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Age-Specific Effects of Lexical–Semantic Networks on Word Production

Giulia Krethlow,^a  Raphaël Fargier,^b Marina Laganaro^a

^a*Faculty of Psychology and Educational Sciences, University of Geneva*

^b*Laboratoire Parole et Langage, Aix-Marseille University*

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Abstract

The lexical–semantic organization of the mental lexicon is bound to change across the lifespan. Nevertheless, the effects of lexical–semantic factors on word processing are usually based on studies enrolling young adult cohorts. The current study aims to investigate to what extent *age-specific* semantic organization predicts performance in referential word production over the lifespan, from school-age children to older adults. In Study 1, we conducted a free semantic association task with participants from six age-groups (ranging from 10 to 80 years old) to compute measures that capture age-specific properties of the mental lexicon across the lifespan. These measures relate to lifespan changes in the Available Richness of the mental lexicon and in the lexical–semantic Network Prototypicality of concrete words. In Study 2, we used the collected data to predict performance in a picture-naming task on a new group of participants within the same age-groups as for Study 1. The results show that *age-specific* semantic Available Richness and Network Prototypicality affect word production speed while the semantic variables collected only in young adults do not. A richer and more prototypical semantic network across subjects from a given age-group is associated with faster word production speed. The current results indicate that age-specific semantic organization is crucial to predict lexical–semantic behaviors across the lifespan. Similarly, these results also provide cues to the understanding of the lexical–semantic properties of the mental lexicon and to lexical selection in referential tasks.

Keywords: Word production; Picture-naming task; Semantic network; Free semantic association; Lifespan

Correspondence should be sent to Giulia Krethlow, Faculty of Psychology and Educational Sciences, University of Geneva, Bd du Pont d'Arve 28, 1211 Geneva 4, Switzerland. E-mail: giulia.krethlow@unige.ch

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1. Introduction

Word selection and production is an everyday activity that allows a person to express concepts by transforming them into lexical forms. Humans only need a few hundred milliseconds to retrieve and produce a word (Johnson, Paivio, & Clark, 1996; Levelt, 1999).

Nevertheless, the time needed to perform such a fast and fundamental task is influenced by several (psycho-) linguistic factors that reflect organizational properties of the mental lexicon. The mental lexicon is thought to compile notably semantic, lexical, and phonological knowledge about words. Words' age of acquisition (AoA), frequency of use in language, and the related semantic networks are, for instance, among the main psycholinguistic factors known to affect the ability to efficiently retrieve words from the mental lexicon and produce them (see Alario et al., 2004; Barry, Johnston, & Wood, 2006; Britt, Ferrara, & Mirman, 2016; Gordon & Cheimariou, 2013; Newman & German, 2005; Perret & Bonin, 2018; Rabovsky, Schad, & Rahman, 2016). In addition to these factors, the age of the speaker also plays an important role in the variability of performance in word production (Kavé, Knafo, & Gilboa, 2010; Laganaro, Tzieropoulos, Frauenfelder, & Zesiger, 2015; Valente & Laganaro, 2015). However, it is largely unclear whether changes in the psycholinguistic factors that affect accuracy and speed of word production across ages reflect changes in the architecture of the mental lexicon. In particular, the organization and richness of the lexical–semantic network likely change across the lifespan, which may underpin differences in word retrieval across ages. In the present study that spans from school-age children to old adults, we tackle this issue by investigating (a) age-related changes in the lexical–semantic organization of the mental lexicon and (b) to what extent accuracy and speed of word production are predicted by age-specific lexical–semantic factors.

1.1. *Lifespan changes in word production*

Even if speakers rarely produce single words, researchers and clinicians have largely used referential word production tasks, such as picture naming, to evaluate and study language production in both children and adults. Indeed, speakers constantly have to select and encode words in fluent language, where words represent the “bricks” that constitute an utterance (Brooks & MacWhinney, 2000). Performance in the picture-naming tasks is usually poorer in the elderly and children relative to young adults in terms of accuracy or production speed (Budd, Hanley, & Griffiths, 2011; D'Amico, Devescovi, & Bates, 2001; Kavé et al., 2010; Laganaro et al., 2015; Newman & German, 2005; Thornton & Light, 2006; Valente & Laganaro, 2015). Kavé et al. (2010) carried out a study on a large cohort of participants showing that word production evolves in a nonlinear (U-shaped or bow shaped) trend across the lifespan, with lower accuracy in children and the elderly compared to young adults.

Poorer performance in children may be related to several factors, such as the size of their vocabulary (Dale & Fenson, 1996) which increases linearly with age (Brysbart, Warriner, & Kuperman, 2014; Light, 1992; Salthouse, 2004), lower practice with lexical

access, or differences in their lexical representations (Brooks & MacWhinney, 2000). By contrast, lower performance in the elderly may be rather related to the overall decrease in cognitive performance (Hanauer, & Brooks, 2005; Salthouse, 2009; Thornton & Light, 2006). However, one can use the same rationale for the elderly as for children. Several authors indeed addressed the issues of word retrieval in aging by focusing on the changes due to enhanced lexical and/or conceptual information acquired in the course of life (e.g., Burke & Shafto, 2008; Kavé et al., 2010; Lemaire & Bherer, 2005; Li, Lindenberger, & Sikström, 2001; MacKay & Burke, 1990; Ramscar, Hendrix, Love, & Baayen, 2014; Ramscar, Hendrix, Shaoul, Milin, & Baayen, 2014). Note that the debate on which processes underlie the changes in aging are beyond the scope of this article.

Nevertheless, we assume that there is a quantitative similarity in accuracy and speed of word production in children and the elderly relative to young adults and mid-age adults. Lower performances at the two extremities of the lifespan giving rise to the bow-shaped curve reflect, among others, lifespan changes in the lexical–semantic networks.

In this work, we address the issues of lifespan changes in word retrieval by considering changes in the organization of the mental lexicon and in the ability to activate its lexical–semantic networks.

1.2. Lexical–semantic network and performance in word production

Language production is semantically driven. Speakers have to select the right word corresponding to the meaning they intend to convey. Words can vary in the number of related semantic features, and they can activate a small or a large number of meaning options. Hence, there is evidence that lexical–semantic properties of the mental lexicon (e.g., semantic association, semantic neighborhood density, categorical/featural organization) can influence language production (Ferrand & New, 2003; Gordon & Cheimariou, 2013; McRae, Khalkhali, & Hare, 2012; Meyer & Schvaneveldt, 1971; Reilly & Desai, 2017; Tree & Hirsh, 2003).

The impact of the lexical–semantic network on word production has been investigated using two quite different approaches. The first approach consists in analyzing the effects of semantically related words on target words in picture–word paradigms (e.g., Costa, Alario, & Caramazza, 2005; Damian & Bowers, 2003; Sailor, Brooks, Bruening, Seiger-Gardner, & Guterman, 2009). Within this approach, the presentation of primes or distractors can induce interfering effects and sometimes facilitating effects on word production (e.g., Abdel Rahman & Melinger, 2009; Mahon, Costa, Peterson, Vargas, & Caramazza, 2007; Sailor et al., 2009). Different kinds of semantic relationships have been manipulated, such as associative versus coordinate relations (e.g., Alario, Segui, & Ferrand, 2000; Sailor et al., 2009), semantic coordinates (e.g., “horse”–“cow”; Costa et al., 2005; Damian & Spalek, 2014; Zhang, Feng, Zhu, & Wang, 2016), associates not being coordinates (e.g., “bee”–“honey”; Abdel Rahman & Melinger, 2007; Alario et al., 2000; Damian & Spalek, 2014), subordinates (e.g., “bee”–“insect”; Costa, Mahon, Savova, & Caramazza, 2003; Hantsch, Jescheniak, & Mädebach, 2012; Hantsch, Jescheniak, & Schriefers, 2005), superordinates (e.g., “flower”–“rose”; Damian & Abdel Rahman, 2003;

Hantsch et al., 2005; Roelofs, 1992), features relations (e.g., Ferrand & New, 2003; Frenck-Mestre & Bueno, 1999; Hutchison, 2003; Lucas, 2000; McRae et al., 2012; Thompson-Schill, Kurtz, & Gabrieli, 1998), and lexical–semantic neighborhood (Bormann, 2011) and semantic richness (e.g., Gordon & Cheimariou, 2013). Yet there is no unique consensus on which semantic relationship has the most influence on word production. In fact, this work shows that, as the mental lexicon is multidimensional, many different lexical and semantic dimensions of words and concepts can modulate language processing (Andrews, Vigliocco, & Vinson, 2009).

A second approach consists in analyzing how the item-specific lexical–semantic network affects word retrieval in terms of semantic neighborhood (e.g., Bormann, 2011; Mirman, 2011), semantic richness, and/or semantic density (e.g., Rabovsky et al., 2016). Rabovsky et al. (2016) in particular revealed that words with a high number of features or with low intercorrelational density were produced faster than words with a low number of features or high density.

It has also been shown that such lexical–semantic factors influence the production of words starting from early childhood to older adults (Roe et al., 2000), with some modulations across ages. A few priming studies reported a different impact of semantic variables on language production depending on the age of the speakers (Balota & Duchek, 1988; Cameli, 1999; Laver & Burke, 1993). Roe et al. (2000) reported that semantic context priming (utterances preceding pictures in a picture-naming task) can induce a facilitation effect from the age of four. These effects remained stable throughout life. The same authors also reported the presence of interference effects at all ages, with larger effects on the youngest children population relative to young and older adults. Increased semantic priming effects have also been reported for both children and the elderly (Chapman, Chapman, Curran, & Miller, 1994) relative to young adults. A meta-analysis by Laver and Burke (1993) showed that the semantic priming effect increases with age on lexical decision and word production tasks.

1.3. Free association tasks and the architecture of the lexical–semantic network

The approach of semantic priming suggests that there are some changes in the semantic organization of the mental lexicon over the lifespan, yet their underlying mechanisms remain unclear. The observed variations of semantic effects on language processing across the lifespan may also be due to the use of measures that are not appropriate for the age of the participants. It is important to point out that multiple approaches have been used across studies to conceive, define, and calculate the organization of conceptual representations of words and bonds between concepts. Such approaches varied from structural organizations in terms of semantic categories (e.g., characterizing the links between concepts from shared features), or lexical nodes (e.g., based on associations or distributional statistics; Bormann, 2011; Martin & Chao, 2001; McRae, Cree, Seidenberg, & McNorgan, 2005; Mirman, 2011; Nelson, McEvoy, & Schreiber, 2004; Rosch, 1975; Saffran, 2000; Vigliocco, Vinson, Lewis, & Garrett, 2004; Zannino, Perri, Teghil, Caltagirone, & Carlesimo, 2017). Different ways to define the lexical–semantic organization of

the mental lexicon and its properties may have different implications with regard to its impact on language processing. More crucially, normative data on the lexical–semantic organization used in these approaches have often been computed from young adults.

Although the organization of the mental lexicon has been mainly studied based on features or categories, it has been suggested that word associations, or lexical–semantic associations, represent a window on the mental lexicon and its lexical–semantic organization, that is characterized by a more general and more impartial approach (De Deyne, Navarro, Perfors, Brysbaert, & Storms, 2018). Lexical–semantic associations have also been used to explain performance in memory and language tasks (McRae et al., 2012). In practice, lexical–semantic associations norms are computed from a task in which a participant is asked to produce the word that first comes to mind in response to a cue. Although this task may seem to rely on episodic memory at first, several studies highlighted that most lexical–semantic associations that are provided are semantic in nature (Santos, Chaigneau, Simmons, & Barsalou, 2011; Vivas, Manoiloff, García, Lizarralde, & Vivas, 2019; e.g., dog-bone, hammer-nail, lemon-sour, zebra-stripes). Lexical–semantic associations can thus be used as lexical blueprints to define words in semantic memory (Deese, 1966). Hence, this task would probably nicely capture changes in the lexical–semantic network across the lifespan. Interestingly, there is recent evidence of lifespan changes in the structure of the semantic information attributed to each concept and the association network (Dubossarsky, De Deyne, & Hills, 2017), in the conceptual representation and organization (Nelson & Goodman, 2002), and in the links between words within the lexicon (Dubossarsky et al., 2017; Zortea, Menegola, Villavicencio, & Salles, 2014; see Wulff, De Deyne, Jones, & Mata, 2019). A step forward in our understanding of the lifespan modifications of the lexical–semantic organization has indeed been recently done by Dubossarsky et al. (2017), who investigated the association networks in 10- to 84-year-old people, by collecting data from over 8,000 individuals. The authors asked Dutch participants from nine age-groups to give three associates in response to 15–42 cue words from a list of 420 words. Their results indicated mainly a U-shaped pattern for the association network across lifespan, with a network which converges and is more structured in early life, and a reverse pattern in late life. However, as highlighted by the authors, the patterns observed in late adulthood cannot be considered merely as the inverse of those in childhood, and their productions of associates did not revert to the same structure.

The way speakers represent the meaning of words and the way they use the lexical–semantic network to retrieve words for production evolves in the course of life. One may thus wonder to what extent such differences in the structure of lexical–semantic organization affect word planning processes and performance in picture naming. The lifespan curve of performance in a word production task, and the curve of free association networks, seem to both follow a U-shaped trend: It is therefore very likely that these two factors are somehow related. In the current study, we seek to bring new insights into this matter by examining whether the lexical–semantic association network at a given age predicts the production of word in the same age-group on top of the same semantic variables collected from young adults (the age-group usually used in many studies on this topic).

To this aim, we first collected free lexical–semantic associations in 240 French native speakers aged 10–81 years (Study 1) and computed different measures that capture modulations in the lexical–semantic organization of, and access to, the mental lexicon across the lifespan. We then use these measures to predict performance in picture naming in 120 other participants aged 10–81 years (Study 2) and test whether age-specific lexical–semantic factors have better explanatory power than factors conventionally obtained in young adults.

2. Study 1. Collection of lexical–semantic associative data

2.1. Methods

2.1.1. Items selection

In all, 204 words were selected for the collection of associative norms. They were all concrete French nouns, corresponding to animated and unanimated concepts. The words varied in terms of length, semantic category, lexical frequency, and AoA (see Appendix S1). The 204 items were divided into two random lists of 102 items each.

2.1.2. Participants

In all, 240 participants volunteered to take part in the study. They were equally divided into six age-groups: “children” (10- to 13-year old; $M_{\text{age}} = 12.03$; $SD = 1.05$; 18 males), “adolescents” (16- to 18-year old; $M_{\text{age}} = 17.28$; $SD = 0.82$; 13 males), “young adults” (20- to 30-year old; $M_{\text{age}} = 22.45$; $SD = 1.88$; 20 males), “adults” (40- to 50-year old; $M_{\text{age}} = 46.93$; $SD = 3.14$; 11 males), “young-old adults” (58- to 68-year-old; $M_{\text{age}} = 61.73$; $SD = 2.80$; 23 males), and “older adults” (69- to 81-year old; $M_{\text{age}} = 75.87$; $SD = 3.53$; 7 males). Participants were all right-handed (according to the Edinburgh Handedness Scale; Oldfield, 1971) and native French speakers, without diagnosed neurological disease or language or speech disorders. All individuals gave written informed consent for their participation in this experiment, which was approved by the local faculty ethics committee of the University of Geneva (FPSE, University of Geneva, Geneva, Switzerland).

2.1.3. Procedure

A free lexical–semantic association task was used. For each word, the subjects had 10 s to say orally all associated words that came to mind. The experimenter read a cue item aloud to the participant and stopped the counter after 10 s, then moved to the next word. Each item was presented to 120 participants, 20 in each age-group. The order of the items within a list was the same for all participants. The entire session lasted around 30 min. All the responses were tape-recorded and transcribed online, then checked offline.

2.1.4. Analyses

The following measures were derived for each word and age-group:¹

1. The mean number of free associates given for each cue word in 10 s (M_{Nb}), which represent the *Available Richness* of the lexical–semantic network;
2. Two measures of the *Network Prototypicality* expressed by the relationships between cue words and their associates: Network Prototypicality obtained from the *first associate* given for each word (H_{1st}) and the Network Prototypicality considering *all associates* given for each item (H_{All}). Zannino et al. (2017) argued that the quantification of the cross-subject consistency in the associates produced for a cue word and the measure of name agreement are superimposable from a statistical point of view. Therefore, we calculated the H statistic for each word in each age-group, considering only the first associate given by the participants (H_{1st}) as well as considering all the associates given for each word (H_{All}), to estimate the scattering of the concept semantic network corresponding to cue words. We computed H using the following equation:

$$H = \sum_{i=1}^k p_i \log_2 \left(\frac{1}{p_i} \right),$$

where k represents the number of different associates produced from subject (considering the first associate, or the total number of associates they given) and p_i refers to the proportion of subject (for the considered age-group) producing each associated word. A small value of H corresponds to a high Network Prototypicality.

Other authors refer to this H measure as the entropy of the distribution derived from continued associations, and the mean number of associates as degree (De Deyne, Navarro, & Storms, 2013). To facilitate understanding of psychological processes related to our tasks, we chose to use labels that reflect the cognitive concepts, rather than the network concepts, that are behind the measures, hence using Available Richness and Network Prototypicality.

To evaluate lexical–semantic associative changes across ages, the data for each measure (Available Richness as the mean number of associates, Network Prototypicality for the first associate, and Network Prototypicality for all associates given), averaged per each word across participants from each age-group, were submitted to linear mixed models with age-groups as fixed factor and items as random variable using the R-software (R-project, R Development Core Team; Bates & Sarkar, 2007). Bonferroni corrections were applied to the group comparisons (p value was set at <0.01).

2.2. Results

Since instructions and words were given orally, 10 items were removed because they had other homophones creating ambiguity in the associates. Therefore, the analyses were computed on 194 items. The Available Richness that is the mean number of free associates

given (M_{Nb}), the Network Prototypicality for the first associate (H_{1st}), and for all associates (H_{All}) computed across the 194 items for each age-group are shown in Fig. 1.

The Available Richness was lowest for “children” and “older adults,” intermediate in “adolescents” and “young-old adults,” and highest in “young adults” and “adults” (see

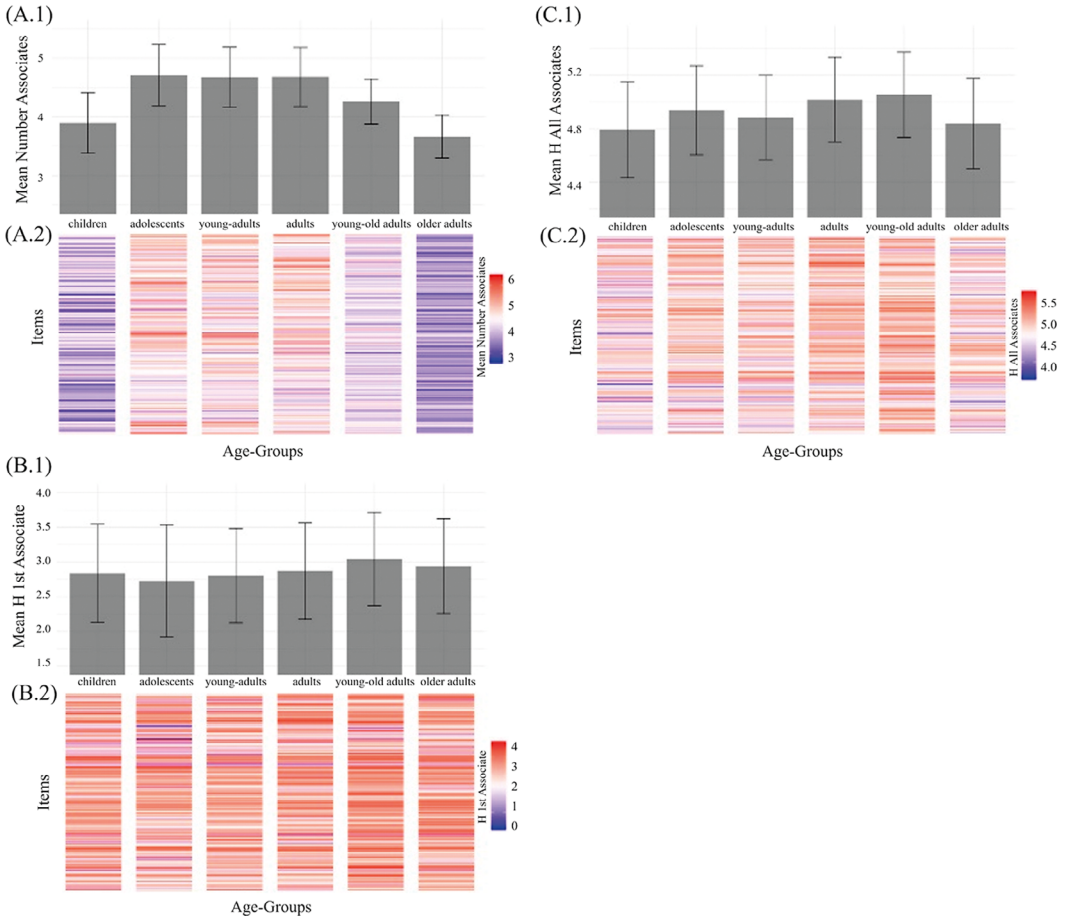


Fig. 1. Mean and standard error across the 194 items for each age-group and for each measure. (A.1) Available Richness, that is, mean number of free associates given (M_{Nb}) averaged over items and participants from a given age-group, (A.2) inter-item variability (within age-group) and intra-item variability (across age-groups) of Available Richness. The measure of M_{Nb} per item is color-coded with low and large Available Richness in blue and red colors, respectively. (B.1) The Network Prototypicality calculated on the first associate (H_{1st}) averaged over items and participants from a given age-group, (B.2) inter-item variability (within age-group) and intra-item variability (across age-groups) of H_{1st} . The measure of H_{1st} per item is color-coded with low and large Network Prototypicality in blue and red colors, respectively. (C.1) The Network Prototypicality on all associates (H_{All}) averaged over items and participants per age-group, (C.2) inter-item variability (within age-group), and intra-item variability across age-groups of H_{All} . The measure of H_{All} per item is color coded with low and large Network Prototypicality in blue and red colors, respectively. On (A.2), (B.2), and (C.2), each bar corresponds to an individual item, and items are sorted in the same alphabetical order across the three measures.

Fig. 1: (A.1)). The main effect of age-groups was statistically significant on M_{Nb} ($F(5, 970) = 378.39, p < .001$). The detailed statistics for group comparisons are presented in Table I in Appendix S1. It can be observed that “children,” “young-old adults,” and “older adults” differed significantly from all the other groups. “Adolescents,” “young adults,” and “adults” do not differ significantly from each other.

On Network Prototypicality of the first associate (H_{1st}) lower values were observed for “adolescents” and “young adults”; intermediate values for “children,” “adults,” and “older adults”; and the highest value for “young-old adults” (see Fig. 1: (B.1)). The age-group effect was significant (H_{1st} : $F(5, 970) = 14.587, p < .001$), with contrasts (Table II in Appendix S1) indicating that “children” differ significantly from all other groups except from “young adults” and “adults,” whereas “adolescents” differ significantly from all other groups except from “young adults.” The group of “young adults” differ significantly only from “young-old adults” and “older adults,” and the group of “adults” differ significantly only from “adolescents” and “young-old adults.” Finally, “young-old adults” differ significantly from all other groups, and “older adults” differ significantly from all other groups except from “adults.”

Lower values for “children” and “older adults,” higher values for “adolescents” and “young adults,” and the highest value for “adults” and “young-old adults” were also observed on Network Prototypicality for all associates given (H_{All} , see Fig. 1: (C.1)). Similarly, there was a significant main effect of the age-group on the Network Prototypicality of associates considering all words given (H_{All} : $F(5, 970) = 46.325, p < .001$), with contrasts indicating that all age-groups differed from each other except “older adults” from “children” and “young adults”; “adults” from “young-old adults”; and “adolescents” from “young adults” (see Table III in Appendix S1).

The representation of individual items across the six age-groups (see Fig. 1: (A.2), (B.2), and (C.2)) shows a variation for each cue word across the lifespan. Moreover, this representation indicates that the evolution pattern for the three semantic variables is not always the same for each item. In fact, even when for two different age-groups the global mean values considering all items together are similar, values for individual items may be different. For example, the very similar low values of mean H_{All} for “children” and “older adults” are not dependent on low values on the same items. This is confirmed by relatively weak correlations between mean H_{All} for “children” and “older adults” ($r(194) = .50$). To further verify whether the distribution of Network Prototypicality and Available Richness across items is similar in the different age-groups, *correlations* were computed between all groups on the M_{Nb} , H_{All} , and H_{1st} measures across the 194 items. Although all uncorrected correlations reach significance (see details in Table IV in Appendix S1), the inter-group correlation are all strong ($r > .60$) only on H_{1st} . On the other two measures (M_{Nb} and H_{All}), strong correlations were observed only between “Children” and “Adolescents” and between “Adolescents” and “Young Adults.” For M_{Nb} in particular, several correlations were quite weak ($r = .25$ between “Children” and “Adults”; $r = .37$ between “Children” and “Older Adults”; $r = .37$ between “Adolescents” and “Adults”), further indicating that the distribution of Network Prototypicality varies across lexical items for the different age-groups.

2.3. Discussion: Study 1

The results of the free semantic association task show an evolution of the lexical–semantic network across the lifespan. In particular, a bow-shaped pattern was found for the Available Richness (i.e., the mean number of associates, M_{Nb}) per age-group, with similar amount of produced associations only between the three central groups (“Adolescents,” “Young Adults,” and “Adults”). Distribution of H_{1st} “Network Prototypicality” (computed on the 1st associate) does not show a clear pattern, higher values can be observed for the two groups of oldest adults. Results on Network Prototypicality computed on all associates given for each item (H_{All}), approached a linear pattern, except for the “Older Adults” group that felt outside this trend with lower values.

These results provide additional evidence for changes in the lexical–semantic network across the lifespan, in agreement with previously reported similar measures of semantic associations by Dubossarsky et al. (2017).

Although vocabulary size increases across the lifespan (Carrol, Warzybok, Kollmeier, & Ruigendijk, 2016), the mean number of associates is maximum in young adults and reduced in older adults. This pattern was observed for virtually each item in the present study (see Fig. 1: (A.2)). The collected measures suggest that the provided associations reflect the reactivation of the cue’s semantic properties. At the level of items, the mean number of associates can thus be considered as a measure of Available Richness of the lexical–semantic network for a given word: The more participants produce words in response to a cue in a limited time period, the more likely the mental lexicon is rich and available. Poorer associations may reflect narrower lexical–semantic networks and/or difficulty in accessing it. Variability in the size and availability of the lexical–semantic networks can be found at the level of the cue words and at the level of the participant. The latter variability may be at least partly attributed to executive functions. In fact, the mean number of answers given by the speakers in 10 s could be influenced in elderly subjects by slower processing speed (e.g., Salthouse, 1996), rather than by the characteristics of the mental lexicon. Note that lower Available Richness (less associates given in 10 s) in elderly participants does not necessarily reflect that they provide a poorer variety of words than younger adults or children.

Compared to the Available Richness, Network Prototypicality seemed to undergo a less structured change in the course of life, in particular for H_{1st} . This lack of a clear lifespan pattern on Network Prototypicality may indicate that the Network Prototypicality computed when considering only the first associate word is less representative of the semantic network of speakers in a specific age-group. Another possible explanation is the lack of sufficient variability in the associates given to the cue words, since they all represent very concrete entities (e.g., objects, animals), but it is not evident whether a clearer pattern would appear when using abstract words. This measure reflects “cross-subject consistency” on the first associate, which may not change so much across the lifespan. In other terms, the first word that comes to mind may be similar *within* each group, but it does not mean necessarily that it is the same word *across* age-groups. In the following, we discuss the results suggesting that our measure of H_{All} better captures

the consistency between subjects for each word's network. Hence, the variation across age-groups would reflect the dynamics of the prototypicality of links between words in the mental lexicon.

What do we mean by cross-consistency? The more subjects are consistent, that is, the more subjects give the same words, the lower the value of Network Prototypicality (H_{All}). This means that similar associates are retrieved and produced for a given target word. In turn, this suggests that the neighboring network of this particular target word is similar across individuals. This reflects the notion of prototypicality. Indeed, as mentioned by Martindale and Moore (1988), the activation of elements that code prototypical items is easier and faster because of the higher strength of these elements within the mental representation. By contrast, higher H_{All} values for a given target word, and in the end for a given group of age, suggest a less prototypical network of words in the mental lexicon. Yet this reasoning also implies an extrapolation of the across-individuals measure of associates to the strength of the links between members of the semantic network at the individual level. In short, low H_{All} values for a given word reflects great consistency between subjects, which in turn likely suggests that links between words in that lexical-semantic network are well-trained.

As vocabulary and language experience likely increase linearly during development, we could have expected a linear decrease in cross-subject consistency and thus an increase in H_{All} . However, cross-subject consistency is higher (H_{All} is lower) not only for the youngest group but also for the other extreme of the lifespan. The trend seems to be the one described, up to the "Young-Old-Adults" group. One attempt to interpret this result is that in the "Older-Adults" group, the present measure of Network Prototypicality is influenced by the fact that they produce fewer associates. According to this interpretation, the words that are produced by the last group may be the most frequent ones or those whose links are the strongest in the mental lexicon and therefore which are less affected by aging, such as problems of transmission of information for example (e.g., Burke & Shafto, 2004).

While taking all these considerations into account, there are nevertheless clear changes in the architecture of the mental lexicon in the course of life. This is also corroborated by the observation that many between-group correlations across items for M_{Nb} and H_{All} are far from being strong. This means that for M_{Nb} and H_{All} , in particular, changes across groups do not reflect a mere systematic decrease/increase in processing speed, but that different words have different number of close associates and different cross-subject consistency across age-groups, reflecting changes in the lexical-semantic organization. Hence, the results cannot be explained exclusively by changes in execution function with ageing, also because "young-old adults" have larger H_{All} , and "older adults" have similar range of H_{All} statistics than "young-adults," who allegedly have optimal resources and executive functions as compared to elderly speakers.

It is also important to note that H_{All} is computed for each group independently, considering the different associations produced within a group. Hence, when groups are compared, it is regardless of the differences in number of words produced.

Finally, if for exploratory purpose we look at the lifespan variation considering items individually, we can observe that for M_{Nb} the expected pattern is present and very clear for all the items (see Fig. 1 (A.2)). Even if the maximal peak can be in any of the middle groups (i.e., “adolescents,” “young adults,” “adults,” or “young-old adults”), we can observe that children and the elderly have always the lower values. Conversely, the evolution of Network Prototypicality shows different patterns across ages depending on items (see Fig. 1 (B.2)). This may also explain the absence of a clearer shaped evolution pattern across age-groups for the Network Prototypicality measure considering all the items at the same time. This is particularly important as it suggests two fundamental findings. First, taking data obtained in group of young adults, as it is done in general, may lead to inappropriate findings. Second, the global mean of an age-group is not always representative for all items. In fact, the trend of each item taken individually may not coincide perfectly with the average trend of all items across age-groups. Instead, it may be more useful and accurate to consider age-specific data to explain memory and language tasks in different groups of individuals and to run the analyses considering values for each item individually. This is what we test in Study 2, by taking into consideration the age-specific lexical–semantic values by item.

Assuming that such lexical–semantic factors have an influence on word selection and retrieval, and given their lifespan modulations, it is fundamental to take into account the age-specific parameters of the mental lexicon when analyzing their impact on word processing. In Study 2, we investigated whether age-specific semantic Available Richness/Network Prototypicality are better predictors of word production than the semantic one collected only in young adults, as usually done in previous studies.

3. Study 2. Picture-naming task

In this second study, we took advantage of the number of semantic associations and Network Prototypicality measures obtained in Study 1 to investigate whether age-specific semantic factors predict naming speed and accuracy in the corresponding age-groups better than the same factors obtained only from young adults, as done in previous studies (e.g., Newman & German, 2005). In fact, we want to determine how far these new mental lexicon measures can influence word production. To this aim, we collected picture-naming data from participants spanning the same six age-groups of Study 1 and analyzed how the non-age-specific (i.e., collected in the classic young adults age-group) and the age-specific semantic factors predict production accuracy and speed. Furthermore, given that the pattern is not always the same at the item level, we consider crucial to carry out the analyses by taking into account the values of the semantic measurements at the level of the individual items using mixed-effects models.

3.1. Methods

3.1.1. Materials

In all, 120 stimuli were selected for the picture-naming task corresponding to monosyllabic ($N = 40$), bisyllabic, ($N = 60$), and trisyllabic ($N = 20$) concrete French words. The words' corresponding black and white pictures were afterward taken from two French datasets (Alario & Ferrand, 1999; Bonin, Peereman, Malardier, Méot, & Chalard, 2003). Their lexical frequency varied from 0.13 to 227 occurrences per million words (mean = 17.3) in the French database Lexique (New, Pallier, Brysbaert, & Ferrand, 2004). The items corresponded to words with an age range of acquisition of 1.19–3.55 on a 5-point scale (1: learned between 0 and 3 years; 4: learned between 9 and 12 years), meaning that all the words were acquired before the age of the youngest age-group (i.e., 10- to 13-year old). For each item, the following psycholinguistic variables were available from the mentioned databases: lexical frequency (Freq), number of phonemes composing each word (Nb_{phons}), AoA, visual complexity, and familiarity from the above-mentioned databases. To ensure that participants gave consistently the same name for a same picture (see Alario et al., 2004), the selected stimuli had a name agreement over 75% (mean = 92.5%). The three lexical–semantic association measures from Study 1 were available for each of the six age-groups for 115 items.

3.1.2. Participants

A total of 120 participants, who did not take part to Study 1, from six different age-groups participated in the study, namely: “children” (10- to 13-year old; $M = 11.1$; $SD = 0.788$; 10 males), “adolescents” (16- to 18-year old; $M = 16.6$; $SD = 0.995$; 9 males), “young adults” (20- to 30-year old; $M = 24.3$; $SD = 3.114$; 9 males), “adults” (40- to 50-year old; $M = 45.75$; $SD = 3.754$; 8 males), “young-old adults” (58- to 68-year old; $M = 63.95$; $SD = 3.187$; 10 males), and “older adults” (69- to 81-year old; $M = 73.8$; $SD = 4.2$; 9 males). Participants were all right-handed (according to the Edinburgh Handedness Scale; Oldfield, 1971) and native French speakers, without diagnosed neurological disease or speech disorders and normal or corrected-to-normal vision. All subjects gave informed consent and were volunteer participants.

3.1.3. Procedure

The participants were installed individually in a dimly lit, sound-attenuated room and seated at approximately 60 cm of a computer screen. The stimuli were presented by the E-Prime software (E-Studio). During an experimental trial, first a fixation cross was presented for 500 ms on the screen, and then the picture appeared for 2,000 ms on a gray screen. Participants were asked to overtly produce the word corresponding to the picture as fast and as accurately as possible. To name each picture, participants had 2,000 ms; responses not entered in this interval were classified as “no response.” Every time, before the following trial, a blank screen lasting 2,000 ms was displayed. All the responses were recorded with a microphone and digitized. Stimuli appeared in two possible

pseudo-randomized orders differing across participants. After giving instructions to the participants, a training with four additional (filler) items preceded the tasks' trials, to familiarize subject with the task.

3.1.4. Analyses

Production latencies (reaction times, RTs) between picture and vocal onset, and accuracy were systematically checked with a speech analyses software (Check-Vocal; Protopapas, 2007), which makes it possible to visualize both waveforms and spectrograms of a verbal response.

For the first analyses, mean RTs and Accuracy data for each of the 120 items and each of the 120 participants were analyzed with the R-software (R-project; Bates & Sarkar, 2007; R Development Core Team, 2014) using linear mixed models for RTs and generalized mixed models according to a binomial distribution for accuracy with age-group as the independent variable. Analyses were performed with packages lmerTest (Kuznetsova, Brockhoff, & Christensen, 2015) and Lme4 (Bates et al., 2017).

For the second analyses, the semantic factors collected in Study 1 (M_{Nb} , H_{All} , H_{1st}) were entered as independent variables in the mixed multiple regression models along with the other psycholinguistic factors mentioned above, namely, AoA, frequency (Freq), number of phonemes (Nb_{phons}), name agreement (NaH), and age-group (Group). At first step, to adhere to what has been done in previous studies, we only included the semantic Available Richness and Network Prototypicality measures from the group of young adults (20–30) and verified if it interacted with age-groups. Given the significant interaction (see Section 3.2), we then run the same analyses with the age-group specific values of M_{Nb} , H_{All} , and H_{1st} for each item.

The fixed part of each model is detailed in the results section after consideration of multicollinearity.

3.2. Results

3.2.1. Group results

Slower production latencies were observed for “children” and “older adults,” “adolescents” and “young-old adults” showed intermediate latencies, and the fastest latencies were found for “young adults” and “adults” (see Fig. 2 (A)). The model with only age-groups as fixed factor indicates a significant effect of age-group on RTs ($F(5, 113.82) = 4.30, p < .01$). The “children” group significantly differs from all the other groups (all $p < .01$), except the “older adults” ($p = .13$; see details in Table V in Appendix S1).

Lower Accuracy was also found for “children” and “older adults,” and higher Accuracy was observed for “adolescents,” “young-old adults,” “young adults,” and “adults” (see Fig. 2 (B)). The main effect of the age-group was also significant on Accuracy ($\chi^2(5, N = 110) = 37.105, p < .01$), with only “children” significantly differing from all other groups (all $p < .01$; see Table VI in Appendix S1).

3.2.2. Semantic and other predictors of performance

The correlations between the psycholinguistic factors on the 115 items are presented in Appendix S1 (Table VII). To test for multicollinearity, the tolerance of the models was checked with the VIF function (Field, Miles, & Field, 2012), with RTs as dependent variable (see Table VIII in Appendix S1), considering all variables of interest without including inter-correlated variables in the same models (i.e., Nb_{phons} and Freq, as well as the two measures of Network Prototypicality, were not entered in the same models, but were tested separately). All VIF were smaller than 10 (mean of $VIF = 1.16$), which is

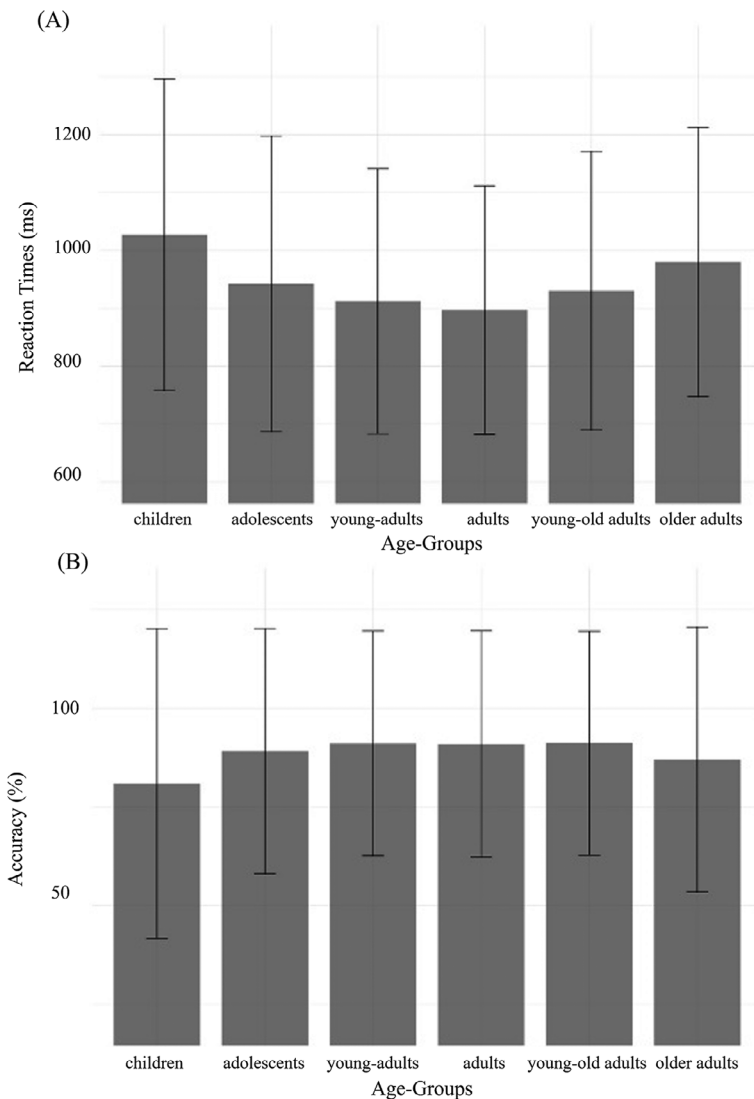


Fig. 2. Mean RTs (A) and Accuracy (B) with SD for each age-group in the picture-naming task.

considered acceptable (Bowerman & O’Connell, 1990; Myers, 1990). As the mean of VIF is only slightly larger than 1, the model was not biased (Bowerman & O’Connell, 1990).

Before testing the effect of age-specific lexical–semantic measures, we verified if the semantic variables collected in the usual young-adult groups (20- to 30-year old) (hereafter $M_{Nb20-30}$, $H_{All20-30}$) interact with age-groups on word production latencies (RTs) or on Accuracy. These analyses showed no significant main effect of the semantic variables on RTs (see Table 1, “Model 20-30”) nor on Accuracy (see Table 2, “Model 20-30”). Main effects of AoA, of NaH and of age-group were observed on RTs and on Accuracy, in addition to a significant interaction between Age-Group and $H_{All20-30}$, while a significant interaction between Age-Group and $M_{Nb20-30}$ was found on Accuracy (for more details, see Table IX, “Model 20-30” in Appendix S1).^{2,3}

The absence of a main effect of the semantic factors collected from the young-adult group, and the interaction with age-groups, warrants further analyses on the semantic variables collected from each specific age-group.

To confirm the relevance of these analyses, we run a comparison between the two models: the model including M_{Nb} and H_{All} only in “Young Adults” (M1 with $M_{Nb20-30}$ and $H_{All20-30}$) and the model including the semantic factors from the corresponding each age-group for each item and participant (M2 with $M_{Nb\ Age-specific}$ and $H_{All\ Age-specific}$). Results showed a lower AIC for the M2 model (AIC = -6,362.9) than for model M1 (AIC = -6,350.7). The R^2 for M2 model was slightly higher ($R^2 = 0.4925$) than for M1 model ($R^2 = 0.4915$). The comparison of the two models by one-way ANOVA revealed a significant difference between the two models ($\chi^2 = 12.225$; $p < .001$), with M2 being the best one (see details in Table XI in Appendix S1).

Therefore, in a subsequent model, semantic association data specific to the age-group of each participant were entered along with the same other psycholinguistic variables described above. In addition to a significant effect of AoA, NaH, and Age-Group, a strong effect of M_{Nb} and a marginal effect of H_{All} ⁴ was observed on RTs (see Table 1, “Model Age-Specific,” and details in Table IXa, “Model Age-Specific” in Appendix S1), which remained statistically significant even after removing the AoA, Freq, or the Nb_{phons} from the models. The effects indicate faster production speed when the semantic network was richer (higher M_{Nb} , $\beta = -2.097e^{-02}$) and more prototypical across subjects (lower H_{All} , $\beta = 1.833e^{-02}$). The two semantic variables seem to have no effect on Accuracy, as only a very marginal trend was observed for M_{Nb} (Table 2, “Model Age-Specific,” and more details in Table IXb, “Model Age-Specific” in Appendix S1).

3.3. Discussion: Study 2

In the picture-naming task, despite lifespan U-shaped and bow-shaped patterns on RTs and Accuracy, only the group of “children” differed significantly from all other age-groups. Similar to previous studies (e.g., Belke & Meyer, 2007; Evrard, 2002; Valente & Laganaro, 2015), we could not find a significant decrease in speed in single object naming in older adults. Valente and Laganaro (2015) reported that the age difference between

Table 1

Results of the mixed effect models on RTs: (1) Model 20-30, with the lexical–semantic predictors from the “young-adults” age-group ($M_{Nb20-30}$, $H_{All20-30}$) and their interaction with age-groups and (2) Model Age-Specific, with the age-specific lexical–semantic predictors (age-specific M_{Nb} and H_{All})

RTs		
Variables	(1) Model 20-30 $F(\text{NumDf}, \text{DenDf})$ p value	(2) Model Age-Specific $F(\text{NumDf}, \text{DenDf})$ p value
Age of Acquisition (AoA)	18.91 (1, 108.0) <0.001***	21.89 (1, 110.1) <0.001***
Number Phonemes (Nb_{phons})	3.62 (1, 107.6) 0.06	3.28 (1, 109.5) 0.07
Name Agreement (NaH)	5.12 (1, 108.7) 0.03*	4.71 (1, 110.7) 0.03*
Frequency (Freq)	0.01 (1, 107.5) 0.93	0.35 (1, 110.4) 0.56
Group	2.40 (5, 5,029.9) 0.03*	3.23 (5, 116.2) 0.009*
Available Richness 20-30 ($M_{Nb20-30}$)	0.41 (1, 107.7) 0.52	Not included
Network Prototypicality of All Associates 20-30 ($H_{All20-30}$)	1.7 (1, 107.5) 0.19	Not included
Available Richness (M_{Nb} Age-Specific)	Not included	13.64 (1, 10,281.1) <0.001***
Network Prototypicality of All Associates (H_{All} Age-Specific)	Not included	3.98 (1, 10,445.9) 0.046*
$M_{Nb20-30} \times \text{Group}$	1.24 (5, 11,613.6) 0.28	Not included
$H_{All20-30} \times \text{Group}$	2.65 (5, 11,613.7) 0.02*	Not included

Notes. (1) Model 20-30: $\text{lmer}(\log(\text{RTs}) \sim \text{AoA} + Nb_{\text{phons}} + \text{NaH} + \text{Freq} + \text{Group} + M_{Nb20-30} + H_{All20-30} + M_{Nb20-30}:\text{Group} + H_{All20-30}:\text{Group} + (1|\text{Subject}) + (1|\text{Items}))$.

(2) Model Age-Specific: $\text{lmer}(\log(\text{RTs}) \sim \text{AoA} + Nb_{\text{phons}} + \text{NaH} + \text{Freq} + \text{Group} + M_{Nb \text{ Age-Specific}} + H_{All \text{ Age-Specific}} + (1|\text{Subject}) + (1|\text{Items}))$.

* $p < 0.05$; *** $p < 0.001$.

younger and older adults was significant only on the low frequency items. Therefore, it is possible that the lack of significant difference across adult groups may be due to the selection of the stimuli in the present study, as all the words had to be known also by the youngest group (i.e., “children”).

Concerning classical psycholinguistic predictors of word production, we observed significant effects of AoA of words and Name Agreement (NaH), which have been repeatedly reported in the literature (e.g., Morrison, Ellis, & Quinlan, 1992; Newman & German, 2005; Perret, Bonin, & Laganaro, 2014). The direction of the observed effects was similar to previous work: RTs were faster for early-acquired words and for words with high Name Agreement. We will therefore not comment on them further, but

Table 2

Results of the generalized mixed effect models on Accuracy: (1) Model 20-30, with the lexical–semantic predictors from the “young-adults” age-group ($M_{Nb20-30}$, $H_{All20-30}$) and their interaction with age-groups and (2) Model Age-Specific, with the age-specific lexical–semantic predictors (age-specific M_{Nb} and H_{All})

Accuracy		
Variables	(1) Model 20-30 χ^2 (Df) <i>p</i> value	(2) Model Age-Specific χ^2 (Df) <i>p</i> value
Intercept	0.20 (1) <0.001***	15.32 (1) <0.001***
Age of Acquisition (AoA)	14.99 (1) <0.001***	16.67 (1) <0.001***
Number Phonemes (Nb_{phons})	0.95 (1) 0.33	0.91 (1) 0.34
Name Agreement (NaH)	18.77 (1) <0.001***	17.89 (1) <0.001***
Frequency (Freq)	0.94 (1) 0.33	2.20 (1) 0.14
Group	21.97 (5) <0.001***	25.72 (5) <0.001***
Available Richness 20-30 ($M_{Nb20-30}$)	1.32 (1) 0.25	Not included
Network Prototypicality of All Associates 20-30 ($H_{All20-30}$)	1.22 (1) 0.27	Not included
Available Richness (M_{Nb} Age-Specific)	Not included	3.05 (1) 0.08
Network Prototypicality of All Associates (H_{All} Age-Specific)	Not included	0.03 (1) 0.85
$M_{Nb20-30} \times$ Group	13.93 (5) 0.02*	Not included
$H_{All20-30} \times$ Group	12.85 (5) 0.02*	Not included

Notes. (1) Model 20-30: $glmer((Accuracy) \sim AoA + Nb_{phons} + NaH + Freq + Group + M_{Nb20-30} + H_{All20-30} + M_{Nb20-30}:Group + H_{All20-30}:Group + (1|Subject) + (1|Items), family = \text{“binomial”})$.

(2) Model Age-Specific: $glmer((Accuracy) \sim AoA + Nb_{phons} + NaH + Freq + Group + M_{Nb} \text{ Age-Specific} + H_{All} \text{ Age-Specific} + (1|Subject) + (1|Items), family = \text{“binomial”})$.

* $p < 0.05$; *** $p < 0.001$.

consider that their replication warrants the reliability of our new results on the semantic factors.

Interestingly, independently of age-group differences in word production accuracy and latencies, only age-specific semantic factors predicted the word production speed. Crucially, the values of semantic Available Richness and Network Prototypicality collected on the young adult group (20–30 years) in Study 1 did not predict performance in picture naming on the whole group of participants aged from 10 to 80, but interacted with age-groups. Conversely, the significant effects of Available Richness and Network Prototypicality considered for each specific age-group indicate faster production speed when the semantic

network is richer and more prototypical across subjects (to note, however, that this latter result is only marginal). Easier access to a large number of words in the lexical–semantic network, and more prototypical associations across subjects, likely reflect highly frequent associations in discourse, which facilitate word retrieval in picture naming. In fact, this may reflect stronger word-to-word links in people’s minds. These results will be discussed in the General discussion along with the age-group effects observed in Study 1.

4. General discussion

The main aim of this study was to investigate changes in lexical–semantic organization across the lifespan and determine to what extent age-specific properties of the mental lexicon predict word production. To verify the hypothesis that age-specific Available Richness and/or Network Prototypicality of the semantic network predict word production in a referential naming task better than Available Richness and Network Prototypicality collected on young adults, we first conducted a free semantic association task in six age-groups (Study 1) and used the collected data to predict performance in a picture-naming task (Study 2).

As previously discussed (see Section 2.3), results of the free semantic association tasks showed an evolution of the semantic network in the course of life. The Available Richness of the semantic network seems to follow a reverse U-shaped pattern. The Network Prototypicality of the semantic network approaches a linear pattern, except for the oldest group. Overall, we can observe larger Available Richness in the middle age-groups relative to the extremes (children and older adults) along with lower Network Prototypicality. The observed trend of the evolution of the semantic network is in line with previous results found by Dubossarsky et al. (2017) who also used a free association task in a larger sample of participants.

As discussed in Study 1, the observation that the group of “older adults” produced fewer associates (Available Richness) may suggest lower performance due to changes in execution functions. This result would therefore be specifically related to the time constraint in the data collection procedure (associates produced in 10 s). However, the executive interpretation does not hold when the same results are analyzed in terms of Network Prototypicality, as the patterns displayed by the group of “older adults” is similar to the pattern observed in “young-adults.”

There is probably no ideal way to tackle the richness of the lexical network, the present approach is nevertheless a better proxy to network richness than a task that focuses only on the first (or first three) associates of a cue word. The procedure used in the present study with a time constraint also allows a better understanding of the change in the course of life of word retrieval skills.

The present results also relate more generally to lexical–semantic changes across the lifespan. It is known that with increasing experience with language, vocabulary increases throughout life (e.g., Brysbaert et al., 2014), and the relationship between words changes (Dubossarsky et al., 2017). This is in line with the observation that Network

Prototypicality increases with age (due to the decrease in cross-subject consistency). Surprisingly however, the cross-subject consistency is higher in the “older adults” group (H_{All} is lower), similarly to “children.” This result, along with lower values of Available Richness, may correspond to differences in lexical–semantic organization and different mental lexicon processing abilities in the two extremities of the lifespan as compared to the middle groups. In particular, the associate words produced by the two extreme groups of the lifespan may be the most “typical” ones or those whose links are the strongest in the mental lexicon.

Similarities at both extremities of the lifespan could also be interpreted as evidence in favor of retrogenesis of lexical–semantic processes in aging (Reisberg et al., 1999; Simoes Loureiro & Lefebvre, 2016), that is, a return to a similar organization of the semantic memory in elderly people as in children. Note that it would require to determine precisely which networks and connections between words are maintained or weakened in aging, and whether it matches the available lexical–semantic system in children.

Finally, performance in the picture-naming task (Study 2) also follows a U-shaped and a bow-shaped trend across age-groups, although differences between groups did not reach significance for older adults.

4.1. Age-specific lexical–semantic network and performance in word production

A first observation is that the lexical–semantic network, investigated with a free association task, undergoes changes in parallel with changes in word production speed and accuracy throughout life. This observation is corroborated empirically by the crucial result that the M_{Nb} and the H_{All} specific of the participants’ age-group predict performance in word production: Word retrieval was faster for items that have a richer (high M_{Nb}) and a more prototypical across subjects (low H_{All}) semantic network. Importantly, such effects were obtained only when the lexical–semantic network corresponding to each specific age-group was considered. By contrast, the Available Richness and Network Prototypicality of the lexical–semantic network measured on young adults ($M_{Nb20-30}$ and $H_{All20-30}$) did not predict performance in participants aged from 10- to 80-year old.

In other words, the fact that a word has a rich (or simply a more available) and prototypical (between subjects) network at a given age seems to determine the speed of word production. These results were observed only on RTs, not on Accuracy. The absence of results on Accuracy is very likely the consequence of high Accuracy in all the participants due to the selection of words which had to be known by our youngest group. It is however also possible that the semantic variables considered here are more related to the speed of retrieval of a word, rather than to the integrity or success of the action.

4.2. Available Richness versus Network Prototypicality

An interesting result is related to the difference between a strong effect of Available Richness (M_{Nb}) and a minor effect of (age-specific) Network Prototypicality measurement (H_{All}) on latencies. At first sight, the observation that the strength of the links between a word and its associates has a minor impact on its production suggests that the strength of

the related network (the structure of the semantic network) is less important than its extent (i.e., the size of the semantic network). However, different interpretations can be considered. As mentioned in Section 2.3, the H measure used in the current study may not fully reflect the same properties of “Density” of the network, in comparison to the measures considered by other authors (e.g., Rabovsky et al., 2016), who reported an effect of this variable on word production. Rabovsky et al. (2016) reported a negative effect of the “Density” of the network, that is, in terms of inhibition on performance in a similar picture-naming task. However, their “Density” measure was computed from semantic features or properties obtained with a semantic feature generation task (collected by McRae et al., 2005) and not from free semantic associates. Features are highly dependent on stimuli category, as they are shared with other words that are in a taxonomic relationship (Mirman, Landrigan, & Britt, 2017; e.g., “wood”–“table,” “beak”–“bird”). By contrast, our measure of H (Network Prototypicality) is computed on free semantic association that is known to elicit more thematic associations. Category-related (taxonomic) and thematic associated words have shown opposite effects in picture–word interference studies, with respectively interference (e.g., Costa et al., 2005) and facilitation (e.g., Mahon et al., 2007; or for a review see also Nozari & Pinet, 2020). In the same line, whereas the measures used by Rabovsky et al. (2016) capture categorical organization thus leading to interference, our measure rather captures associations and strength of links, thus a richness that lead to easier production.

Finally, the stronger effect of M_{Nb} relative to H_{All} may be related to the characteristics of those semantic variables and their relevance according to the task used. As opposed to H_{All} , M_{Nb} is probably the variable that captures a characteristic of the network (available richness) but also the ability to access, retrieve, and use the words that make up the network. Hence, this could lead us to think that the free production of associate words within 10 s may reflect the accessibility of the related words more than the extension of the network. The consequence that may arise to this reflection is that the network might be similar across ages, but the selection of associated lexical items may vary according to age simply because of the speed of lexical selection. This can explain the similarity between the bow-shaped curve across ages in naming latencies and in the number of associates in Study 1. Yet, the other results reported here do not fit with this only explanation. Indeed, if the number of associates given in each age-group reflected only age-related processing speed, and not different networks across ages, the across item correlation between age-groups should have been much larger than what observed (see Section 2.2 and Table IX in Appendix S1). Moreover, the prediction of picture-naming speed should not have been dependent upon age-specific measures.

4.3. How does a rich network facilitate word production?

An issue which needs to be discussed is why a word associated with a richer network or with more available associated words is produced faster than a word with a poorer network or less accessible associates. In other words, why a more dynamic, functional, and

accessible semantic network promotes the retrieval of the words which are embedded in such networks?

A possible interpretation can be found in studies reporting an impact of lexical–semantic networks in word *comprehension*. Better performances on words with stronger association strength have also reported in semantic judgment tasks for instance (Chou, Wong, Chen, Fan, & Booth, 2019). Those results have been interpreted in the framework of spreading-activation (Collins & Loftus, 1975), where an increased activation of the semantic network induces a more efficient access to the target word.

A more specific question to the present results in word *production* then is: Which of word production process is accelerated vs. slowed down by the presence of a more or less functional semantic network? As previously said, the facilitation observed in the picture–word interference paradigms may be close to the effects reported here. Facilitation for associate primes has been interpreted mainly at the pre-lexical (conceptual) and lexical levels, with the activation of the related conceptual nodes spreading to lexical nodes and speeding up lexical selection (Dell & O’Seaghdha, 1991; Mahon et al., 2007). Other models however speculate on the facilitation due to associate words at post-lexical (phonological) levels (Python, Fargier, & Laganaro, 2018; Starreveld & La Heij, 1995). In such accounts, semantic and phonological nodes are interconnected, and interact, making possible to the phonological nodes of the target word to receive activation from both the concept depicted in the picture and the related word(s). Differently from the picture–word paradigm, the facilitation of naming with a rich semantic network is not related to an explicitly provided associate word, but seems rather related to the automatic activation of the association network while naming a picture. Such effect seems compatible with different explanations. At the lexical level, lexical selection may be facilitated by a well-trained semantic network. If, instead, the semantic network affects post-lexical processes, in the case of a large M_{Nb} the links between lexical–semantic and phonological representations are expected to be stronger (e.g., “semantic binding hypothesis” by Patterson, Graham, & Hodges, 1994) and therefore word encoding may be faster. The more the semantic representations are activated quickly, the more they strongly activate the phonological representations through a distributed neuronal network (Python et al., 2018). Conversely, when the word is embedded in a semantic network which is not very prototypical and less accessible, lexical selection is not facilitated and/or links between semantic and phonological lexical representations are weaker and are therefore activated less rapidly.

4.4. *How does a more prototypical network facilitate word production?*

Despite the only marginal effect of H_{All} , interpretation of this effect fits the previous ones. When H_{All} is small (and thus the network more prototypical), there is a lower variability in the associates of the system and the bonds of the network are therefore stronger. The lexical–semantic and phonological representations would therefore be more strongly connected. On the contrary, with a large H_{All} (corresponding to a less prototypical system), there would be larger variability hence the links in the network would be weaker.

The lexical–semantic and phonological representations would therefore be more weakly connected and the recovery of the word would be less efficient. However, as previously said, the H measure could also be considered as a cross-subject consistency measure that reflects prototypicality within a group of subjects. It remains unclear to what extent it is representative of the semantic network of each subject taken individually, a caution note that is also valid for other studies (see Wulff et al., 2019).

5. Conclusion

The current study provides additional empirical evidence that the organization of the mental lexicon changes across the lifespan. We showed that the measures of the lexical–semantic network states at a specific age is a better predictor of word production speed in picture-naming tasks than the measures obtained in young adults only, predominantly used in previous studies.

Future work is needed however to understand what properties determine the lifespan evolution of the lexical–semantic network proper to each word. It has been shown that the more heterogeneous were the responses to cue words, the more likely these words showed age-related changes in their lexical–semantic associations (Dubossarsky et al., 2017). Yet, the information that can be gained from cross-subjects consistency measures remains unclear. To the same extent, the way the mental lexicon architecture across the lifespan constrains the spreading activation across related lexical–semantic nodes, affecting word retrieval and encoding, also needs further exploration. In conclusion, our results thus call for the use of age-specific norms in psycholinguistic studies. Indeed, age-specific lexical–semantic organization may be missed when the semantic features or association data used to predict the word processing at different ages is collected only on a sample of young adults (Ferrand & Alario, 1998; McRae et al., 2005). Finally, our work may also have several implications in the understanding of the lexical–semantic organization of the mental lexicon and for theories of lexical access.

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Notes

1. Mean values of the three lexical–semantic variables for each concrete word and for each age-group are available on this website: <https://www.doi.org/10.26037/yareta:vd6ilyw5l5cabb7e2td3tqrn6y>.

2. For exploratory purposes, we run the same analyses using the semantic features from McRae, Cree, Seidenberg, and McNorgan (2005), namely number of features (M_{Features}) and their Entropy (H_{Features} , corresponding to our Network Prototypicality), which were available for 75 items. Given the correlation between these two variables ($r = .98$, $p < .001$), only one measure was kept in the model at time. Results show no significant main effect of any of these two factors, but a significant interaction of both M_{Features} and H_{Features} with age-groups (see Table X in Appendix S1). Hence, the semantic variables issued from McRae et al. (2005) did not predict performance in picture naming on the whole group of participants aged from 10 to 80 years similarly to what observed with our Available Richness and Network Prototypicality collected on the young adult group (20–30 years). In addition, to evaluate the relevance of the difference in the choice of measures (associates vs. features), we run a comparison between the two models: the model including M_{Nb} and H_{All} only in “Young Adults” ($M_{\text{Nb}20-30}$ and $H_{\text{All}20-30}$; M1a) and the model including these variables calculated on McRae et al (2005) database (M_{Features} and H_{Features} ; M2a). Results showed a lower AIC for the M1 model (AIC = 4,098.1) relative to the M2 model (AIC = -4,092.1). However, the comparison of the two models by one-way ANOVA revealed a non-significant difference ($\chi^2 = 0$; $p = 1$). This latter result suggests that the difference in the way we collect our semantic variables on young adults is not relevant.
3. The same analyses were also run using Available Richness (M_{Nb}) and Network Prototypicality (H_{All}) data averaged across all age-groups from Study 1. The model on RTs indicate no significant effects of the two semantic predictors averaged across all groups (M_{Nb} for All Groups: $F(1, 107.62) = 0.43$, $p = .51$; H_{All} for All Groups: $F(1, 107.63) = 1.88$, $p = .17$). On Accuracy, an effect of the Network Prototypicality was observed without effects of Available Richness (M_{Nb} for All Groups: $\chi^2 = 0.23$, $p = .63$; H_{All} for All Groups: $\chi^2 = 4.19$, $p = .04$). All together, these results do not allow us to consider that these semantic variables are the best predictors when merging all age-groups.
4. In the model without M_{Nb} , keeping only H_{All} as semantic variable, the main effect of H_{All} is not significant. This means that the effect of this variable is very weak and probably partially carried by the other semantic variable (M_{Nb}).

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Appendix S1. Supplementary Material: Additional details on the analysis and results discussed in the article.