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► **To cite this version:**

Angéline Bourbon, Anne Hermes. Have a break: Aging effects on sentence production and structuring in French. 12th International Seminar on Speech Production, Dec 2020, Virtual, United States. pp.102-105. hal-03510934

HAL Id: hal-03510934

<https://hal.science/hal-03510934>

Submitted on 4 Jan 2022

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Have a break: Aging effects on sentence production and structuring in French

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Abstract

Across life span there is inter alia a change in respiration in that with increasing age, the ribcage cannot expand and contract as well during breathing and the diaphragm becomes weakened. These changes are expected to affect the control of breathing and thus also prosodic structuring. Studies investigating the effects of aging on speech breathing with respect to prosodic structuring are relatively sparse and mostly limited to English. Investigating the behaviour of the speech system in the aged population will provide insights into how linguistic structures are realized on different phonological and prosodic tiers, when the physical system is challenged. In this study, we investigate the effects of aging on durational parameters related to sentence structuring (i.e., length and complexity) in French. The results provide evidence that (i) both age groups (younger and older speakers) produce phrasal breaks at expected syntactic boundaries, with (pause) durations that are sensitive to sentence structure. Furthermore, (ii) a clear age effect can be observed: older speakers produce longer pauses, longer sentence durations and lower articulation rates across all structures than younger speakers.

Keywords: Aging, speech production, pauses, articulation rate, sentence length, sentence complexity, French

1. Introduction

1.1. Aging effects on speech

Aging is part of a more fundamental question concerning the evolution of the production system and the relations between the different dimensions interacting in speech such as the physiological level, motor control, cognitive capacities, adaptability and individual strategies.

The overall claim is that acoustically we are dealing with a slower speaking rate in older subjects (Amerman & Parnell 1992, Ramig 1983). For example, there is a decrease of speech rate in fast syllable repetition tasks for older subjects (Bilodeau-Mercure & Tremblay 2016). However, there are also some contradictory results, where there no age-related differences were found (Pierce *et al.* 2013). One has to keep in mind, that certain sounds and structures are more compressible than others, hence slowing down is not expected to take place homogeneously (Fletcher 2010). Furthermore, it is unlikely that age-related reduction in speaking rate compares to intentional rate reduction in younger individuals (e.g., when attempting to speak clearly). A study by Kang & Dingwell (2008) on general motor control revealed that a slower walking tempo due to aging is not the same as an intentionally slower walking tempo at a younger age.

1.2. Prosodic structure and pauses

Prosodic structure is essential in speech communication as information needs to be highlighted to convey specific linguistic meaning. This highlighting includes both the

planning and the production of larger prosodic constituents, such as the utterance, and smaller prosodic constituents, such as the syllable.

We know that maintaining subglottic pressure is essential to produce the sound of speech throughout the exhalation period which is longer than a breathing cycle without speech production. This lengthening of the exhalation phase is due to the muscular control of the rib cage, diaphragm, chest and abdominal muscles (Haynes & Netsell, 2001). Research on aging effects have shown that with increasing age, the expansion and contraction of the ribcage during breathing is affected due to a weakening of the diaphragm, entailing less effective muscle control in breathing (Kahane 1981). These changes could possibly result in the production of shorter sentences on average.

Evidence has been provided that speech breathing in older subjects revealed higher lung volume to initiate speech and longer sentences are split into smaller units with less breathing at larger units and more breathing at smaller units (Hoit & Hixon 1987; Huber 2008). Thus, the production of more pauses in long and complex sentences, i.e., commas-indicated could reflect this age-related phenomenon. In Huber (2008), it has been shown that indeed older speakers produce in general shorter utterances than the younger speakers. Furthermore, age effects aggravated with utterance length. Beside the reported age effect, the study by Huber (2008) provided evidence that both age groups adjusted speech breathing depending on the upcoming utterance length, thus showing a plan a priori.

In a study by Fuchs *et al.* (2013), prosodic planning in a German reading task was investigated to shed light on how sentence length and complexity affect certain parameters, such as pause duration, inhalation depth and inhalation duration. They provided evidence that the length of a sentence had an effect on the above mentioned parameters, whereas complexity did not.

This acoustic study aims to shed light on the effects of aging on prosodic structuring in French by analysing several durational parameters in sentences differing in length and complexity.

2. Methods

2.1. Subjects

We collected acoustics recordings from 27 French native speakers (18f, 9m) which we grouped into ‘younger’ (14 subjects, 23-44 years, mean 34 ± 8.01) and ‘older’ group (13 subjects, 68-88 years, mean 80 ± 5.53). All subjects had a normal or corrected-to-normal vision and no self-reported speech, voice, language, psychological, neurological, or neurodegenerative disorder at the time of the study. Older participants were screened for cognitive alterations using a standardized clinical tool, the Mini-Mental State Examination (MMSE, Folstein *et al.* 1975). All participants were above the 24/30 threshold (mean $28,52 \pm 1.79$). The number of years of

education of the participants was on average 16.37 years (± 1.27) for the younger group and 12.08 (± 3.25) for the older group. The study was approved by the local Ethics Committee of the University Sorbonne Nouvelle and the French National Ethical Committee for the Protection of Persons (ID-RCB:2019-A02553-54).

2.2. Material

The speech material consisted of sentences (based on Fuchs *et al.* 2013), varying in length (short vs. long) and complexity (simple vs. complex), e.g., for short-simple condition “Mélanie Dupont a réservé ses vacances” (Engl. *Mélanie Dupont booked her holidays*) and for long-complex condition “Mélanie Dupont a dit à sa mère, qui l’a appelée dans la matinée, qu’elle attend avec impatience ses vacances.” (Engl. *Mélanie Dupont told her mother, who called her in the morning, she’s looking forward to her vacation.*). For each of the four conditions (short-simple, short-complex, long-simple, long-complex), we designed three different versions (Table 2). Each sentence was repeated three times, i.e., in total each speaker produced 36 sentences. The order was randomized for sentence structures, identically for each speaker, except for 2 speakers (i.e., one from each group) who only produced one version of the sentences (i.e. 12 sentences), resulting in 924 sentences. Participants were seated in a quiet room in front of a laptop with a FocusRite® sound card and a head mounted microphone (SHURE SM35-TQG) recording with Python software (using *pyaudio*) at 48 kHz sampling rate.

2.3. Measurements

To test the age effects on the production of these sentences, differing in length and complexity, we analysed: (1) the FREQUENCY OF PAUSES, where pauses are marked as breaks produced at comma-indicated boundary, and additional breaks; (2) SENTENCE DURATION was measured with the whole duration of the sentence (including pauses); (3) PAUSE DURATION and (4) ARTICULATION RATE, as the number of phonemes divided by sentence duration, excluding pauses.

Annotations were done manually in Praat (Boersma & Weenink 2017). Segmentation of pauses was done by visual and audible inspection (Fig. 1), taking as criteria the major intonational boundaries, the marking of syntactic autonomy and the absence of hesitation. Boundaries were segmented as clear visual (using the oscillogram and spectrogram) and audible breaks in the speech stream, including inspiratory and physiological phenomena (e.g., breathlessness, glottalization, etc.). The measurement was consistent and constant within each speaker, the threshold of excluded pauses was below 100ms (pauses <100ms were discarded).

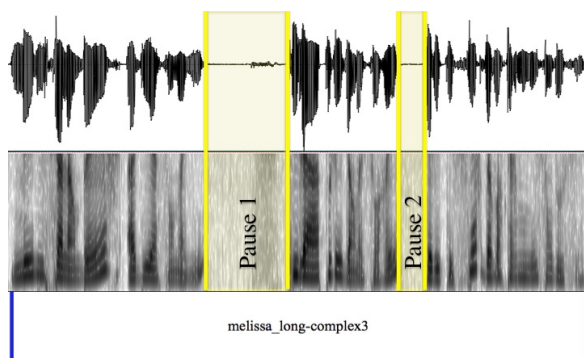


Figure 1: Example of a 'long-complex' sentence segmentation.

2.4. Statistics

The data were analysed with a series of mixed models using the library ‘lme4’ (Bates *et al.* 2015) of the R software (R Development Core Team 2008) and posteriori contrast analyses were carried out with the *lsmeans* function for each analysis. We built three mixed models for sentence duration (SENTENCE_DUR), pause duration (PAUSES), and articulation rate (RATE). As fixed factors we included AGE (younger vs. older), the sentence structure (SENTENCE) and the interaction between AGE and SENTENCE. The random structure of our models was ITEM as intercept and SPEAKERS and SENTENCE as random factors.

3. Results

Results for the analysed variables will be presented in the following.

(1) FREQUENCY OF PAUSES: Both age groups produced the majority of pauses at expected comma-indicated boundaries in the complex conditions. In short-complex, the younger group produced pauses in 41% of the sentences compared to 61% in the older group. The long-complex condition entailed more pauses for both age groups (younger: 57%; older 80%). In the long-simple condition, we observed for the older groups 68% pauses (compared to 11% in the younger group), although we did not expect pauses due to no comma-indicated boundaries.

Table 1: FREQUENCY OF PAUSES across sentence structures and age groups.

Condition	Younger	Older
short-simple*	10%*	14%*
long-simple*	11%*	68%*
short-complex	41%	61%
long-complex	57%	80%

* unexpected pauses

We refer to ‘expected’ pauses as those marked by commas (see speech material in Table 2). We considered the two pauses in the complex conditions as one category. We found a balanced marking of pauses at the first and second comma for the short-complex condition (younger = 48 vs. 51 times; older = 68 vs. 68 times). However, we found a difference in the long-complex condition, where a pause was produced more often at the second comma (younger = 58 vs. 78 times; older = 83 vs. 95 times).

(2) The total SENTENCE DURATION, including the pauses, is presented in Figure 2. First, in both age groups, we observed that sentence duration increased with length and with complexity. Furthermore, we see that in the older group, sentence durations were even longer than in the younger group. Thus, the longer and complex a sentence, the longer its duration, with age even more affecting it. For example, in long-complex condition for younger speakers on average was 485 ms, whereas it was 669 ms for older speakers. Averaged across all conditions, older speakers in general produced about 133 ms longer sentences.

The model shows an effect of AGE ($p < 0.001$) and SENTENCE ($p < 0.001$) on SENTENCE_DUR. Sentence duration is longer for the older group than the younger group across all four conditions (short-simple, $p < 0.001$; short-complex, $p < 0.001$; long-simple, $p < 0.001$; long-complex, $p < 0.001$). We found an increase of duration depending on length and complexity, except between condition short-complex and long-simple for younger group.

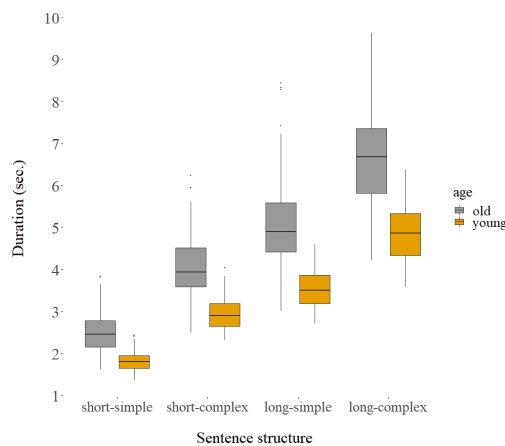


Figure 2: SENTENCE DURATION in seconds – across sentence structure (short-simple, short-complex, long-simple, long-complex) and age groups (younger vs. older).

Beside the remarkable increase in sentence duration for older speakers, we also observed a higher variability for the older speakers ($SD \pm 136$ ms).

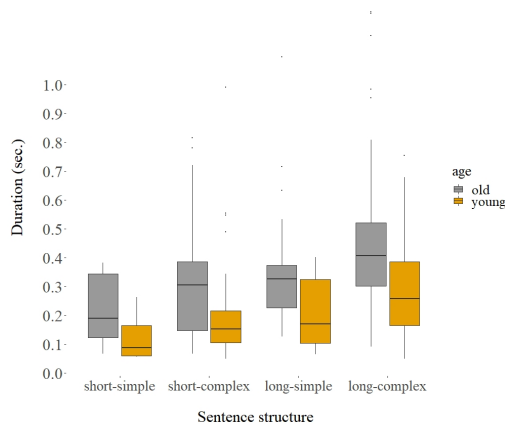


Figure 3: PAUSE DURATION in seconds – across sentence structure (short-simple, short-complex, long-simple, long-complex) and age groups (younger vs. older).

Figure 3 displays the results for the variable (3) PAUSE DURATION. Both age groups showed an increase in the duration of the pauses depending on the length and complexity of the sentence (e.g., pauses at first comma: younger: short-complex=171 ms vs. long-complex=228 ms; older: short-complex=308 ms vs. long-complex=420 ms). Furthermore, all pause durations were much longer for older than for younger speakers (on average 120ms longer).

Pause duration was not affected by age in simple sentence condition, whereas pauses were significantly longer for older speakers in the complex sentences (long-complex: $p < 0.05$; short-complex sentences: $p < 0.05$). Thus, the biggest age effect is visible long-complex sentences.

(4) For the variable RATE, presented in Figure 4, we observed that speakers with the slowest articulation rate were those who also produced the longest pauses, i.e., the older group.

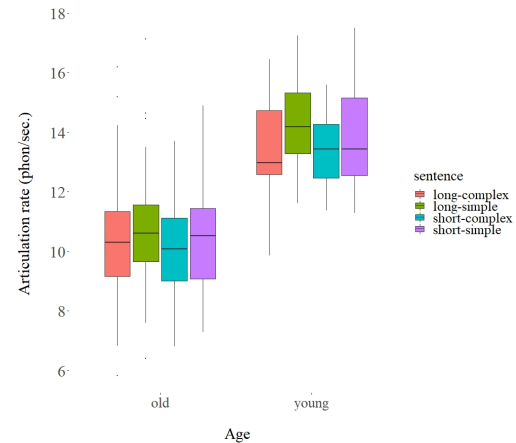


Figure 4: RATE (number of phonemes/sentence duration, excl. pauses) across sentence complexity (short-simple, short-complex, long-simple, long-complex) and age groups (younger vs. older).

We found a difference of 3.30 phonemes/seconds between the two groups, thus, showing that older speakers produced less phonemes per second. The average across all conditions is 13.74 phon./sec. (± 0.30) for the younger group and 10.44 phon./sec. (± 0.18) for the older group. This aging effect was visible in all conditions. The model shows an effect of AGE ($p < 0.001$) on RATE for each condition. Nevertheless, there was no significant effect of sentence structure (length-complexity) on articulation rate for both groups.

4. Discussion and conclusion

This study applied different durational acoustic parameters to shed light on the effect of age on the structuring of sentences, differing in length and complexity. We found more pauses in the production of older speakers in the simple as well as in the complex condition. Furthermore, we were able to show that - in both younger and older speakers - phrasal breaks were produced at expected syntactic boundaries. Moreover, sentence length as well complexity did affect durational patterns, e.g., with longest sentence durations in long-complex sentences (which could be due to an increase in cognitive demands, cf. Swets *et al.* 2013). Age entailed an additional increase in duration, not only in sentence duration, but also in pause duration. Our results further point towards an age-related increase in duration variability, which has been reported before (Smith *et al.* 1987; Tremblay *et al.* 2018).

The observed lower articulation rate for older speakers is in line with the most robust (and reported) age-related effect (e.g., Ramig & Ringel 1983). However, we did not observe an overall effect of sentence structure on articulation rate for older speakers compared to younger speakers. The slowing down of articulation rate in older speakers could inter alia be explained by a slowing-down mechanism to make sure reaching the targets properly (Hermes *et al.* 2018, Mücke *et al.* 2020). A study by Hardy *et al.* (2018) provided evidence that healthy aging can affect some aspects of online planning. However, the increased sensitivity to phrasal boundaries in older speakers might show that they are more sensitive to the reading task.

For the next steps, we aim to analyze potential breathing noises in the pauses (cf. Trouvain *et al.* 2020) as well as provide a detailed segmental analysis.

Table 2: *Speech material for different conditions.*

Sentences	Structure
Mélanie Dupont a réservé ses vacances. (<i>Mélanie Dupont booked her holidays.</i>)	short-simple
Mélicia Lambert a terminé son dossier. (<i>Mélicia Lambert finished her file.</i>)	
Mélocie Moreau a préparé son repas. (<i>Mélocie Moreau prepared her meal.</i>)	
Mélanie Dupont, qui adore le soleil, a réservé ses vacances. (<i>Mélanie Dupont, who loves the sun, booked her holidays.</i>)	short-complex
Mélicia Lambert, qui travaille cet été, a terminé son dossier. (<i>Mélicia Lambert, who is working this summer, has finished her file.</i>)	
Mélocie Moreau, qui habite à Montreuil, a préparé son repas. (<i>Mélocie Moreau, who lives in Montreuil, prepared her meal.</i>)	
Mélanie Dupont a réservé lors d'un froid jour d'hiver ses vacances en Andalousie. (<i>Mélanie Dupont booked her holidays in Andalusia on a cold winter's day.</i>)	long-simple
Mélicia Lambert a terminé la semaine dernière son dossier pour l'Université. (<i>Mélicia Lambert finished her file for the University last week.</i>)	
Mélocie Moreau a préparé durant l'après-midi son repas avec du saumon. (<i>Mélocie Moreau prepared in the afternoon her meal with salmon.</i>)	
Mélanie Dupont a dit à sa mère, qui l'a appelée dans la matinée, qu'elle attend avec impatience ses vacances. (<i>Mélanie Dupont told her mother, who called her in the morning, she's looking forward to her vacation.</i>)	long-complex
Mélicia Lambert a dit à son ami, qui l'a appelé dans la soirée, qu'elle est fière d'avoir terminé son dossier. (<i>Mélicia Lambert told her friend, who called her in the evening, that she is proud to have finished her file.</i>)	
Mélocie Moreau a dit à son père, qui l'a appelé sur son portable, qu'elle est en train de préparer son repas. (<i>Mélocie Moreau told her father, who called her on her mobile phone, that she is preparing her meal.</i>)	

5. Acknowledgements

This work was partially supported by the Swiss FNS (CRSII5_17371/1) and by the French ANR (ANR-10-LABX-0083).

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