TANULMÁNY

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Stem and suffix durations in words of increasing length across the lifespan

A jelen tanulmány célja annak vizsgálata, hogyan változik a különböző hosszúságú szavak időzítési mintázata az életkor előre haladtával (70 beszélő részvételével). A tanulmány arra keres választ, hogy miként tapasztalható rövidülés a szótövekben, illetve a toldalékokban a növekvő szótagszámú szavak esetében, illetve hogyan változik ez a mintázat 7 és 80 éves kor között. A vizsgálati anyagot három adatbázis beszélői alkották, akiknek az ejtésében olyan szavakat elemeztünk, amelyek 1–5 szótagból álló szótövet és 5 különböző, egy szótagos toldalékot tartalmaztak. A toldalékolt szavak és a szótövek szignifikáns különbséget mutattak az időtartamukban az életkor mentén. A toldalékok időértékei azonban relatíve stabilnak mutatkoztak, azok időzítése csak a gyermekek és az idős beszélők esetében különbözött a többiekétől. A szótő hosszúsága nem gyakorolt szignifikáns hatást a toldalék időtartamára. Úgy gondoljuk, hogy a mért időzítési mintázatok funkcionálisan megalapozott jelenségek, amelyek mind a beszédprodukcióban, mind a beszédpercepcióban meghatározók.

1. Introduction

Spoken word production is preceded by a number of underlying processes including the speaker's selection of a syntactically and semantically appropriate word, the retrieval of the word's phonological properties, and preparations for the corresponding articulatory gestures including temporal control over words and parts of words (Levelt, 1999). Duration is a physical parameter of spoken language in that words exist in time. Temporal properties of words are influenced by universal (e.g., physiological), language-specific (e.g., phonetic realizations of phonemic differences of segments), and individual characteristics (e.g., speaker-related behaviour, emotion). Klatt (1975) summarized those factors that form the temporal patterns of speech: extralinguistic factors (e.g., speaker's condition), discourse factors (context-related characteristics), semantic factors ('new' information, emphasis), syntactic factors (e.g., phrase-final lengthening, word-final lengthening), phonological/phonetic factors (e.g., phonological quantity, stress), and physiological factors (e.g., intrinsic time structure).

A large number of studies discussed various factors that influence the duration of a word and the variability therein (Beckman and Edwards, 1990; Losiewicz, 1995; Fougeron and Keating, 1997; Greenberg et al., 2003; Bell et al., 2009; Gósy, 2010; Kuperman and Bresnan, 2012; Redford, 2015; etc.). A branch of studies focused on various linguistic factors like dialects, phrase length, morpheme

properties, part of speech functions, syllabification, word contexts, stress patterns, syntactic position, occurrences (word frequency), etc. while another branch of studies considered psycholinguistic factors like age, speaker, gender, lexical retrieval of words, etc. to explain durational patterns (e.g., Fowler and Housum, 1987; Lindblom, 1990; Beckman & Edwards, 1990; Losiewicz, 1995; Verhoeven et al., 2004; Aylett & Turk, 2004; Quené, 2008; Jacewicz et al., 2010). The repeated utterances of the same speaker with the same intention, under similar conditions are not fully identical – this is a phonetic commonplace (Rose, 1999). Although the articulation gestures during the production of the same word in diverse contexts are relatively stable (in order to be processed appropriately by the listener), the temporal patterns of the same word in diverse contexts might show far wider ranges than the articulation gestures do (without making the listener's speech processing too difficult or vulnerable).

High-frequency words were reported to be shorter than low-frequency words as early as in 1929 (e.g., Zipf, 1929; Walsh & Parker, 1983; Whalen, 1991; Pan & Hirschberg, 2000; Aylett & Turk, 2004; Gahl, 2008; Yang et al., 2013). (Word frequency itself, however, raises many questions and shows a number of various dependencies, see Jescheniak & Levelt, 1994.) Measured word durations were shown to be correlated with part-of-speech affiliation (e.g., Kaiki et al., 1990). These results, however, raise doubt because of the different syntactic positions of the words analyzed. French [a] vowels were shown by Grégoire (1899) to be shorter in long words (e.g., *patisserie* 'confectionery') as opposed to short words (e.g., *pâte* 'pastry', *pâté* 'pie'). Some years later, Hungarian vowels were also observed to be shorter as the number of the syllables of words increased from the word *tát* ('open wide', verb) to the word *tátogatóknak* ('open wide' + frequentative suffix + agentive suffix + plural + dative, noun), see Gombocz & Meyer, 1909. (The phenomenon was largely known as Menzerath's law (1928; 1954). Similar changes in vowel durations as the effect of the increasing length of words were confirmed across diverse languages, like Swedish, Estonian, English, Hungarian, Slovak, Indonesian, etc. (see Lindblom, 1968; Lehiste, 1972; Teupenhayn & Altmann, 1984; Krott, 1996; Turk & Shattuck-Hufnagel, 2000; Tily et al., 2009; Köhler, 2012; Mačutek et al., 2017). No such changes, however, have been found in Finnish (Suomi, 2007). The original Menzerath's law was further developed by Altmann (1978; 1993); the Menzerath–Altmann law claims that corresponding syllables in words containing more syllables are produced shorter than they are in words consisting of fewer syllables (see also Aurajo et al., 2003; Cramer, 2005).

The last syllable (frequently also the previous ones) of the word is lengthened in a phrase-final position (at a prosodic boundary) or before a phrase-final pause resulting in longer duration than that of a segmentally identical phrase-medial syllable. This phenomenon is known as phrase-final lengthening (e.g., Turk & Shattuck-Hufnagel, 2000; Turk, 2007; Nakai et al., 2009; Cho, 2016; Gósy &

Krepsz, 2018). Morphologically conditioned lengthening was shown in the cases of morphemic and non-morphemic /s/ in English (Walsh and Parker, 1983). Also in English, segments were reported to be longer in polymorphemic than in corresponding monomorphemic sequences (Sugahara & Turk, 2009). Morphological boundaries seem to influence stem duration: the stem is shortened when suffixes are added to it in English (Lehiste, 1974). According to the measurements, however, the duration of the whole word containing the suffix was not very much longer (on average) than that of the stem on its own. This phenomenon is not surprising since the majority of words in English spontaneous utterances are monosyllables. The number of segments that the suffix consisted of did not have any systematic effect on the stem duration. The English past tense suffix (*-ed*) on low-frequency verbs was shown to result in longer duration than the addition of *-ed* to matched high-frequency verbs (Losiewicz, 1995).

To our knowledge, there is no research investigating the temporal interrelations between diverse morphemes within a word in an agglutinating language. The core question of our study is whether there is a specific temporal interrelation between stem and suffix considering the morphologically conditioned shortening of syllables. The term 'suffix' is used here for inflectional suffixes attached to nouns and verbs and occurring either directly after the stem or after another suffix. We will focus on noun endings, which indicate the grammatical cases of nouns, and verb endings, which form the conjugation of verbs. These suffixes change the morphological properties of a noun or a verb within their unchanged category. Suffixes used in this study carry grammatical information, like in the word *házban* 'in house' where the stem is *ház* 'house' and the suffix is *-ban* 'in').

Intrinsic durations of stem and suffix in a word may shed light on how the speakers control stem and suffix durations in the words of a language with a rich morphology (e.g., Mousikou et al., 2015). In Hungarian, there are many suffixes (e.g., inflections to nouns, verbs, adjectives and numerals) with various meanings and functions. In spontaneous speech, the majority of words are suffixed words containing frequently more than one suffix. Suffixes govern utterances both grammatically (morphologically) and with respect to speech processing, being decisive also for sentence comprehension (e.g., Bornkessel & Schlesewsky, 2006; Flemming, 2010; Ferreira & Çokal, 2015). For words, the temporal interrelations of stems and suffixes might carry cue information in an agglutinating language about the speakers' lexical access, speech planning of the articulation of lexemes, covert monitoring, as well as about understanding the mechanisms underlying the production of spoken words (Marslen-Wilson et al., 1994; Roelofs, 1996; Vannest & Boland, 1999; Onysko & Michel, 2010; Özdemir et al., 2007).

Age often turns out to be a decisive factor in speech patterns (e.g., Jaczewicz et al., 2010). Temporal phenomena of speech, like speech rate, phrase lengths, word and syllable lengths, interrelations of morphemes within a word, segment durations, etc. are different across ages. The reasons underlying the measured

data, however, seem to be different depending on the particular ages that the studies concern. For the sake of our present study, the intrinsic durational structures of words produced by children, teenagers, and young, young-old and old-old adults are particularly interesting. The core question of our research is whether there are any differences in temporal organization of suffixed words across age groups. The goal of the present study is to explore stem and suffix durations of words of various lengths across the lifespan with Hungarian-speaking subjects.

We will discuss briefly (i) some consequences of language development and ageing that influence the temporal phenomena in the subjects' speech, and (ii) some findings concerning the intrinsic temporal structure of words produced both by children and elderly people based on the literature. Young children and elderly speakers were reported to show longer durations for words than groups of young adults in several studies (e.g., Smith, 1992; Kent, 2000; Torre & Barlow, 2009). The differences are explained by changes in the effectiveness of speech motor control, and accuracy which is underdeveloped in children and declines in the elderly. Age-related changes to speech are attributed to changes in the anatomy and physiology of the speech mechanism, age-specific auditory feedback, as well as diverse psychic and cognitive functions influencing communicative effectiveness (e.g., Wohlert & Smith, 1998; Degrell, 2000; Czigler, 2003; Xue & Hao, 2003; Burke & Shafto, 2004; Zraick et al,. 2006; Rodríguez-Aranda & Jakobsen, 2011).

The development of fluency in children's speech concerns muscular and mental efforts according to Woodruft Starkweather (1980). Although this approach is an obvious simplification, these two core factors are really important when temporal aspects of speaking are concerned. The fact that the articulation of words is getting faster during language acquisition seems to be a commonplace explained by several factors like growing articulation skills, developing speech planning processes, cognitive development, developing motor control, familiarity of words, skilled access to the mental lexicon, etc. (Flipsen, 2006; Bannard & Matthews, 2008). The increase of the number of syllables in words was reported to be 1.15 syllables between the ages of 3 and 5 years based on English-speaking children's conversations (Yaruss, 2000). Another study where 320 (English-speaking) children's word lengths were analyzed claimed this increase to be between 1.06 and 1.42 syllables between 3 and 8 years (Flipsen, 2006).

The temporal patterns of speech can be analyzed focusing on phrases, words, syllables, even segments. Speech tempi and word durations have been confirmed to be age-specific (Horváth, 2014; Krepsz, 2017). The intrinsic temporal structures of words can be analyzed by measuring (i) syllable durations, including various positions of the syllables within the word and (ii) morpheme durations which are particularly decisive in languages with a rich morphology like Hungarian. Several studies suggest that phrase-final lengthening may appear as

early as age 2 (Snow 1994), while other studies show that even eight-year-olds were unable to mark phrase boundaries appropriately (Dankovičová et al., 2004). An analysis of phrase-final lengthening in Hungarian-speaking children's speech showed that the durations of both phonemically short and long vowels were significantly longer in phrase-final positions than in phrase-medial and phrase-initial positions from the age of 3 up to 12. Large overlaps have been found, however, in the 3- and 6-year-old children's data (Horváth et al., 2019). We mentioned the tendency for reduction of syllable durations as word length increases across various languages earlier in this paper (see Menzerath's law). The same applies to temporal organization of syllables in children's speech according to findings with Hungarian-speaking 4-, 5-, and 6-year-old children (Gósy & Krepsz, 2017).

A large number of studies reported that the use of various suffixes increases after the two-word stage of language acquisition (e.g., Walley, 1993; Crystal, 2012). This confirms that children at a certain age are able to segment stems and suffixes as different morphemes as opposed to the earlier 'frozen' lexical units that are devoid of grammatical inflections (Handl & Graf, 2010; Berko Gleason & Bernstein Ratner, 1993). The rich morphological system is reported to be used relatively error-free by the age of 2, for example in Turkish, Spanish, and Hungarian, some time earlier than in the case of languages with less rich morphology due to various reasons (Aguado-Orea & Pine, 2015; Gósy, 2005; Bunta et al., 2016). The order of appearance of suffixes exhibits language-specific properties. Grammatical inflections such as the English plural *-s* in nouns and third person singular *-s* in verbs are acquired at different points in time by young children (Hsieh et al., 2008). Mastering the various suffixes in Hungarian child language starts in the second year of life, in general (Bunta et al., 2016). The increasing morpheme count of words is interpreted as the result of the children's developing motor skills and also some cognitive and non-cognitive factors that influence their development (Redford, 2015).

The development of the durational ratio of stem and suffix(es) in words is reflected in the decrease of suffix durations relative to those of stems. In other words, children regulate the temporal interrelations of stems and suffixes by shortening the durations of suffixes (Gósy, 1997; Gósy & Krepsz, 2017). A child who recognizes that word-like entities are built of 'morphemes' with different meanings and functions, relatively quickly arrives at an inventory containing words and non-words, in our case, suffixes that allow them to apply the adult's pattern for the perceived intrinsic temporal structure of their words. In sum, by the age of 7 Hungarian-speaking children use words with complex morphology, and with various lengths including even 6-syllable words (Horváth et al., 2019).

In sum, by the age of 7 children acquire their native language at a level that they are able to learn to read and write (age-specific phonology and phonetics, grammar, fluency, pragmatics, etc. of the language). Adolescence is a specific

period of selective and rapid oral facial growth and dental arch development (Riski, 1995; Coulmas, 2013). With respect to speech development, this period is characterized by refining and adjusting existing speech skills. Teenagers' speech is a kind of mixture of standard and substandard, dialectal and slang forms (Coulmas, 2013). Their language competence (including continual growth of semantic knowledge that influences their speech production) and language use are still different from that of young adults in many ways (see e.g., Coulmas, 2013; Laczkó, 2013; Oancea, 2016; Libárdi, 2015).

Four adult age groups have been identified for our study: Young adults (in their early twenties), middle-aged (or pre-elderly) adults, young-old and old-old adults. Typical ageing has a natural effect on breathing, musculature, articulation movements, speech motor control, overall speech planning processes, and so on (e.g., Enright et al., 1994; Berry et al., 1996; Bashore et al., 1998). 'Old age', however, does not mean a homogeneous group of people since the factors that naturally influence people when getting old do not operate the same way with each subject (e.g., Degrell, 2000). In addition, cumulative effects of various factors may influence people differently even at the same age (e.g., Bóna, 2010). To gain finer results on temporal aspects of speech, we distributed the range of 'old age' to young-old adults and to old adults (e.g., Kail & Salthouse, 1994). Studies on speech timing of elderly people showed that elderly speakers adjusted the length and durational patterns of their utterances according to their physiological capacity (Winkworth et al., 1995). As expected by experience, old people's speech rate was significantly slower than those of young speakers, they produced significantly slower articulation gestures than young speakers did, and as a consequence, old speakers produced remarkably longer speech sound durations than those of young ones (Kent, 2000; Fletcher & McAuliffe, 2015; Amerman & Parnel, 1992; Huber, 2008; Jacewicz et al., 2010). Although old speakers produced longer vowels in their spontaneous utterances than young speakers did, both their phonemically short and long vowels were significantly longer in phrase-final positions than in initial and medial positions in Hungarian, similarly to those of young speakers (Gósy & Krepsz, 2018). There are studies that report practically no differences in speech timing between young and old speakers, for example in voice onset time measurements or, in temporal parameters in lip and jaw tracking (Sweeting & Baken, 1982; Amerman & Parnel, 1992; Ballard et al. 2001; Brenk et al., 2009).

We assume that age-specific temporal patterns may involve word durations in terms of two interrelated properties: change of syllable durations depending on word length and specific temporal behavior of suffixes. In this study we seek to explore the internal temporal patterns of the words of various lengths across the lifespan (in terms of a cross-linguistic analysis from the age of 7 to 80). The main question of this study is whether there is a morphologically conditioned

shortening of stems and a morphologically conditioned stability of suffixes in Hungarian across ages.

Our current hypotheses are that (i) duration of stems in suffixed words would increase according to number of syllables but differently across ages, (ii) syllable durations of stems would show gradual but age-specific decrease, (iii) suffixes would not show durational changes irrespective of word length and age.

2. Methodology

2.1 Subjects

Seventy speakers were selected to form seven groups: 7-year-olds, 14-year-olds, 17-year-olds, young adults, middle-aged adults, young-old adults, and old-old adults (see Table 1 for all ages and SDs). Each group consisted of 10 speakers (with an equal number of males and females). Teenage and adult speakers were part of the BEA and TiniBEA Hungarian speech databases (see Gósy, 2012; Gyarmathy & Neuberger, 2015), while 7-year-olds were randomly selected from the GABI Hungarian children's database (Bóna et al., 2014).

Table 1. Age details of speakers selected for the study (y=year, m = month, SD=standard deviation)

Age characteristics of the speakers			
mean age (years)	ranges	SD	labels used in the paper (if not the exact mean age)
7	6;10 – 7;2 (y; m)	0.549	children
14	13;10 – 14;3 (y; m)	0.448	teenage speakers/teenagers
17	16;9 – 17;2 (y; m)	0.322	teenage speakers/teenagers
25	24 – 26 (years)	0.774	young speakers
50	49 – 51 (years)	0.831	middle-aged speakers
65	64 – 66 (years)	0.816	young-old speakers
80	79 – 81 (years)	0.788	old-old speakers

We applied the following criteria to identify the age groups. Speakers' biological age was the primary factor to be considered, though aspects of chronological, psychological, and social ages may influence the age categories. We considered also the WHO proposal (www.who.int/healthinfo/survey/ageingdefnolder/en/). Fourteen-year-old teenagers completed 8 years of schooling in this country (and are beginning their secondary education). 17-year-old teenagers approach finishing their secondary education, and are ready to leave their teenage period. Two age groups belong to the period of life generally called 'elderly' which is an umbrella term, and covers diverse periods and thresholds

according to ages. People in their twenties are 'young ones' while those around the age of 50 are middle-aged subjects. The chronological age of 65 years is widely accepted as the beginning of the 'elderly' or 'older period of life'. Speakers falling between 60 and 74 years are generally called young-old. Subjects with ages between 75 and 90 years are the old-old people. In order to diminish the overlaps between age groups, age-specific distances were defined between them according to the age characteristics of lifespan. We have made an effort to keep the speakers' age very close to each other within an age group (considering the specific age).

All speakers had normal hearing, and age-specific good hearing in the case of the elderly at the time of testing. None of them had any speech defects. No known history of delayed onset of language acquisition was reported in children and teenage speakers. All subjects were native speakers of Hungarian as their first language. 7-year-olds had started their schooling and were in the first year of education. All the teenage speakers learned in secondary schools. Adult speakers had either a secondary education or a university degree. Speakers of the oldest group were all retired while only half of those in the young-old group were. All of them had a similar socio-economic status and lived in a large city.

2.2 Speech material

Subjects were asked to speak about their family, life, hobby according to the protocol of both databases. Close to 40 hours of Hungarian spontaneous speech material was analyzed; the average length of speech material of 7-year-old children was 12 minutes, in the case of 14-year-olds it was 25 minutes, in the case of 17-year-olds 34 minutes, while in the cases of adults it was 42 minutes per speaker.

Suffixed verbs and nouns were selected according to the same inclusion criteria (and measurements) in order to control for them as much as possible. (i) Stems consisted of various numbers of syllables from 1 to 5, together with suffix syllables from 2 to 6, (ii) 5 frequent monosyllabic suffixes, three nominal (*-ban/-ben* 'in', *-nak/-nek* 'for', *-val/-vel* 'with') and two verbal (*-tam/-tem* '1sg past', and *-nak/-nek* '3pl') were selected that indicated grammatical relationships, (iii) all suffixes were the last syllables of the words preceded only by the stem, (iv) all words occurred in the middle of a phrase (in order to avoid phrase-final lengthening), (v) the suffixes occurred in similar ratios across stems and speakers. The two forms of the suffixes containing either a front or a back vowel (e.g., *-nak/-nek*) refer to the vowel harmony requirements in Hungarian (e.g., *olvas+nak* '/they/ read' vs. *beszél+nek* '/they/ speak').

Examples of various suffixed words:

Nouns: *fiú+ban* 'in /a/ boy', *fiú+nak* 'for /a/ boy', *fiú+val* 'with /a/ boy'

Verbs: *olvas+tam* '/I/ read (past)', *olvas+nak* '/they/ read (present)'

The following examples demonstrate the increasing number of syllables in the stems both in nouns and verbs followed by a suffix (stems are marked by bold letters):
Nouns: ***ház****ban* ‘in /a/ house’, ***újság****ban* ‘in /a/ newspaper’, ***kalapács****ban* ‘in /a/ hammer’, ***szerkesztőség****ben* ‘in /an/ editorial office, ***vizsgaidőszak****ban* ‘during examination time’.
Verbs: ***száll****nak* ‘/they/ fly’, ***tanul****nak* ‘/they/ learn, ***foglalkoz****nak* ‘/they/ deal /with something/’, ***kommunikál****nak* ‘/they/ communicate’, ***csoportosíta****nak* ‘/they/ categorize’

No monomorphemic words could be used as possible comparisons to suffixed words due to the inappropriate number of such words (low occurrences of words without suffixes but with comparable last syllables) in Hungarian spontaneous speech. A total of 10,430 suffixed words were selected for analysis (Table 2). Although the number of words was different across ages, the distribution of words according to their lengths was very similar (Figure 1).

Table 2: Distribution of words analyzed according to the number of syllables the words contain and ages.

Number of words analyzed								
Syllables of words	Mean age (years)							Total
	7	14	17	25	50	65	80	
2	38	252	546	878	270	306	144	2434
3	126	210	1146	2046	837	567	189	5121
4	60	184	804	1400	548	468	468	3932
5	20	80	585	515	335	135	270	1940
6	60	24	36	228	90	162	108	708
Total	304	750	3117	5067	2080	1638	1179	10,430

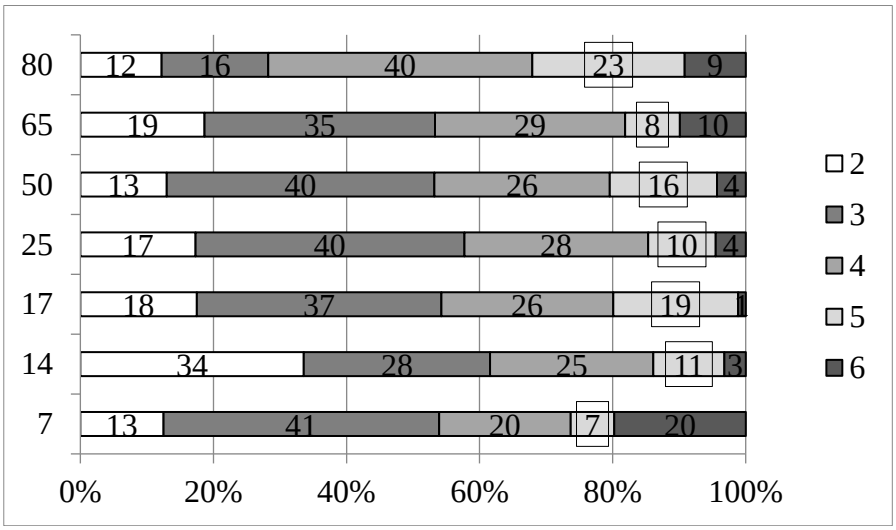

Figure 1. Ratios of occurrences of the words analyzed according to word lengths (number of syllables) and ages

2.3 Measurements

The speech material was carefully hand-labeled using Praat (Boersma & Weenink, 2014). Boundary location reliability was assessed at the time of segmentation using the labelers' confidence as a measure. Suffixed words, stems, stem syllables, and suffixes were segmented by one of the authors while the other author checked each marking with an agreement ratio of higher than 98%. In cases of disagreement, a third phonetician was asked to decide. The word and syllable boundaries (between acoustically distinct regions in the signal) were identified in the waveform signal and spectrogram display via continuous listening to the words. Markers were inserted at the closure and release of obstruents, and at the onset of voicing after the release in stops following standard acoustic-phonetic criteria (see Turk & Shattuck-Hufnagel, 2000).

Durations of suffixed words, stems and suffixes as well as all syllables of the stems were taken by measuring the duration between the onsets and the offsets of the stems, their syllables and suffixes (respectively). In case of (i) coarticulation at the boundary of stem and suffix that resulted in a long segment (marked by bold in the example), like *fiúna**k kellett* [fiju:nɔ**k**:ɛl:ɛt:], and (ii) a phonemically long consonant, like *á**ll**atnak* [a:**l**:ɔtnɔk] the word was excluded in order to obviate segmentation problems. A specific script was written to obtain the values automatically.

To test statistical significance, General Linear Mixed Models and pairwise comparisons have been used (SPSS 20.0 version). Measured durations of stems, suffixes, and suffixed words were dependent variables while number of syllables of the stems, word class, age and gender were the independent factors. The confidence level was set at the conventional 95%.

3. Results

The starting point of the analysis is to be informed about the temporal values of the suffixed words produced by speakers of ages between 7 and 80 years (Table 3). The 7-year-olds articulated the longest words followed by the old-old and the 17-year-old speakers with specific differences among them according to word lengths. The 14-, 25-year-olds and middle-aged speakers had the shortest word durations. The temporal properties of suffixed words produced by 65-year-olds are similar to those of the latter age groups but the durations are in some degree longer in their case.

Table 3: Measured durations of suffixed words according to the number of syllables of words and ages

Ages (years)	Durations of words with various lengths (ms)						
	Syllables of words (stem+suffix)						
		2	3	4	5	6	Mean
7	mean	721	936	1105	1327	1302	1078
	SD	131	413	174	194	261	
14	mean	367	473	585	735	751	582
	SD	113	101	78	74	109	
17	mean	717	763	861	1073	975	878
	SD	254	365	263	302	221	
25	mean	411	567	696	754	812	648
	SD	119	137	187	220	268	
50	mean	339	467	616	764	798	597
	SD	106	118	146	162	229	
65	mean	354	596	701	894	1061	721
	SD	75	122	90	117	108	
80	mean	460	657	829	1059	1651	931
	SD	62	83	145	136	285	

Durations of the suffixed words showed significant differences depending on both word length [$F(4, 10430) = 861.817$; $p < 0.001$] and age [$F(6, 10430) = 139.173$; $p < 0.001$]. The factor of word class (i.e., whether the stem was a noun or a verb) and gender had no effects on durations of suffixed words.

3.1. The effect of increasing word length on stem durations across ages

The mean duration of the stems irrespective of the number of syllables and ages was 544 ms. Mean durations of the stems turned out to be longer than 700 ms with 7-year-olds (754 ms) and close to this value with old-old speakers (691 ms). Young-old speakers' mean value exceeded 500 ms while those of all the other subjects from 14-year-olds up to middle age adults were below 500 ms. There was practically no difference in the mean stem duration values of 17-year-olds and 25-year-olds (481 ms, 495 ms, respectively). Young-old speakers had shorter durations (465 ms) than the 17-year-olds and 25-year-olds, and the 14-year-olds produced the shortest durations (410 ms). Stem durations showed significant differences depending on age [$F(6, 10430) = 83.006$; $p < 0.001$]. Pairwise comparisons showed no significant differences between 14-year-olds and all the other groups (with the exception of old-old speakers). Similarly, no significant differences could be proved between 14-year-olds and 25-year-olds or between 14-year-olds and 50-year-olds.

Analyzing the stem durations depending on the increase of stem length, a significant increase of stem durations can be seen across ages [$F(6, 4413) =$

217.862; $p < 0.001$], see Table 4 for the mean values. We found the most spectacular increase of stem durations in the cases of 7-year-olds and old-old speakers. Moderate increase was found for 14- and 17-years olds, while the stem durations show the least increase with young, middle-aged and young-old speakers. Out of the latter speakers the 50-year-old speakers' stem durations were the shortest meaning the least increase depending on word length (Figure 2). The factors of 'word class' and 'gender' had no effects on the durations of stems.

Table 4: Measured durations of stems according to the number of syllables and ages

Number of syllables of words	Duration of stems (ms)						
	Mean age (years)						
	7	14	17	25	50	65	80
2	347	192	341	212	193	175	235
3	554	303	355	373	315	390	424
4	750	408	375	516	459	479	592
5	957	562	609	617	613	670	825
6	1162	584	724	757	746	866	1377

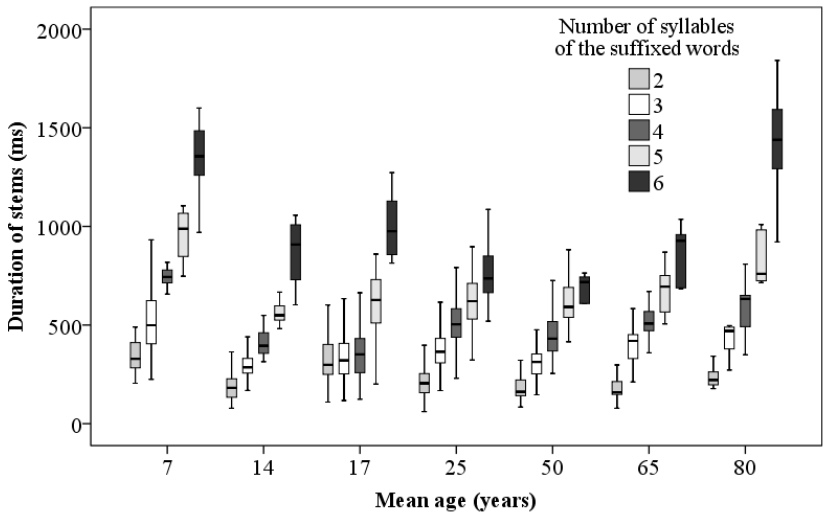

Figure 2. Durations of stems across word lengths and ages (median and ranges)

3.2 The effect of increasing number of syllables on suffix durations across ages

The duration of suffixes ranged between 146 ms and 265 ms in adult speakers' speech, on average. 7-year-olds and teenage subjects produced the suffixes longer, between 155 ms and 374 ms, on average (Table 5). The durations of suffixes depending on word length were similar in all age groups (Fig. 3). Significant differences were found between the different age groups ($F(6, 10430) = 259.450$; $p < 0.001$). 7-year-olds produced the longest suffixes while 50-year-olds produced

the shortest ones. Young-old and old-old speakers had longer suffixes than those of younger adults and teenagers. The length of stems did not have any significant effect on suffix durations in either group. The mean duration of the nominal suffixes was 189 ms while that of the verbal suffixes was 208 ms irrespective of ages and word lengths; the differences did not turn out to be significant depending on word length.

Table 5: Measured durations of suffixes according to the number of syllables of words and ages

Number of syllables of words	Duration of suffixes (ms)						
	Mean age (years)						
	7	14	17	25	50	65	80
2	374	175	164	202	146	179	222
3	347	170	155	203	152	207	227
4	335	177	154	208	157	222	232
5	370	174	160	189	163	223	228
6	362	167	158	190	159	195	265

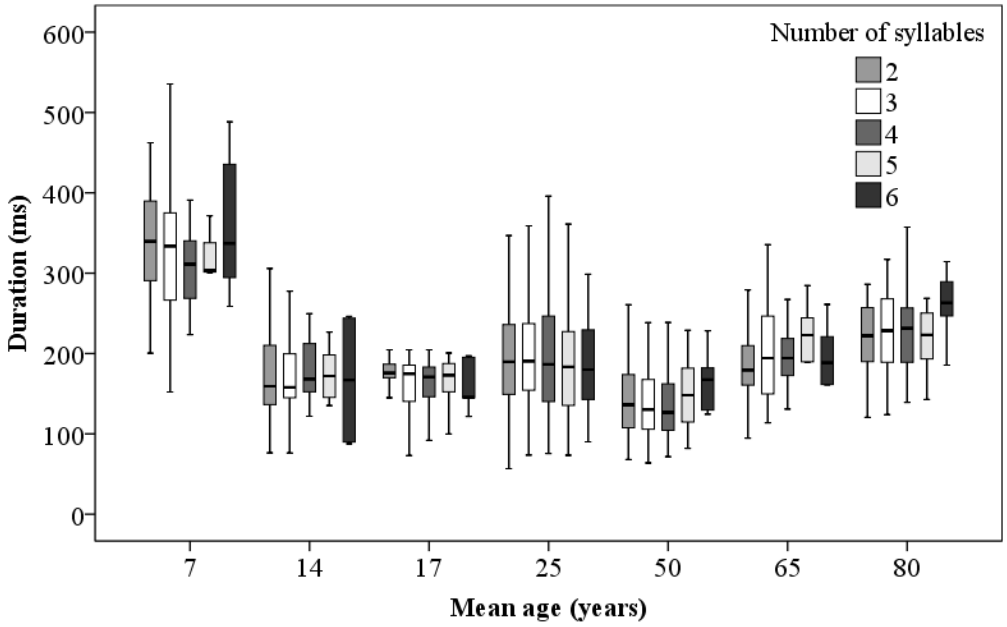

Figure 3. Durations of suffixes across word lengths and ages (median and ranges)

3.3 Durations of syllables according to increasing word/stem lengths across ages

In the former analyses the durations and the interrelations of stems, suffixed words, and suffixes were presented and compared. The next question that arises is how the syllables of the stems behave temporally influenced by total stem length. Looking at the durations of the syllables irrespective of ages, a specific change can be seen: the syllable durations decrease from monosyllabic stems to

3-syllable stems followed by no difference in the case of 4-syllable stems and by an increase in the case of 5-syllable stems (mean values of all syllables of the words: 235 ms, 182 ms, 161 ms, 162 ms, 180 ms, respectively). The suffixes slightly alter the temporal patterns of the syllables. The mean durations of the syllables in the suffixed words according to the suffixed word length from disyllabic words to 6-syllable ones are: 234 ms, 202 ms, 184 ms, 181 ms, 173 ms, respectively.

The syllable durations of stems show a spectacular gradual decrease in the case of 7-, 14- and 25-year-olds and almost no change in the case of middle-age speakers. 17-year-olds' and old-old speakers' temporal values after a gradual decrease across the 1–3-syllable stems show increase with 4-and 5-syllable stems which is more marked in the case of the longest stems produced by old-old speakers. The temporal patterns of syllables of young-old speakers demonstrate some kind of irregularity – with both decreases and increases of syllable durations – compared to those of other speakers' (see Table 6).

Table 6: Syllable durations of suffixed words and stems according to the number of syllables and ages

Ages (years)	Durations of syllables in suffixed words (SW) and stems (S) of various lengths (ms)										
	Syllables of suffixed words/Stems										
	data	2/1		3/2		4/3		5/4		6/5	
		SW	S	SW	S	SW	S	SW	S	SW	S
7	mean	361	347	312	277	276	250	265	239	217	232
	SD	131	89	207	119	58	24	49	38	52	53
14	mean	184	192	158	151	146	136	147	140	125	117
	SD	113	74	51	35	26	22	19	14	22	4
17	mean	359	341	254	177	215	125	215	152	163	145
	SD	254	147	183	75	88	44	76	42	44	20
25	mean	205	212	189	186	174	172	151	154	135	151
	SD	119	85	69	48	62	41	55	36	54	32
50	mean	169	193	156	157	154	153	153	153	133	149
	SD	106	78	59	45	49	36	41	30	46	27
65	mean	177	175	199	195	175	160	179	168	177	173
	SD	75	55	61	45	30	46	29	27	22	25
80	mean	230	235	219	212	207	197	212	206	275	275
	SD	62	49	42	39	48	41	34	31	57	58

3.4 Durational interactions of stems and suffixes across ages

Finally, we analyzed our data by comparing them as the interrelations of stem and suffix durations depending on word lengths across ages (Fig. 4). Although the stem durations vary according to the number of syllables as opposed to those of

suffixes in all ages, the extent of the temporal differences between stems and suffixes show age-specific properties. This extent is relatively large in the case of 7-year-olds and old-old speakers while much less in the cases of 14-, 17- and 25-year-olds.

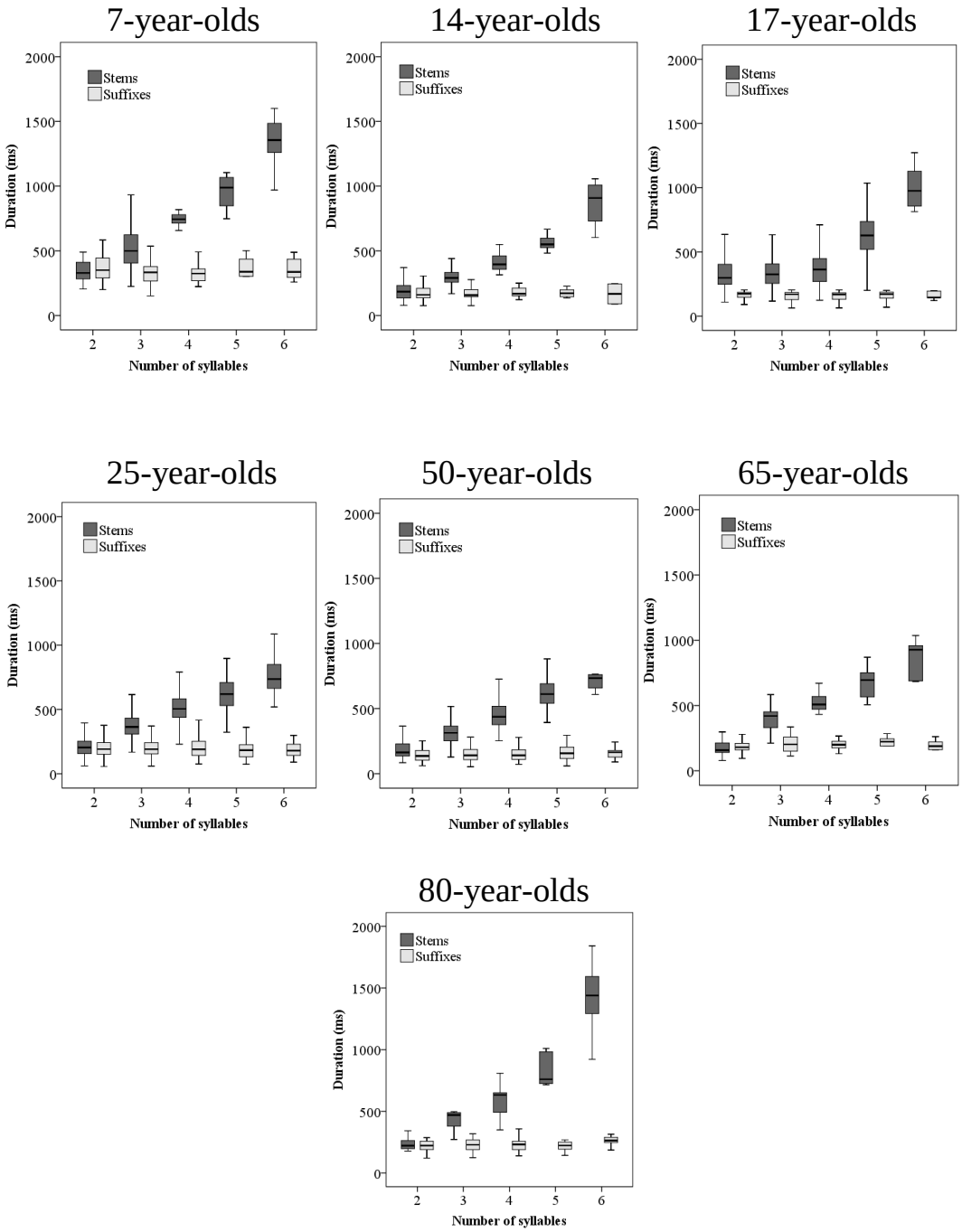

Figure 4. Durations of stems and suffixes of words with various numbers of syllables across ages (medians and ranges)

4. Discussion and conclusions

This study focused on the intrinsic durational patterns of suffixed words with various stem lengths across ages in Hungarian spontaneous speech. Findings revealed significant differences in the durations of both suffixed words and stems depending on word length and age. No differences could be found, however, in the suffix durations irrespective of word length and age. The reduction tendency of the syllables showed more complex temporal patterns across ages than had been assumed.

Our first hypothesis was confirmed. As expected, durations of stems in suffixed words increased according to word lengths across ages. Although the durations of individual syllables of the stems decrease depending on stem length, the more syllables the stems contain the longer they are, irrespective of the reduction tendency. What is interesting here is the existence of age-specific differences of the stems' temporal patterns. The durational increase of stems is linear and gradual in all age groups but the extent of the increase seems to be dependent on the reduction tendency. The durations of the stems do not increase multiplied by their shortest durations. The reduction tendency of stems is age-specific: less characteristic of 7-year-olds and old-old speakers while it is robust in the cases of 25- and 50-year-olds. The reduction tendency shows different patterns in teenage speakers indicating that they have a different relative frequency of use of their vocabulary in spontaneous utterances from that of adults (Aylett & Turk, 2006; Yang et al., 2013). The fact that the durations of the 5-syllable words increased sharply produced by 65- and 80-year-olds suggests different reasons in their case. Old speakers tend to be slow in all their movements including the articulation gestures resulting in overall slowing down, particularly in producing long words.

There are two data sets left to be explained. Why do 14-year-olds produce the shortest stem durations? Why are the stem durations produced by 17-year-olds longer than those produced by younger teenagers and young and middle-aged speakers? The measured data do not allow us to give an obvious explanation. We think that language acquisition in late puberty might be responsible for the findings. 17-year-old speakers' language mastery reaches a good level for speaking in various aspects including cognitive development. However, these developments might impede their fast selection among thoughts and fast speech planning followed by slower execution. On the contrary, the range of thoughts and the selection from them are supposed to be limited in young teenagers. In addition, their speech planning is simpler than that of the older teenage speakers. These facts might explain their faster speech production.

We expected that syllable durations would show gradual (e.g., Altmann, 1978; 1993) and age-specific decrease. This hypothesis was partly confirmed. The decrease of the syllable durations was not present in all age groups and showed various patterns depending on stem length. Speakers of the mean ages of 50, 65, and 80 years as well as the 17-year-old teenagers showed specific temporal

patterns against a gradual and linear reduction tendency. Such different realizations of the syllable reductions can be explained differently depending on age. Speech motor control (see Kent, 2000) does not work properly with speakers older than 50. The temporal reduction of syllables in the cases of 14-years-olds and 50-year-olds is not as gradual as in the cases of 7-year-olds and 25-year-olds. As for an explanation for the different temporal behavior of certain age groups, we suppose that diverse factors, such as phrase length, word contexts, stress patterns, syntactic position, relative information content of words, lexical retrieval and the speaker's vocabulary use also play important roles in the intrinsic temporal durations of words. The temporal reduction of syllables is influenced by various factors, not only by an intrinsic motor control. In addition, these influential factors might change across ages. In this study, we intentionally did not control for any other factors possibly influencing word production when we analyzed the reduction tendency. Other factors that might be responsible for the deviation from the reduction tendency of syllables in certain ages cannot be defined without proper investigation in order to avoid speculating.

The second hypothesis suggested that the suffixes would not show durational changes irrespective of word length and age. This was also confirmed: no significant differences were found in this study in suffix durations, irrespective of stem length. Invariable duration in suffixes may be supposed to be a consequence of the agglutinative character of Hungarian, in which concatenation of stems and suffixes takes place relatively early in the process of language acquisition (Bunta et al., 2016). Our findings can be discussed from the perspective of information-smoothing theories (e.g., Kuperman & Bresnan, 2012), which might provide further explanation for the greater stability found in the durations of suffixes. We think that it is safe to say that the measured discrepancy in durations between stems and suffixes is primarily a consequence of language-specific traits. The semantic content of the suffixes is decisive in order to understand the syntactic relations of sentences; therefore speakers wish to ensure their identification by the stable temporal properties of suffixes produced for the sake of the listeners.

The suffix durations of the 7-year olds were the longest in this study indicating that children are still in the phase of underdeveloped suffix use for several reasons. It seems that the retrieval of suffixes and their phonological and phonetic planning need longer time from the child than the same operations in the case of stems. In addition, selecting the suffixes and attaching them to stems require longer time from children, resulting in relatively longer suffixes compared to those produced by older speakers. Long duration of children's suffixes raises the possibility of extra control over suffixes (articulation, appropriateness, etc.) in this age.

We expected that young-old and old-old speakers would produce longer suffix durations than young speakers because of their slower articulation and motor control. The data confirmed the expectation. The temporal patterns of the suffixes produced by the 25-year-olds require some explanation. They are longer than

those both of the teenagers and the middle-aged speakers. We think that young speakers use the prolongation of suffixes to obtain more time for speech planning in order to avoid various types of disfluencies.

The relatively stable suffix durations within an age group show different values across ages indicating different reasons for the absolute values and for the lengthened suffixes in some cases (such as acquisition of suffixes, speech planning function, slow movements and slow control).

This study on intrinsic temporal patterns of words with various lengths in an agglutinating language is an important approach for two reasons: Findings shed light on (i) the temporal interrelations of stems and suffixes, and (ii) various temporal properties of words produced in spontaneous speech across ages from 7 to 80 years. Stems with various lengths show a more or less gradual decrease in their durations in all age groups of this study supporting the fact that short words are produced slower than long ones. However, this decreasing tendency does not concern the suffixes. Various linguistic and non-linguistic factors might be responsible for this finding whose consideration is beyond the goals of the present analysis. We are convinced by the data that the temporal stability of the suffixes irrespective of stem length and age refers to their specific role in speech governed by listeners' speech processing. The temporal control over word articulation should be analyzed both separately (stems and suffixes) and also in their combinations (suffixed words) where their phonological and phonetic planning operations are considered in the mechanism. These findings raise a number of new questions about lexical access in an agglutinating language, the psycholinguistic function of the temporal stability of suffixes, articulation control of suffixed words, and of speech perception of various word components.

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