deficit hypothesis of normal aging (Naveh-Benjamin, 2000). Next, temporal and semantic associations and their employment in verbal learning tasks are compared.

Although temporal order memory studies have shown a similar inverse U-shape across the life span in the ability and efficiency to utilize both strategies, it is reasonable to assume that the two association types are probably not supported by the same mechanisms. Shuell (1969) distinguished between the nature of these two association types. Temporal associations reflect a primary organization as a consistent relation between input and output order that does not depend on prior familiarity with the items. In contrast, semantic associations, which are based on the meaning of words, reflect an individual organization based on some second-order habits, pre-experimental associations or conceptual relations. Wingfield and Kahana (2002) suggested the complementarity of these strategies, pointing out the different requirements that characterize them: new online bindings of the items presented according to their temporal position and associations of items with well-established semantic relations, respectively. Temporal and semantic associations were studied in the same framework in various studies.

These two association types were found to dissociate in a free recall study with unrelated word lists. With an interfering task of varied duration between words presented for recall, there was a differential effect on the two association types. A decrease in the production of semantic associations was seen in recall, the longer the interfering task was used. In contrast, the amount of temporal order reproduced in recall was insensitive to the interference task duration (Howard & Kahana, 2002). Studies that measured both association types with repeated trials showed varied adoption of the two strategies in older ages. In one study, older participants showed more impairment in serial recall than in free recall of unrelated word lists. They persistently adopted semantic associations when the task changed from a free recall to a serial recall procedure, which required participants to intentionally recall the order. However, younger adults shifted from a mixed temporal and semantic organization to a main temporal organization, adapting to the requirements of the task. The authors suggested that the use of semantic information was relatively retained in older adults and indicated a decreased ability to make temporal associations during recall (Golomb et al., 2008). In contrast, in one free recall study (with related words in fixed presentation order), younger and older adults utilized serial clustering more frequently than semantic clustering, as measured across four learning trials with a categorized list (Griffin et al., 2017). These authors compared serial position components in recall (primacy, middle and recency) and the two cluster types, analyzing their variation over trials. As in previous studies, it was confirmed that both clustering types were increasingly used from one trial to the next and that temporal clustering was employed with a less positive slope than semantic clustering.

The engagement of temporal and semantic strategies, and subjective organization (which partly includes semantic associations) across trials requires further investigation, and it is noteworthy that these two old age studies measured the different association types differently, with significant procedural differences. One way to clarify this subject is to further investigate the differences in the measures used and the procedural conditions that could explain the contrasting results. Another way to further clarify the adoption of these strategies across trials with age (young and older adult groups) is by monitoring these strategies' engagement and efficiency across the life span. This would extend the analysis to the entire continuous age segments across the life span, including childhood, in the same framework. Furthermore, measurement of temporal associations and subjective clusters in separate (mutually exclusive) measures across trials can help to clarify the distinction.

In the present study, we utilized the normative data bank on the Rey AVLT conducted on child populations (Vakil et al., 1998) and on adult populations (Vakil & Blachstein, 1997).

The Rey AVLT consists of a multi-trial presentation of an unrelated word list presented in a fixed order, offering a basis for the input order to be used as a cue in recalling the list; at the same time, the instruction to remember the presented list in any order allows us to investigate a process of subjective associative nature in the recalled words. In the present study, we attempted to clarify changes in the dynamic use of the two strategies across trials, in the same task across the life span, with the use of two clearly separated indices for the two association types, carefully excluding possible mixed association types.

Two-word units are commonly measured temporal, semantic, and subjective organization clusters; however, pairs of words may underestimate the total amount of organization (Pellegrino & Battig, 1974). Pellegrino and Battig (1974) used 2- to 5-word units in their study. They found that with the use of semantic clustering, participants used longer units in the more advanced stages of acquisition, so that part of the information on SC could also be embedded in the dimension of the cluster. Previous studies scored temporal organization by considering the number of word pairs with forward and backward correct adjacent positions. The reproduction of order in units longer than two could reflect degrees of more substantive adoption of parts of the correct order in recall. Thus, in addition to the number of clusters count, the present study also considered the number of items in a cluster (2–4), which permits a qualitative evaluation of the strategies adopted by the participants.

On the basis of previous studies of children and adults, each of the TC and SC factors is expected to be age sensitive across the life span. Furthermore, based on results that measured both temporal and semantic factors indicating a dissociation between the two association types, it is expected that the two cluster types will differ in sensitivity to age across the life span.

Temporal order memory is expected to follow the curvilinear inverted U-shaped profile across the life span. Furthermore, adults in the older age groups are expected to show a less pronounced decrease in the SC profile than in the TC profile. This takes into consideration previous studies that indicated that older participants compensate by using semantic associations. Second, the two association types should result in different increases in clusters across trials, with a pattern that is also expected to change across age groups.

The use of a given clustering strategy relative to the use of other strategies allows us to observe the extent of adoption of a singular vs. mixed strategy across age groups. Longer cluster sizes are expected to mark higher-order organization and to aid in better distinguishing the two cluster types adopted at different age segments. Accordingly, when compared to young adults, young children and probably older adults will have particular difficulty forming longer clusters, as demonstrated for children vs. young adults (Bjorklund & Jakobs, 1985). Furthermore, the extent of the cluster sizes adopted relative to each cluster type allows us to better distinguish between the two cluster types adopted in different age segments.

Method

The data analyzed in the present study are the normative Rey AVLT raw data for children and adults already published by Vakil et al. (1998) for children, and Vakil and Blachstein (1997) for adults. The data were merged in this study for part of the analyses. The normative scores quantified recall and were computed as the *summary number of words* *recalled* on the test trials. However, in the present study, the raw data were approached differently, by considering the sequential patterns of *single recalled words*, following their retrieval order across the learning trials.

Participants

The children's data were collected from a sample of 943 children (487 boys and 456 girls). The age range 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). These schools ranked in the middle range of a Ministry of Education scale composed according to five criteria: parents' income, parents' education, family size, proportion of immigrants in the school, and distance from a major city. Based on teacher's or principal's judgment, children with either very high or very low academic achievements were not sampled. Children from each grade were selected according to their birth date (with a gap up to 3 months from birth date) at the testing time. Included in the sample were an additional 124 children (63 boys and 61 girls) in the same age groups from different parts of the country, who on a preliminary analysis did not differ from the rest of the sample on any parameter and were merged into the mean sample. Children diagnosed with learning disabilities, attention disorders, or those requiring special assistance in school were excluded. Hebrew was the native language for all the children in the sample. The children's sample was subdivided into 10-year age groups (each for a single age), including a mean of 94 participants in an age group. Boy participant representation ranged from 51% to 54% of each age group. The years of education were implicit in the children's age.

The adult data were collected from a sample of 528 participants (257 men and 271 women). The age range of the sample population was 20–91 years. All the 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 either from among students attending a special series for elderly people offered at Bar-Ilan University or from several senior citizen community centers. All the elderly participants, when tested, were alert and oriented to time and place. Based on their report, participants with a history of learning disabilities, alcohol or drug abuse, or neurological or psychiatric illness were excluded. The adult sample was divided into six groups representing each decade, with the exception of the oldest group which included participants aged 70–91 years, that included a mean of 105 participants in each decade group. Male participant representation ranged from 43% to 52% of each age decade. Mean education for the age decades through 59 years ranged between 13.01 and 13.78 years of schooling, and for the old and oldest age groups 12.46 and 12.51 years of schooling, respectively.

Age cohorts in the present study were determined with two considerations. The first was the intent to capture the increase and decrease in learning rates for children and adults, respectively. The second was the intent to determine comparable age segments, with similar performance within the children's sample and the adults' sample. Thus, the cutoff points of the age segments were chosen to better capture performance changes. This was based on preliminary analyses of the data identifying age ranges for children and adults, in which performance was more stable than in age ranges in which significant changes were observed.

According to these considerations, the children's sample was divided into three age cohorts (8–10, 11–14, 15 − 17), and the adult sample was divided into five age cohorts (20–29, 30–49, 50–59, 60–69, 70–91). (Demographic characteristics of the two samples are presented in Blachstein & Vakil, 2016, Table 1). Preliminary analysis revealed that two adult cohorts, 30–49 and 50–59, did not differ on the various scores of learning and were therefore combined for the following analyses.

Tests and procedure

Children were tested individually in a room allocated for this purpose in their own schools during school hours. The children participated voluntarily in the study. Furthermore, they were told that they could stop at any time if they wished to do so. This occurred with just 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. Adults were tested individually, partly in their senior citizens' home in a room allocated for this purpose, and partly at the university. They participated voluntarily in the study, and they were told that they could stop at any time if they wished to do so.

The Rey AVLT: The Hebrew version of the Rey AVLT was used (Vakil et al., 1998). Administration was standard, as described by Lezak et al. (2004). It consists of 15 common nouns, which were read to the participants at a 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. This was followed by two more trials, which were not considered in the present study. The measures utilized were the number of words recalled for each of the learning trials and proactive interference (difference score, trial 5 – trial 6).

All of the clusters were composed of those words that were repeatedly recalled in a close position on two adjacent trials in succession. The *serial clusters* were composed of those repeatedly recalled words on two adjacent trials and in the same successive position that were also positioned in the presentation in an adjacent ascending serial position (the serial clusters were counted only for an ascending position). The "*subjective clusters"* were composed of the group of words that were repeatedly recalled on two adjacent trials in close proximity, forming groups of the same recalled words closely retrieved but not always in the same order (between the two trials). In the present study, for subjective clusters we used similar measures, although not identical to the subjective organization measures adopted by Davis et al. (2013) and Kurtz and Zimprich (2014), which were based on Sternberg and Tulving (1977) subjective organization measure. But in these previous studies, these measures were restricted to word pairs, while in our analysis they addressed two-, three- and four-word clusters.

In order to disentangle the subjective from the serial clusters, the subjective clusters that included smaller serial clusters (as described below or in backward seriality) as partly serial clusters were excluded. Thus, serial clusters and subjective clusters were mutually exclusive.

Assuming that the longer clusters are indicators of a higher rather than shorter levels of organization, longer clusters were prioritized, and the clusters were searched for in decreasing order from the longest to the shortest. In each cluster type, the count was computed with a rule of precedence for longer clusters, meaning that of four word clusters were considered first, followed by three-word clusters and finally pairs of words. Furthermore, once a particular word was counted in a cluster, it could not be counted again in a smaller cluster (each word in a four- or three-word cluster was considered taken, and could not be counted again as part of a three-word cluster or a word pair, respectively). The cluster count and recall protocol of one participant is presented in Appendix 1.

Five learning trials provided four sets of cluster scores, which were obtained by comparing the recalled words of four pairs of adjacent trials (Trials 1–2, Trials 2–3, Trials 3–4 and Trials 4–5). To obtain a cluster measure not contaminated by the number of words recalled, a relative measure of the words recalled in a trial was used. Furthermore, since three cluster sizes were compared, a relative measure of the number of words clustered in a trial was preferred over a relative measure of the cluster count. Thus, the cluster's sum (X) in a trial was multiplied by its respective size. The measure used was for pairs (X*2/sum of words recalled in a trial), for three-word clusters (X*3/sum of words recalled in a trial), and for four-word clusters (X*4/sum of words recalled in a trial). For each trial (compared to the previous one) a set of six scores of percent of words clustered were computed, three for each cluster type. The three scores included one for each of the three sizes. TC percentage score for a trial across cluster sizes = (∑ (number of temporal clusters for each size * cluster size)/number of words recalled on that trial) *100. SC percentage scores for a trial across cluster sizes = (∑ (number of subjective clusters for each size * cluster size)/number of words recalled on that trial) *100.

Results

The scores of word acquisition across trials were analyzed in a previous life span study by Vakil et al. (1998) in a child population, and by Vakil and Blachstein (1997) in an adult population (see figure 1).

Temporal vs. semantic cluster adoption in the three cluster sizes

First, we needed to determine differences in the use of cluster strategies over the course of the life span, in the scope to which they are adopted, and in the differential effect of age on the length of the clusters. A life span distinction between the two cluster types would indicate that two different strategic factors affect verbal acquisition. To compare temporal and subjective clusters in the three cluster sizes across the life span, a summary score of the words clustered in the learning process (sum of the four cluster scores in the learning trials) was computed. Mixed design ANOVA (2×3×7) with cluster type (temporal and subjective), cluster size (pairs, three-word clusters, and four-word clusters), and age (7 age cohorts) was conducted. The first two factors were within-subjects factors, and the third was a between-subjects factor. As can be seen on Figure 2, overall, more words recalled were clustered via subjective associations than via temporal associations $F(1, 2868) = 201.41$, $p < .001$, $\eta^2 = 0.12$, and overall, more words were clustered into smaller

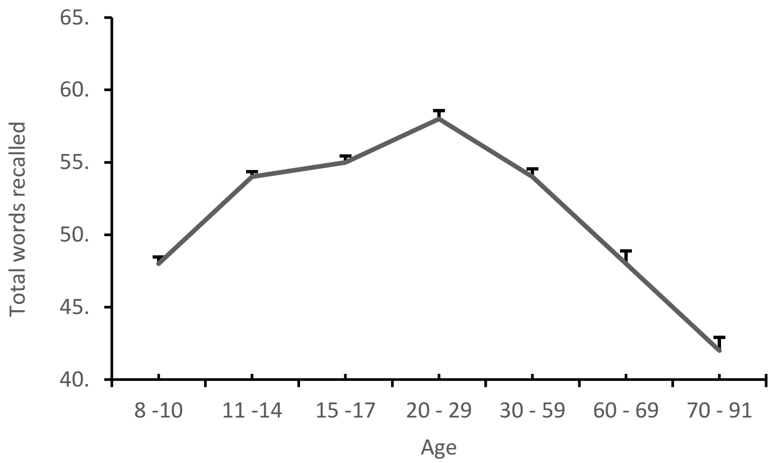

Figure 1. Total words recalled in life span age cohorts.
Note: A trend analysis across the age groups for summary total learning (trials 1-5) indicated a significant quadratic contrast (CE = -2.48, SE = .13, p < .001). The 20-year-old reference group achieved the highest number of words recalled; in 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 - 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 age groups, the lowest achievement was attained by the 70 years and older group. From Blachstein, H., & Vakil, E. (2016). Verbal learning across the lifespan: an analysis of the components of the learning curve. Aging, Neuropsychology, and Cognition, 23, 133-153.

clusters $F(2, 2868) = 815.06$, $p < .001$, $\eta^2 = 0.36$, with more words clustered in pairs than in the two longer clusters and with more words clustered in three-word clusters than in four-word clusters, as indicated by Duncan (see Figure 3). All two-way interactions were significant, but the three-way interaction did not reach significance $F(12, 2868) = 1.40$, $p = .16$, $\eta^2 = 0.006$. The significant type by age interaction is very informative, $F(6, 2868) = 11.49$, $p < .001$, $\eta^2 = 0.045$, as it indicates that temporal clusters are more sensitive to age than subjective clusters and are manifested in a different path across the life span. As seen in Figure 2, the temporal cluster scores increase and decrease across the life span in an inverse U path. In comparison, subjective clusters show higher scores, but at a relatively stable level across the life span. The one-way procedure conducted for age separately on each of the cluster types indicated that temporal cluster scores in the 11- to 17-year-old groups were higher than those in the two extreme age groups, lower than the peak at 20–29 years which were higher than in the 30–59-year-olds, which in turn were higher than the two oldest groups. In contrast to the temporal cluster scores, the subjective cluster scores did not change within the 11- to 70-year-old cohorts, and the 8–10 year cohort scores were lower than the 40 and 70 year cohort scores. It is important to note that the young adult age group (20–29) showed the maximal level of both cluster types. The ability to adopt both strategies can explain this age group's highest recall performance.

To understand the significant size by age interaction $F(12, 2868) = 4.40$, $p < .01$, $\eta^2 = 0.01$, three mixed ANOVAs (3×3) for each of three age segments were conducted, with size (2 to 4) as the within subjects factor and age (the three youngest cohorts for the

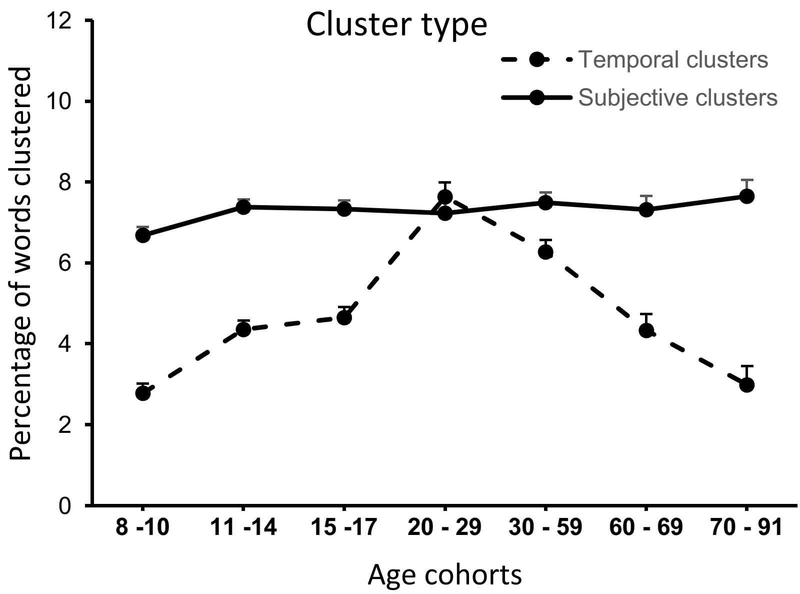

Figure 2. Percentage of words clustered in temporal and subjective clusters in life span age cohorts.

first analysis; the 15–17, 20–29, and 30 – 59 cohorts for the second; and the three oldest cohorts for the third) as a between subjects factor. As seen in Figure 3, the interaction was due to a unique pattern in the transition from the 15–17 year cohort to the 20–29 year cohort, with a steeper increase in the use of four-word clusters relative to smaller clusters ($F(4, 1208) = 4.72$, $p < .001$, $\eta^2 = 0.015$, for the age by size interaction). Similar profiles in the three clusters size increase were found for the children and the 30–59 cohorts ($F(4, 1880) = 1.60$, $p = 0.17$, $\eta^2 = 0.003$; $F(4, 774) = 0.93$, $p = 0.44$, $\eta^2 = 0.005$, for the age by size interaction, in the first and last age segments, respectively).

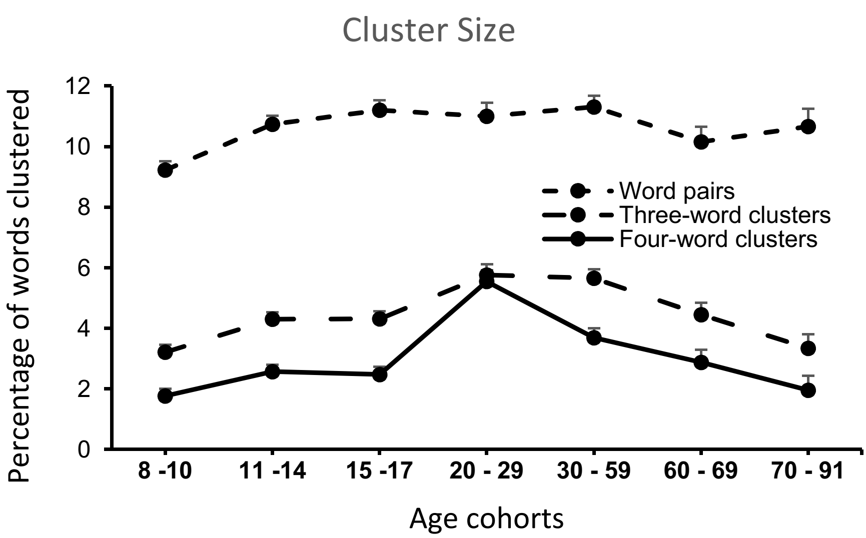

Figure 3. Percentage of words clustered in the three cluster sizes in life span age cohorts.

The type by size interaction $F(2, 2928) = 86.86$, $p < .001$, $\eta^2 = 0.056$, was due to the greater occurrence of subjective pairs than of temporal pairs (12.50% vs. 7.50%) of words clustered relative to words recalled, respectively. While three- and four-word clusters were similarly common but less frequently adopted, with 5% and 4.5% of words clustered in three-word clusters, respectively, and 2.70% and 2.50% of words clustered in four-word clusters, respectively.

Temporal vs. subjective cluster formation across trials

Means and standard errors for clustering scores (across sizes and trials) in each age cohort from the younger children to the oldest adults for TC were 2.64 (.23), 4.27 (.22), 4.55 (.25), 7.56 (.35), 6.18 (.29), 4.22 (.39), 2.87 (.46), respectively; for SC were 6.51 (.20), 7.23 (.19), 7.20 (.22), 7.15 (.30), 7.36 (.25), 7.13 (.34), 7.52 (.40), respectively. To better comprehend the dynamics between the two strategies during acquisition, their increasing profiles across the acquisition trials were analyzed. To track the participants' temporal and subjective cluster formations across trials as a function of age, mixed ANOVAs with three factors (4×2×7) were conducted, with trial (four trials), cluster type (temporal and subjective), and age (7 age cohorts), with the first two as within subjects factors, and the third as a between subjects factor. The number of words clustered increased across trials, $F(3, 4392) = 200.78$, $p < .001$, $\eta^2 = 0.12$, and overall, more words were clustered in subjective associations than in temporal associations, $F(1, 4392) = 200.81$, $p < .001$, $\eta^2 = 0.12$. Furthermore, the age effect was significant, $F(6, 1464) = 29.09$, $p < .001$, $\eta^2 = 0.11$, as were the two-way interactions, $F(6, 4392) = 11.6$, $p < .001$, $\eta^2 = 0.04$, for the cluster type by age interaction (see Figure 2); $F(6, 4392) = 4.12$, $p < .01$, $\eta^2 = 0.003$, for trial by cluster type. As can be seen in Figure 4, the trial by cluster type interaction reflected a different pattern through trials of the two cluster types. More words recalled were clustered via subjective associations, and their increase across trials began faster than the increase across trials via temporal associations.

The triple interaction was only marginally significant $F(18, 4392) = 1.60$, $p = .052$, $\eta^2 = 0.007$.

Correlations

Among the children's population there is a positive relation of education to TC but it reflects the relation of age with clustering, since education is included in age (children were sampled close to their birthday, according to years of schooling). The relation of age to clustering is presented in Figure 2. Among adults, Pearson product moment correlation of TC with education was significant ($r = .156$, $p < .001$). When conducted for the separate adult age groups, this relation was not significant, with the exception of the 60–70 year old group ($r = .199$, $p < .05$). In the oldest group, this relation was not maintained.

Previous clustering studies have usually reported the relation between the degree of clustering using the two strategies and performance. This relation is indicative of the efficiency in the use of clusters. To compare the influence of the two clustering strategies on the efficiency and quality of list acquisition, two summary cluster scores were computed for each individual. One score for each cluster type was used to measure the proportion of words totally clustered in each type across the five trials.

Table 1. Pearson correlations of the total words recalled with words clustered in temporal and subjective clusters and with total words clustered (across cluster type) by age cohorts.

	Temporal clusters_	Subjective_clusters
08 - 10 (*n* = 310)	.20**	.28**
11 - 14 (*n* = 363)	.20**	.27**
15 - 17 (*n* = 270)	.15*	.14*
20 - 29 (*n* = 138)	.29**	.09
30 – 59 (*n* = 199)	.34**	.06
60 – 69 (*n* = 110)	.34**	.10
70 – 91 (*n* = 81)	.39**	.05

* $p < .05$; ** $p < .001$.

Pearson product moment correlations were conducted separately in each age cohort, since in the previous analyses, age affected the preferences and course across trials in adoption of the two strategies. The correlations were conducted between the two clusters' sum scores, with the sum of words recalled (achieved in the five trials), and with proactive interferences.

As seen in Table 1, the number of words recalled was directly related to the proportion of words clustered for temporal clusters in all age cohorts; however, for subjective clusters, this relation reached significance only for child and adolescent ages. Another interesting result is that the more the participants clustered the recalled words (the two

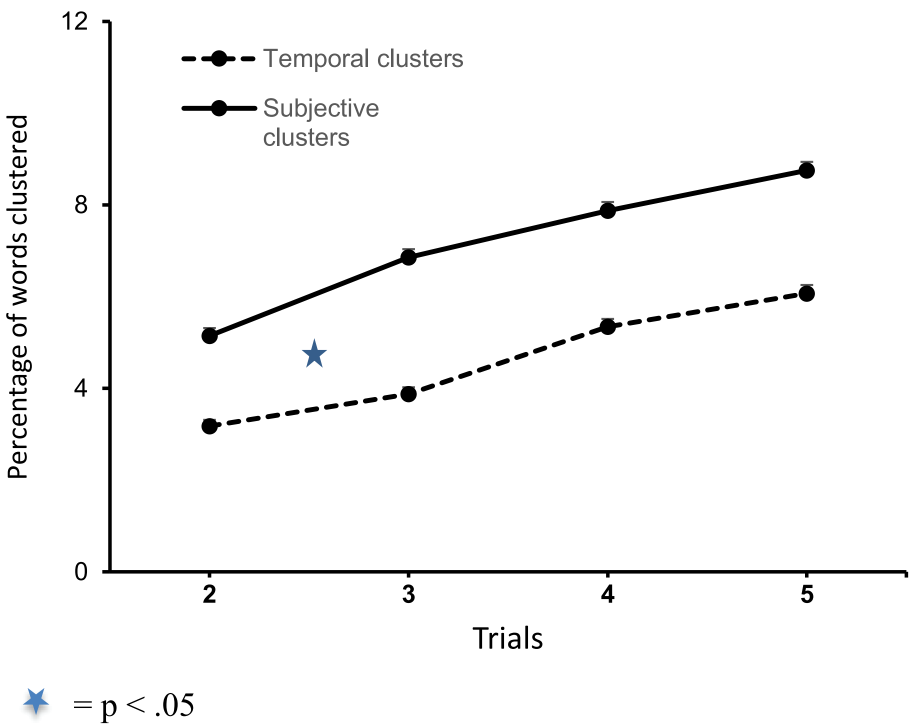

Figure 4. Percentage of words clustered in temporal and subjective clusters.

cluster types together), the more they showed proactive interference in all age groups, except for the 20–29 age group ($r = .17$, $p < .01$; $r = .16$, $p < .01$; $r = .18$, $p < .01$; $r = .01$, $p = .83$; $r = .24$, $p < .001$; $r = .19$, $p < .05$; $r = .27$, $p < .05$, from the younger to the older age groups).

Since the adoption of subjective clusters was efficient (positively related to the number of words recalled) only in the children's population but was not found in adults, this relation (clusters-performance) was further analyzed broken-down by cluster size. Although in the analysis of the words clustered (across trials), the triple interaction of age by type by size did not reach significance, this correlation profile suggests that individuals composed the subjective clusters in different modes across the various age groups. Four one-way analyses for age (three age groups from 8 to 20 years), conducted separately for each cluster type, one for pairs and a second for four-word clusters, revealed a trend toward this pattern. Subjective pairs did not change with age, $F(2) = 1.49$, $p = .23$; in contrast, subjective four-word clusters showed an increasing trend with age, $F(2) = 2.6$, $p = .07$. For the temporal clusters, both pairs and four-word clusters increased with age, $F(2) = 6.64$, $p < .001$, $F(2) = 4.8$, $p < .01$, respectively. In the adult cohorts, cluster size analysis did not change the trends.

Discussion

The primary aim of the present study was to reveal life span trajectory tendencies in the adoption of TC and SC, and how they interact across acquisitions over a continuous and large age range. Specifically, it was meant to determine whether and how temporal and subjective clustering trajectories dissociate across the life span. As expected, the two clustering types revealed a different profile of change with age. For all age groups, temporal clusters were associated with performance level. Children were increasingly apt to generate these clusters as they became older and reached a maximal point in young adulthood, while compared to young adults, older adults showed a decrease in cluster formation. In comparison, subjective clusters were related to the performance level only in the child and adolescent cohorts, and were generated at a similar frequency across the entire life span (Figure 2). These findings of differential change in the use of temporal and subjective clusters with age are in accordance with the previously suggested dissociation of temporal and semantic factors (Howard & Kahana, 2002; Shuell, 1969; Wingfield & Kahana, 2002), and with two recent studies in which the two factors were differently employed (Griffin et al., 2017; Nairne et al., 2017).

The positive relation found between the adoption of a temporal strategy and overall recall accuracy is consistent with the adult study of Kahana (1996) , and extends this relation to the entire life span, including childhood and adolescence. Previous studies on temporal memory in children included younger children (10 years old and younger) (Lehman & Hasselhorn, 2012, for a review, see Healey et al., 2019). Furthermore, these age groups show curvilinear outcomes, which are in accordance with imaging studies that have reported frontal lobe involvement in temporal order memory (Cabeza et al., 2000; Rajah & McIntosh, 2008). Cerebral areas that have been shown to increase and mature during adolescence and young adulthood (Changeux & Danchin, 1976; Sowell et al., 2003) showed the most significant decremental changes in old age (Raz et al., 1997), developing slowly and declining rapidly across the life span (Imperati et al., 2011).

On the other hand, this relation with overall recall accuracy and the clear age sensitivity found here conflicts with Delis et al.'s (1988) interpretation of temporal associations in the California Verbal Learning Test (CVLT) factor analytic findings: the temporal strategy was less effective than the semantic strategy, and only the semantic strategy positively loaded on the general verbal learning factor. Probably the fact that the CVLT consists of categorized word lists could have given a priority to use of semantic strategy, in contrast with the Rey (AVLT), which is formed by unrelated word lists.

The young adult group (20–29) was the only age group that used the two association types at a similar level, due to the increase in the use of temporal clusters with age. This equal use in the maximal frequency of the two cluster types indicated that for optimal recall performance, both strategies are adopted. This is consistent with the findings of Golomb et al. (2008) that suggest mixed strategy use in young adults. It is interesting to note that, other than the best performing adult age segment, subjective clusters were consistently used more often than temporal clusters across all age groups, despite the fixed serial order of word presentation, which could have enhanced the increment of temporal associations across trials. Furthermore, the increase in SC appeared from the initial trials. We will now consider SC findings in children and then adults.

In children and adolescents, subjective clusters resulting in efficient recall (as a result of the positive relation between SC employment and recall performance) are in accordance with the findings of a relation between recall performance with semantic strategy in Bjorklund et al. (1992), and with subjective organization in Davis et al. (2013) studies. It is surprising that the superiority of SC in childhood seen in the younger children's group did not gradually increase with age as expected, assuming that strategic clustering is based on an effortful activation. In young children SC probably reflects a subtle associative tendency, not based on the strategic use that is expected to be activated in older children's ages. Consistent with this Bjorklund et al. (1997), (2009) in a series of studies on child strategy development, distinguished between *associative* and *categorical* organization factors in recall (Bjorklund & Jakobs, 1985). In a study of 7- to 16-year-olds, the degree to which children associate in recall was evaluated, as were categorical relations with or without associative relations. Seven- and eight-year-old children activated pairs in an associative – relative automatic nature, whereas from 16 years of age until young adulthood, a transition occurs when a strategic – effortful organization approach is added and clusters of longer than two words were formed (Bjorklund & Jakobs, 1985). As was shown by analyzing the word pairs separately from the three- and four-word clusters, the low-associative level that characterized the young children's semantic associations can explain the resulting stable subjective cluster scores (across the cluster sizes) found in the children's data. Young children could have engaged in subjective clustering of a low-associative nature, as reflected in the word pairs, which was the most common cluster size.

Regarding adults, the basis on which subjective clusters were produced in this study, it is still unclear, since in adults aged 30 or older, the semantic strategy did not decrease with age (even when controlling for cluster size). On the other hand, SC was not effective (as revealed by the nonsignificant correlation between the use of subjective clusters and overall recall accuracy), despite SC being used more often than temporal clustering. This result accords partly with the findings of Golomb et al. (2008) and Wingfield and Kahana (2002), which indicated a recall decrease and a relative sparing of semantic versus temporal abilities in older participants. Golomb et al. suggested that the semantic strategy is maintained even when unproductive. In a recent study, semantic superiority respective to temporal clustering was also revealed by an unexpected single trial recall, following a survival scenario encoding condition (Nairne et al., 2017). The opposite superiority appeared with an explicit request to reconstruct the presentation order. The present findings conflict with the superiority of temporal clustering found in Griffin et al.'s (2017) study, and the semantic clustering decline with age found using the CVLT (Norman et al., 2000). It is important to note that subjective clusters in comparison to semantic clusters (as in the CVLT) consisted of recalling in adjacency pairings of words not necessarily belonging to common semantic categories. These clusters, not based on a categorical structured list, were probably composed partly of semantic associations with some associative strength, partly based on familiarity or some idiosyncratic association, and also partly based on phonetic similarity. As such, this could also have been the reason for being more frequently used, probably less effortful and also less stable. Further study is required to clarify the nature of these subjective clusters, and why no relation was found between them and overall recall accuracy in adults.

It is important to mention one consideration regarding the size of the subjective cluster measure. It was suggested above that among children's age groups, the nature of semantic associations adopted changed with age from an automatic association to a categorical grouping (showing a tendency toward increase of the longer clusters with age). However, there was no way to specify the exact nature of the subjective clusters particularly among adults, for whom the length of the cluster was not related to age.

Additionally, giving precedence to consider temporally serial clusters, and also excluding subjective mixed clusters, could have caused underestimation of the subjective clusters. But on the other hand, we must also consider that by measuring clusters longer than two word, there was a better opportunity to identify the subjective clusters. Furthermore, the broad inclusion criteria applied to the subjective clusters compared to the temporal clusters, could have contributed to the relatively higher SC scores generally found in all the cluster sizes across all ages. Three- and four-word subjective clusters were particularly common when such clustering was defined as the repetition of the same group of words between two adjacent recalls, irrespective of their recalled order (words considered in the same cluster unit can be interposed by other words when repeatedly recalled in two consecutive recalls). On the other hand, we must also take into account that most of the subjective clusters found in the present study were word pairs.

To view more closely which words were grouped in the subjective clusters, we representatively observed a few examples of single participants SC. Frequent examples were parent – coffee, school – bell, garden – turkey, hat – farmer – garden examples that could represent associative links based on the meaning of words. Other examples can be distinguished like drum – bell that can represent a semantic link, and other examples like moon – river, parent – farmer, garden – farmer – parent – school that seem less obvious, and more idiosyncratic.

Another interesting finding is the different incremental profiles of the two cluster types across trials. As expected, both TC and SC increased throughout trials (see Figure 4), in accordance with previous studies (Davis et al., 2003; Griffin et al., 2017; Kurtz & Zimprich, 2014). The smoother increase seen for TC than for SC is consistent with the findings of Griffin et al. (2017) that measured temporal vs. semantic clustering. In the present study, this increased profile distinction (between the cluster types) is shown in the initial trials. In the Griffin et al. study, the point of distinction of the two slopes was not specified.

Life span changes in the whole pattern of the two cluster types shown overall and across trials can be interpreted with respect to three different frames of cognitive life span changes. The first framework is the frontal lobe hypothesis (Cabeza et al., 2000; Rajah & McIntosh, 2008), according to which symmetrically inverse direction changes are expected of the two extreme life span age segments. The present results are in partial accordance with this hypothesis, regarding only temporal order memory showing the increase, peak and decrease of temporal clusters across the life span. Temporal order memory was found to be supported by frontal structures (Cabeza et al., 2000). The second framework is the phenomenon of differentiation during the childhood developmental trajectory (Tucker-Drob, 2009), and dedifferentiation in old age (Li et al., 2004). Furthermore, dedifferentiation is associated with episodic memory performance among the elderly (Koen et al., 2019). Maximal ability is reached in young adults when new information is registered, and was characterized by an ability for pattern separation and *discrimination* of similar experiences, which shifts to *generalization* in older ages (Leal & Yassa, 2015). The present study results are in partial accordance with this phenomenon, relating to children's initial SC superiority across trials with respect to temporal clustering. However, clustering of an associative nature would reflect a transition to a more competent mixed strategy adoption, as among young adults. Young adults' adoption of both strategies, in steeper growth through trials with the addition of longer subjective cluster sizes, probably represented a more differentiated condition. The third framework is the compensation model (Cabeza & Dennis, 2012), according to which different functional changes are expected, that reflect the different neural adjustments of brain activity to neural age decrements. According to this model, brain activity is linked to task demands in an inverted U pattern. With increased task demands reserve resources are implemented, suggesting that with lower task demands, levels of activation increase, and performance improves by successful compensation. But this activity change helps up to a point, after which task demands are excessive and a drop in brain activity is observed, so that compensation results are unsuccessful. With reference to the older adults' performance, task demands were probably near a high level, as evidenced by older adults' resultant inefficient SC use, even if adopted at the same frequency as younger adults. This model refers to adult life span neural and cognitive decrements. In support of this hypothesis are the different relation patterns of TC with education, shown for the 60–69 year group in contrast to the 70–91 year group. A significant relation of TC with education at age group of 60–69 years was shown, at the same time that TC was in continuous decrease with age. In contrast, in the next and oldest age the relation of TC with education was not maintained. One of the limitations of this study is that we do not have clustering-relevant background for the sample in general, such as vocabulary measure, or more generally crystallized intelligence. Future neuroimaging research is needed to link mechanisms characterizing the acquisition process (verbal learning patterns) across the life span, to mechanisms of neural network activity. Each of these frameworks does not exclude the others, since more factors probably have a role in age-related episodic memory changes across the life span.

The present study indicated variations in cluster type and cluster size, including clusters longer than two words that underlie acquisition across trials in individuals from different life span age segments. A life span study would help improve our understanding of the cognitive processes and their underlying mechanisms by comparing age segments.

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Appendix 1

Appendix 1. A cluster's count example as computed on one subject, with the subject's recalled words.

Trial	1	2	3	4	5	
Words remembered.	curtain coffee nose drum river farmer	river drum curtain coffee farmer garden school	drum curtain river coffee school house farmer garden	river drum curtain turkey school coffee house farmer moon	drum curtain bell farmer coffee house turkey school river	
Number of words recalled	6	7	8	9	9	
Adjacent trials on whichclusters are computed.		1-2	2-3	3-4	4-5	Total score across the trials
Temporal clusters words			Drum curtain	Drum curtain	Drum curtain	
Number of temporal clusters		-	1	1	1	3
Subjective clusters words		Curtain coffee Drum river	Farmer garden	House farmer	Coffee house turkey school	
Number of subjective clusters		2	1	1	1	5