OSMO EEROLA, JANNE SAVELA (Turku)

PRODUCTION OF SHORT AND LONG FINNISH VOWELS WITH AND WITHOUT NOISE MASKING

Abstract. In order to further examine the possible quality differences between produced short and long Finnish vowels, we studied the formant frequencies F1–F4 and duration of the eight Finnish vowels /a/, /e/, /i/, /o/, /u/, /y/, /æ/ and /ø/[1] when uttered in carrier words (e.g., /tili/ — /tiili/) in two different masking conditions and without a noise mask. Babble noise at 92dB SPL was used to simulate a loud, crowded cocktail party, and pink noise at 83dB SPL an environment with the maximum noise level allowed for continuous working. Minor quality differences were found between the short and long vowels. Noise masking caused a significant prolongation of produced short vowels, and a significant increase in the F1 frequency.

Keywords: Finnish, vowel production, vowel quality and quantity, noise masking.

1. Introduction

The Finnish vowel system includes eight vowels: /a/, /e/, /i/, /o/, /u/, /y/, /æ/ and /ø/, which all can occur as short (single) or long (double) in any position of a word (Suomi, Toivanen, Ylitalo 2006). The modern orthography of Finnish reflects the interpretation that the long vowel segments of spoken Finnish consist of two similar shorter segments (Karlsson 1983).

Karlsson (1983) presents three possible phonological interpretations for the Finnish quantity opposition. According to the monophonematic interpretation, the short and long vowels and consonants represent different phonemes: e.g. /tule/ — /tUle/, or /tule/ — /tuLe/ (here, a capital letter stands for a long phoneme). This interpretation has not been widely accepted since it would almost double the number of Finnish phonemes from the 8 vowels and 22 core consonants, which is undesirable for the economy of linguistic description. Karlsson further argues that this interpretation is against the Finnish orthography and also against the intuition of Finnish speakers. According to the second interpretation, the long phonemes are short phonemes followed by a chrome /:/ (originally proposed by Jones (1944)), which extends the duration of a short phoneme. This interpretation can partially be justified on the basis of the fact that the phonetic quality differences between short and long vowels in Finnish are small as compared, for example, to English or Swedish. However, it would complicate the analysis of certain morphological categories in Finnish. According to the third interpretation, the long segments of vowels or consonants consist of two successive and identical short segments. Karlsson refers to this

[1] The symbols used in this paper are those of the International Phonetic Alphabet (IPA). Equivalents in the Finno-Ugric transcription system are as follows: ɑ = a, æ = ä, ø = ö, y = ü.

interpretation as the identity group interpretation, and it is generally accepted in Finnish phonetic textbooks (Suomi, Toivanen, Ylitalo 2006; Iivonen, Tella 2009) as the de facto explanation of the phonological quantity opposition in Finnish. We refer to this interpretation in the following also as the general view. Harrikari (2000) has presented a complementary and partially opposing view on identity group interpretation, using the optimality theory of generative phonology as the framework and considering dialectic epenthesis, gemination, and language games as examples. However, Harrikari approaches the segmental length in Finnish from the viewpoint of theoretical phonology and morphology, not from that of experimental phonetics.

Generally, the two durational variants of the eight Finnish vowels are regarded as being similar in p e r c e i v e d q u a l i t y. Eerola, Savela, Laaksonen and Aaltonen (2012) investigated the perception of short and long Finnish /y/ and /i/ vowels, and found that the location of the category boundary between /y/ and /i/ on the F2 formant frequency axis, the width of the category boundary on the F2 formant frequency axis, the goodness rating value of the prototypical /i/, and the location of the prototypical /i/ on the F2 formant frequency axis were all independent of the stimulus duration. The main results of the study by Eerola, Savela, Laaksonen and Aaltonen (2012) thus did not challenge the general view that the perceived Finnish short and long vowels are of equal quality.

However, the results of some earlier studies on the p r o d u c t i o n of Finnish vowels suggest that there exist minor spectral dissimilarities in the formant frequencies F1—F3 of the produced short and long vowels. For example, based on five informants, Wiik (1965) reported clear differences in the variability ranges of Finnish single and double /y/ and /i/ vowels, as measured in terms of F1, F2 and F3, stating that F1 is 40 Hz higher and F2 is 75 Hz lower in [y] than in [y:], and, correspondingly, F1 is 65 Hz higher, F2 is 140 Hz lower, and F3 is 265 Hz lower in [i] than in [i:]. The results indicate that the produced single vowels are more centralized than the double vowels are. In a later study on vowel production by Kukkonen (1990), differences of similar type but smaller magnitude were reported in a normal Finnish-speaking control group ($N = 4$): F1 was 16 Hz higher, and F2 and F3 were 63 Hz and 32 Hz lower in single than in double /i/ vowel. Correspondingly for single and double /y/ vowels, the differences were as follows: F1 was 19 Hz higher, F2 was 75Hz lower, and F3 was 20 Hz lower in the single vowel. However, only differences in F1 were statistically significant. In our earlier studies (Eerola, Laaksonen, Savela, Aaltonen 2003), a non-significant difference of 108 Hz was found for F2 between the short /i/ ($F2 = 2391$ Hz, $SD = 194$ Hz) and long /i:/ ($F2 = 2500$ Hz, $SD = 212$ Hz) produced by 26 informants in the first syllables of the words *tikki* and *tiili*. In a more recent study by Eerola and Savela (2011), a significant difference (paired t-test, $p < 0.01$, $N = 14$) of 104 Hz was found for F2 between the short /i/ and long /i:/ in an uttered word pair *tili*/*tiili*.

Iivonen and Laukkanen (1993) studied the qualitative variation of the eight Finnish vowels in 352 bisyllabic and trisyllabic words uttered by a single male speaker. They found a clear tendency for the short vowels to be more centralized in the psychoacoustic F1—F2 space, as compared to the long ones. However, except for the /u/—/u:/ pair, this difference was smaller than one critical band, and thus auditorily negligible. In a comparative study of the monophthong systems in the Finnish, Mongolian and Udmurt languages, Iivonen and Harnud (2005) report on minor spectral differences in the short/long vowel contrasts in stressed (e.g., [sika] / [si:ka]) and non-stressed (e.g., [etsi] / [etsi:]) syllables in Finnish words uttered by a single male speaker. The biggest differences between short and long vowels were found in /u/. As in the study by Iivonen and Laukkanen (1993), [u] is more centralized and does not overlap with [u:]. Also for /y/ and /i/, the short vowels are more centralized than their longer counterparts, but the short and long vowel versions overlap on the F1 axis. Interestingly, the /y/ and /i/ vowels, both short and long, also overlap on the F2 axis instead of being clearly separate phoneme categories. To summarize, minor spectral differences have been reported in the F1 and F2 formant frequencies of the produced short and long Finnish vowels, and the biggest difference occurs between the high back vowels [u] and [u:].

In this study, we further examine the reported quality differences between produced short and long variants across the entire Finnish vowel system in two different noise masking conditions and without any noise mask. It was assumed that noise masking may cause hyperarticulation, and possibly accentuate the reported minor quality differences between short and long Finnish vowels. Since speakers are known to alter their vocal production in noisy environments (Lane, Tranel 1971, the Lombard effect), such as a loud restaurant or a noisy factory, we included two different types of masking noise to simulate these conditions. Multi-talker babble noise at 92 dB SPL (sound pressure level) was used to simulate a loud, crowded cocktail party, and pink noise at 83 dB SPL an environment with the maximum noise level allowed for continuous working. The Lombard effect has been reported to cause measureable differences in vowel intensity and duration, and also in formant frequencies: ambient noise elevates the speech amplitude by 5—10 dB, increases word durations by 10—20%, and increases significantly the F1 and F2 frequencies, thus causing a shift in the vowel space (van Summers, Pisoni, Bernacki, Pedlow, Stokes 1988; Castellanos, Benedi, Casacuberta 1996; Beckford Wassink, Wright, Franklin 2007).

2. Materials and methods

2.1. Subjects

Ten normally hearing young adults speaking the modern educated Finnish of South-West Finland volunteered as subjects. All subjects were screened for hearing impairments by means of an audiometer (Amplivox 116). For different vowels, the number of recorded subjects varied: 10 subjects for /i/, /e/, /y/, and /ø/. 9 subjects for /u/, and 4 subjects for /a/, /æ/, and /o/.

2.2. Procedure and analysis

The articulation of the eight Finnish vowels /a/, /e/, /i/, /o/, /u/, /y/, /æ/ and /ø/ when uttered in different carrier words and non-words (e.g., /tili/ — /tiili/, see Table 1) was recorded in two different masking conditions and without a noise mask. The subjects were asked to utter each word five times successively using their normal speech style, first without the noise mask, and then in the masking conditions. The recordings were carried out in an acoustically dampened room (27 dB_A SPL) by using a high quality microphone (AKG D660S) that was connected via an amplifier to a PC. The recordings were made at a sampling rate of 44.1 kHz, and saved as sound files for later analysis. Praat software was used for both the recordings and analysis.

Table 1

Carrier utterances used in the experiments

Short		Long	
IPA, Finnish	**Meaning**	**IPA, Finnish**	**Meaning**
[tɑli], *tali*	'tran'	[tɑ:li], *taali*	non-word
[teli], *teli*	'twin axle'	[te:li], *teeli*	non-word
[tili], *tili*	'account'	[ti:li], *tiili*	'brick'
[toli], *toli*	non-word/NA	[to:li], *tooli*	non-word
[tuli], *tuli*	'fire'	[tu:li], *tuuli*	'wind'
[tyli], *tyli*	non-word	[ty:li], *tyyli*	'style'
[tæli], *täli*	non-word	[tæ:li], *tääli*	non-word
[tøli], *töli*	non-word	[tø:li], *tööli*	non-word

The sound samples were automatically analyzed using a text grid in which the steady-state part of each target vowel was windowed varying between utterances. The f0, formants F1—F4, and vowel durations were analyzed by using the Burg method in which short-term LPC coefficients are averaged for the length of an entire sound. The Praat formant analysis settings were 0.025 s for Window length, and 5000 Hz (male) and 5500 Hz (female) for Maximum formant. The analysis results of the five repetitions were averaged for individual results.

2.3. Noise masks

Multi-talker babble noise at 92 dB SPL was used to simulate a loud, crowded cocktail party, and pink noise at 83 dB SPL an environment with the maximum noise level allowed for continuous working. Being difficult to synthesize, recorded babble noise was used. Pink noise was selected because of its good speech masking properties (Rao, Letowski 2006). Its spectral envelope follows the spectral properties of speech signals: the peak intensity in the f0—F1 range and an even roll-out of 6 dB per octave at the higher frequencies of F2—F5 formants. Masking was on throughout the recording of each utterance, and the noise masks were presented via Sennheiser PC161 headphones, which were calibrated in the beginning of each session by Brüel and Kjaer Type 2235 SPL meter to deliver 83 +/– 0.5 dB_A SPL at the pink noise mask.

3. Results

3.1. Short versus long vowels

The individual results of articulated Finnish vowels in the F1—F2 space are illustrated in Figure 1. As can be seen from the figure the /y/ and /i/, and correspondingly, /ø/ and /e/ categories overlap clearly with each other. The short and long vowels differ in terms of F1 and F2 between the categories with the differences being largest between /u/ and /u:/. Except for /y/ and /ø/, the other vowel categories show a pattern where short vowels are more centralized than long vowels. This is in accordance with the results of Iivonen, Laukkanen 1993.

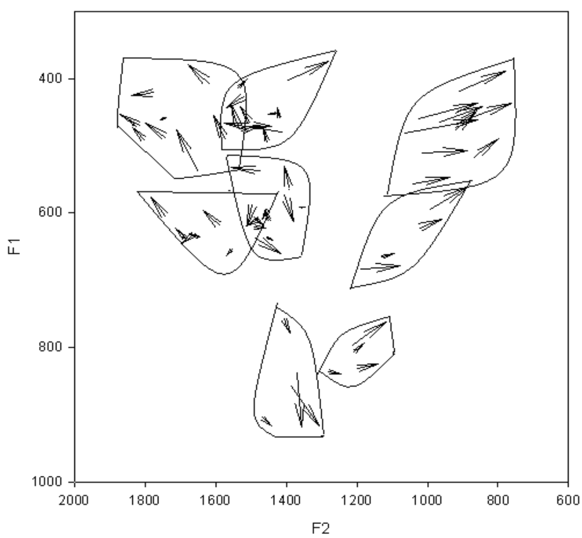

Figure 1. **Individual articulations of the short and long Finnish vowels in the F1—F2 space (in mel). Vector starting points represent the short vowels and end points the long vowels. Note that the number of subjects varies in different categories. The categories are from top left to right down: /i/, /y/, /u/, /e/, /ø/, /o/, /æ/ and /ɑ/.**

The mean values of the five repetitions of all subjects for the short and long Finnish vowels are shown in Table 2 and Table 3, respectively, and illustrated in Figure 2. The grand average of mean durations of all vowel categories was 125 ms (and for standard deviations SD 34 ms) for the short vowels and 345 ms (SD 75 ms) for the long vowels, resulting the durational ratio 1 : 2.8 between the short and long vowels. The coefficient of variation (CV = SD/mean) was slightly higher for the short vowels (0.27) than for the long vowels (0.21). These results are in line with the earlier reports on the durational variation of the Finnish short and long vowel quantities (for a review, see Eerola, Savela, Laaksonen, Aaltonen 2012).

Table 2

Mean values (and standard deviations) of the durations (in ms) and formants F1—F4 (in mel) for the produced short Finnish vowels

Vowel	Duration	F1	F2	F3	F4
i	103 (25)	471 (37)	1708 (107)	1902 (63)	2135 (104)
e	120 (32)	617 (27)	1608 (93)	1862 (62)	2129 (111)
æ	140 (42)	840 (61)	1408 (43)	1786 (14)	2010 (52)
y	118 (36)	452 (33)	1452 (60)	1748 (88)	2037 (48)
ø	125 (24)	599 (33)	1448 (46)	1805 (69)	2093 (88)
u	113 (28)	483 (40)	968 (71)	1791 (104)	2037 (92)
o	139 (43)	642 (41)	1083 (92)	1803 (62)	2032 (85)
ɑ	140 (43)	818 (19)	1225 (37)	1801 (33)	2054 (45)

The averaged results confirm the earlier findings that there are minor quality differences of 29—128 mel between short and long vowels in Finnish (Table 4, column S—L). The mean individual distance in the F1—F2 plane between the long and short vowels without noise masking was 62 mel over all vowel categories. Variation was found between vowel categories: /e/ and /ø/ had distances of 29—39 mel and no centralization tendency was observed, whereas /o/, /u/ and /æ/ showed clearly larger distances, up to 128 mel. Noticeable centralization of the short vowels was found especially in /i/, /u/, /o/, /a/, and /æ/ (Figure 2). The individual differences in F1 and F2 values were tested using Wilcoxon signed rank test. Differences between short and long vowels were significant for /i/ in F1 ($Z = -2.497$, $p = 0.013$) and F2 ($Z = -2.807$, $p = 0.005$), for /e/ in F2 ($Z = -2.499$, $p = 0.012$), for /y/ in F1 ($Z = -2.499$, $p = 0.012$), and for /u/ in F1 ($Z = -2.524$, $p = 0.012$).

Table 3

Mean values (and standard deviations) of the durations (in ms) and formants F1—F4 (in mel) for the produced long Finnish vowels

Vowel	Duration	F1	F2	F3	F4
i	301 (59)	449 (29)	1749 (108)	1946 (66)	2147 (113)
e	316 (51)	617 (30)	1630 (99)	1872 (59)	2142 (109)
æ	387 (96)	883 (69)	1374 (57)	1797 (39)	2078 (67)
y	329 (58)	436 (41)	1449 (88)	1732 (92)	2044 (77)
ø	326 (71)	603 (42)	1444 (62)	1791 (85)	2110 (101)
u	336 (74)	461 (45)	842 (57)	1799 (113)	2071 (107)
o	396 (94)	628 (53)	1004 (98)	1818 (51)	2032 (74)
ɑ	366 (95)	805 (34)	1170 (56)	1801 (37)	2055 (69)

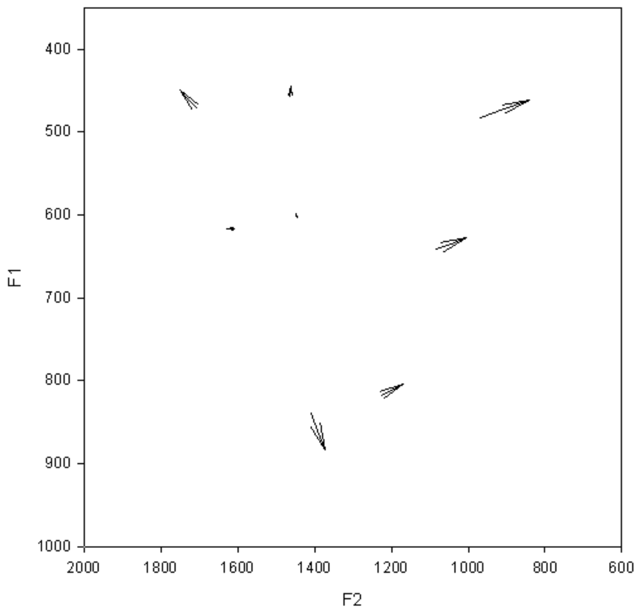

Figure 2. **The grand averages of short and long Finnish vowels in the F1—F2 space (in mel). Vector starting points represent the short vowels and end points the long vowels. The number of subjects varies in different categories. The categories are from top left to right down: /i/, /y/, /u/, /e/, /ø/, /o/, /æ/ and /ɑ/.**

3.2. The effect of a masking noise

Interestingly, both types of noise masking caused a highly significant prolongation in the duration of the short vowels, but not of the long vowels. With babble noise, the mean durations over 61 subjects were 143, ms (SD 37 ms) and 349 ms (SD 76 ms), and correspondingly with pink noise, 130 ms (SD 32 ms) and 341 ms (SD 79 ms). By using Wilcoxon signed rank test, the differences in duration between the quiet (Q) and noise (B = Babble, P = Pink) conditions were significant for short vowels in Q versus P ($Z = -3.040$, $p = 0.002$), and in Q versus B ($Z = -6.037$, $p = 0.000$). In case of long vowels the differences between the two noise conditions were significant; in B versus P ($Z = 2.069$, $p = 0.039$).

Table 4

Mean values of individual Euclidean distances (and standard deviations) in mels between the produced short (S) and long (L) Finnish vowels without noise masking (column S—L), and between the short vowels without and with babble (SBN) and pink noise (SPN) masking, and between the long vowels without and with the babble (LBN) and pink noise (LPN)

Vowel	S—L	SBN	SPN	LBN	LPN
i	49 (22)	59 (33)	58 (35)	60 (33)	46 (25)
e	29 (16)	53 (34)	53 (34)	63 (40)	59 (38)
æ	59 (36)	50 (11)	33 (11)	92 (116)	40 (17)
y	56 (48)	59 (34)	56 (37)	80 (57)	86 (68)
ø	39 (23)	72 (52)	53 (23)	77 (73)	76 (58)
u	128 (44)	51 (26)	51 (27)	86 (42)	85 (43)
o	80 (37)	55 (24)	38 (16)	51 (36)	43 (17)
ɑ	57 (32)	46 (20)	44 (14)	28 (7)	33 (7)
Mean	62	56	48	67	58

Since the durations increased along with increasing sound pressure level, the phenomenon may rather be explained by the amplitude of the mask than its type. However, when using a low pass filtered white masking noise, Summers, Pisoni, Bernacki, Pedlow and Stokes (1988) did not find any significant differences between the effects of the 80 dB and 90 dB SPL masks on durations, but instead, they found a highly significant ($p < 0.0001$) difference between non-masking and masking conditions. On the other hand, Beckford Wassink, Wright and Franklin (2007) did not find significant differences in segment durations between Lombard speech and (non-mask) citation speech. Our finding that the short vowels are prolonged with Lombard speech is interesting and motivates further investigation.

The effect of noise on the produced vowel quality was similar in both two masking conditions, and no major differences between babble and pink noise were found (Figure 3). Both noise types seem to cause higher F1 frequencies in the production of the mid-high vowels: On the average, the F1 values of the short and long vowels produced in the masking conditions are about 34 mel higher than without masking. No similar effect was found for the low vowels /a/ and /æ/. The results indicate that noise masking causes a systematic shift of F1—F2 values in the production of mid-high Finnish vowels, as illustrated in Figure 3. By using Wilcoxon signed rank test, the differences in F1 between the quiet (Q) and noise conditions (B = Babble, P = Pink) were significant for short vowels in Q versus P ($Z = -5.872$, $p = 0.000$), and in Q versus B ($Z = -5{,}983$, $p = 0.000$), and for long vowels in Q versus P ($Z = -5.732$, $p = 0.000$), and in Q versus B ($Z = -5.671$, $p = 0.000$).

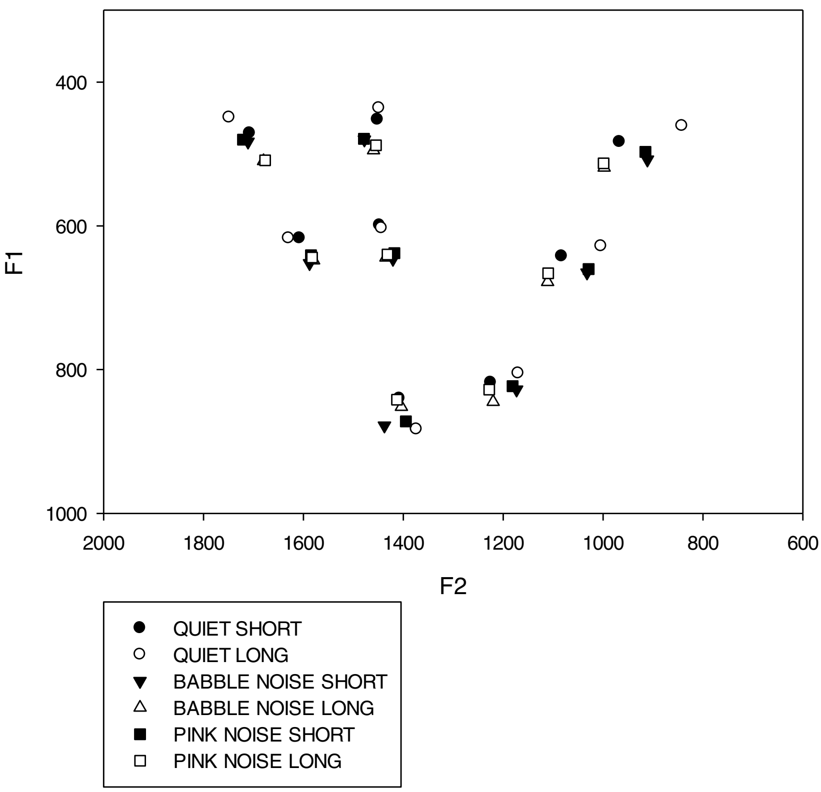

Figure 3. **The grand averages of short and long Finnish vowels in the F1—F2 space (in mel) in the two different masking conditions and without noise masking. The number of subjects varies in different categories. The categories are from top left to right down: /i/, /y/, /u/, /e/, /ø/, /o/, /æ/ and /ɑ/.**

4. Discussion and conclusions

The results of this study on the production of the short and long Finnish vowels confirmed, first, the earlier findings that the short vowels /i/, /u/, /o/, /a/ and /æ/ are more centralized in the F1—F2 space than their longer counterparts. Second, the Lombard effect induced by the two different noise masks caused the duration of the short vowels, but not the long ones, to increase significantly. The increase was larger with the louder babble noise than with the pink noise. Whether this difference was due to the higher amplitude of the babble noise or due to the noise type itself is a subject for further studies.

Third, the Lombard effect resulted in an increase in the F1 of the mid-high vowels, but had no effect on the Euclidean distances of the short and long vowels. These results in terms of the F1 value and the Euclidean distances are in line with the findings of Summers, Pisoni, Bernacki, Pedlow, Stoke (1988), and Beckford Wassink, Wright, Franklin (2007). The latter study among Jamaican speakers is particularly interesting, since Jamaican Creole utilizes the phonemic vowel length in a similar manner as Finnish, which, however, is a distinctive quantity language. The vowel quality (in terms of F1 and F2) was affected similarly by the Lombard speech in both these languages, but a clear durational prolongation of short vowels was only found in Finnish

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ОСМО ЭЭРОЛА, ЯННЕ САВЕЛА (Турку)

ПРОИЗНОШЕНИЕ КОРОТКИХ И ДЛИННЫХ ФИНСКИХ ГЛАСНЫХ ПРИ ШУМОВОЙ МАСКИРОВКЕ И БЕЗ ШУМА

Для дальнейшего изучения возможных различий по качеству коротких и длинных финские гласных, мы исследовали формантные частоты F1—F4 и длительности восьми финских гласных /a/, /e/, /i/, /o/, /u/, /y/, /æ/ and /ø/, произнесенных в контексте слова (например, /tili/ — /tiili/) в двух различных условиях шумовой маскировки и без шума. Для шумовой маскировки использовали речевой шум на уровне 92 дБ и розовый шум на уровне 83 дБ. Установлено, что различия по качеству между короткими и длинными гласными незначительны, но шум маскировки привел к значительному удлинению длительности кратких гласных и, кроме того, к значительному повышению частоты F1.