Asymmetries between production and perception of consonant length*

Olga Dmitrieva
Stanford University
dmitro@stanford.edu

This paper addresses context-dependent asymmetries between the perception and production of consonant length in three distinct languages: Russian, American English, and Italian. These asymmetries are argued to present evidence of the perceptual advantage for consonant length identification in certain phonetic environments and play an important role in defining the crosslinguistic distribution of long consonants across different contexts.

1. Introduction

Recent advances in the field of experimental phonology have shown that perceptual motivations often play an important role in shaping the typology of phonological processes. Among the most influential works is the P-map proposal by Steriade (2001, 2008), see also (Hayes et al. 2004). What connects the many projects that explore the effect of perception on phonology is a frequent conclusion that perception is crucially position-dependent: certain acoustic properties stand out in some contexts and get lost in others. In this paper, I argue that certain phonetic environments facilitate the perception of consonant length as indicated by the presence of production-perception asymmetries. Since the experimental data presented here agree with the results of the typological surveys of geminate consonants, it is likely that this perceptual advantage influences the way geminate consonants are distributed among different word-positions and phonetic environments crosslinguistically.

It has been observed by previous research that long consonants do not occur with equal frequency in every context: certain word positions and segmental environments are preferred while others are avoided. Intervocalic position

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is the most favored context for the consonant length contrast, especially when the preceding vowel is stressed (Thurgood 1993). Languages such as Delaware, Somali, Egyptian Arabic, Tiwa, Karok, Moroccan Arabic, Hopi, Tzeltal, Maltese, Arabic, Icelandic, and Hindi-Urdu have been reported to place geminates after stressed vowels. Adjacency to another consonant, on the other hand, is avoided, as are word-initial and word-final positions (Thurgood 1993, Kraehenmann 2001). While some languages implement these principles categorically, others implement them as statistical tendencies. For example, in Russian long consonants have been argued to function in a semi-phonemic fashion (Matusevich 1976) and can degeminate in speech. It has been established that the probability of degemination depends on a number of factors. In particular, intervocalic and stress-adjacent consonants degeminate less often than preconsonantal ones and those at word edges. Among the latter, word-initial consonants degeminate less often than word-final ones (Kasatkin & Choj 1999).

The proposed explanations for these preferences generally follow the phonetic reasoning: Padgett (2003) suggests that any contrast based on duration is better situated in intervocalic positions which offer clear beginning and end points for the perception of the target segment's duration. Word-edges, on the other hand, provide poor cues for consonant duration identification, especially in the case of stops (Kraehenmann 2001; Kraehenmann & Lahiri 2008). A boundary between two consonants may also be more difficult to detect than a boundary between a consonant and a vowel. An attraction of long consonants to stressed vowels has been explained by a general tendency for durational increase in the vicinity of stress (Thurgood 1993). It has also been noticed that consonants under higher pitch, which sometimes accompanies stressed vowels, are often phonetically longer (Pike 1974).

However, few of these suggestions have been tested in perception. (Pajac 2009) showed that in the "same-different" discrimination task listener's sensitivity to the durational contrast in consonants was better in vowel-adjacent than in consonant-adjacent positions and in word-medial than in word-initial positions. These results are not completely surprising given that the geminate-singleton ratio in the recorded material increased in the same order. I this paper I present evidence that even in the absence of such cues in production, listeners show context-dependent differences in the perception of consonant length. These differences can not be explained by the corresponding differences in production, representing a perception-production asymmetry. An asymmetry is understood here as follows: if

consonants in context Y are generally longer than consonants in context X the perception of length in each case will be relative to each consonant's duration and context-dependent. That is, listeners will perceive length at the later point in context Y than in context X, as does happen for example, for consonants of different manners of articulation (these findings are not discussed here for the considerations of space). If this does not happen, or if the order is reversed, we have a perception-production asymmetry. In this paper, I will show that this asymmetry arises in a number of contexts demonstrating a striking parallelism with the crosslinguistic preferences for the placement of geminates.

2. Experiment

The experiment reported here examines the perception of consonant length in a variety of contextual environments: word-edge related conditions (word-initial and word-final); stress-related conditions (pre-, post-, and not-adjacent to stress); and immediate segmental environment conditions (intervocalic and preconsonantal). It has as its goal to establish the location on the durational continuum of the perceptual shift between "short" and "long" percepts for the consonants in these context and differences, if any, between the length identification curves. Results of the perceptual test are supplemented by the durational measurements of the acoustic material.

2.1. Participants

Native speakers of Russian (24 subjects), American English (31 subjects), and Italian (preliminary results from 8 participants are reported here) participated in the perceptual experiment. Production data were collected from 5 Russian, 9 American English, and 2 Italian speakers. Russian participants were recruited on the Stanford campus and in the neighboring communities through word of mouth and electronic fliers distributed to the subscribers of Stanford Russian Students Association and Center for Russian, East European, and Eurasian Studies mailing lists. Both parts of the experiment took place in the linguistics laboratory of Stanford University. For the perceptual experiment, speakers of American English were recruited from the subject pool of the linguistics department of Stanford University and tested in the linguistics laboratory of Stanford University. For the production experiment, American participants were recruited through fliers on the campus of Purdue

University and recorded in the Audiology Clinic of Purdue University. Italian participants were recruited through word of mouth and fliers on the campuses of Stanford University and Purdue University. They were tested respectively in the linguistics laboratory of Stanford University and in the Audiology Clinic of Purdue University. A majority of the participants were young adults involved in educational activities at Stanford or Purdue University. None of the participants reported speech or hearing disorders.

2.2. Stimuli

Stimuli for the perceptual experiment were created on the basis of the 23 naturally recorded non-words where the duration of the target consonant was instrumentally manipulated using Praat (Boersma & Weenink 2010) to represent 19 different steps from 50 ms to 410 ms with 20 ms intervals. As a result 437 tokens were created. In these non-words target consonants appeared in the following contexts: pre-stress [t] - *kotápu*, post-stress [t] - *kótapu*, and not-adjacent to stress [t] - *kotapú*; intervocalic [s] - *isek* vs. preconsonantal [s] - *islek*; word-initial [s] - *po savap* vs. word-final [s] - *pos avap*. Only the alveolar fricative [s] was used as a target in the preconsonantal environment, always followed by a sonorant, to facilitate acoustic measurements. Similarly, only an alveolar fricative [s] was used in word-final and word-initial positions. Stress-related conditions included target consonants of different manners of articulation: plosive [t] and [d], fricative [s], nasal [n], and liquid [l].

For the production part of the experiment a list of non-words was presented to the participants for reading. Russian participants read the same non-words that were used for the perceptual stimuli, with a singleton and a geminate as a target consonant: *kótapu - kóttapu*. Stimuli were arranged in three columns on a sheet of paper in a pseudo-random order. A few additional fillers were introduced, in particular at the beginning and the end of each column. The list contained 57 items in total including 46 experimental stimuli and 11 fillers.

For American and Italian participants separate reading lists were created where the non-words conformed to the phonotactics of each of the languages but were otherwise equivalent to those used for Russian participants. No geminates were used as targets in the reading list for American participants (42 items; 31 experimental stimuli plus 11 fillers). Words were arranged

in two columns in pseudo-random order. To assist the participants with the correct placement of stress in addition to the accent sign above the vowel an existing word with an equivalent stress pattern was given in parenthesis: e.g. *caládin (as in Aláddin)*, *cápavan (as in cáravan)*, *rasadán (as in ramadán)*.

The reading list for Italian participants contained target consonants as geminates only in stress-related contexts, since those contained target consonants in intervocalic positions and were not to be contrasted with preconsonantal and word-edge positions, where geminates are not found in real Italian. The words were arranged in pseudo-random order in one column on three sheets of paper: 72 items, including 46 experimental stimuli and 26 fillers. To assist the speakers with the stress patterns in the non-words, a sentence containing a real word with an equivalent stress pattern was provided: e.g. *cátitano 'Queste cose cápitano spesso'* 'These things happen often'. Sentences instead of individual words were used in this case to disambiguate two of the example words which differed only in the stress pattern: *capitáno* 'captain' and *cápitano* 'to happen'. In addition, all preconsonantal targets were in word-initial positions, as were their intervocalic counterparts, because in Italian intervocalic [s] voices to [z]. Placing the comparison in word-initial position eliminated this issue.

2.3. Procedure

The perception experiment was implemented using the E-Prime software (Psychology Software Tools Inc., Pittsburgh, Pennsylvania, USA) and employed a forced-choice identification task. Participants were seated in front of the computer screen wearing headphones. Instructions were presented on the screen and verbally in Russian, English, or Italian. Participants were instructed to listen to each word and answer as quickly as possible whether the target consonant was short or long by pressing one of the two buttons on the button box. Buttons were labeled "short" and "long" in Russian, English, or Italian. Each audio presentation of the stimulus was preceded by its visual presentation on the screen, where target consonant was substituted by a question mark. Each stimulus presentation was followed by a 2.5-second answer period whereafter the program moved on to the next stimulus. The main experimental blocks were preceded by a short trial session, consisting of 10 items similar to those used in the experiment. The trial session was designed to familiarize participants with the task and present them with the types of stimuli used in the experiment. A trial session was followed by three

experimental blocks. After each block, participants had an option to take a 5-minute break or move on to the next block immediately. Stimuli were randomized for each presentation. The experiment took approximately 40 minutes to complete.

To collect the production data, participants were asked to read the word-list 3 times at a pace comfortable for them. They were encouraged to pronounce the stimuli as naturally as possible and to pay attention to the stress placement where applicable. The duration of the target consonant was measured in the resulting recordings, using the waveform and the spectrogram in Praat. The measurements were then averaged across the three repetitions.

3. Results

3.1. Russian

The results are summarized below by language and by context. Participants' responses to the perceptual task were submitted to a two-way Repeated Measures ANOVA with the percent "long" response as a dependent variable, and consonant duration (19 different durations) and the context type as independent variables. Results for the word-edges contexts showed that the number of "long" responses was affected significantly by both consonant duration ($F(1,16) = 78.855$, $p < .001$, eta-squared = .831) and position of the target consonant in the word ($F(1,16) = 19.160$, $p < .001$, eta-squared = .545). Not surprisingly, the number of "long" responses increased as the duration of the target consonant increased, following a function characteristic to the categorical perception (S-curve). At the same time, the curve corresponding to the perception of word-initial consonants was displaced to the left relative to the curve corresponding to the perception of the word-final consonants (see Figure 1). This displacement illustrates a significant bias for "long" responses in word-initial context, or an earlier shift to the perception of length. In other words, to trigger the response 'long', a shorter duration suffices word-initially than word-finally.

This difference in perception between word-initial and word-final consonants could have a simple explanation from the production standpoint. If word-final consonants are generally longer than word-initial ones, it is only to be expected that the perceptual boundary between singletons and geminates would accommodate for this difference. To test this hypothesis, word-final

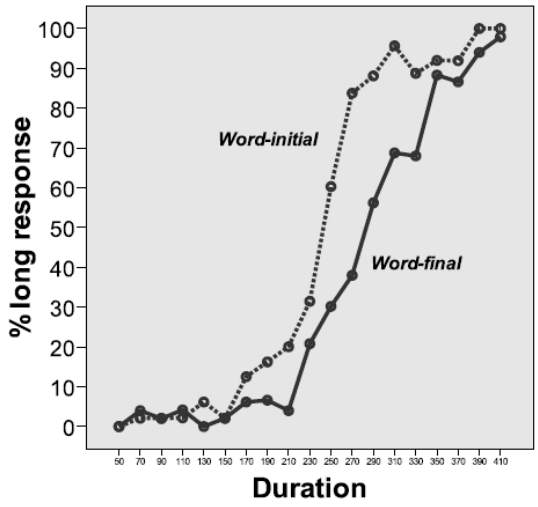

Figure 1. Perception of consonant length in word-edge contexts

and word-initial singletons and geminates were measured and submitted to a two-way Repeated Measures ANOVA with consonant duration as dependent variable and length contrast (singleton/geminate) and position in the word as independent variables. There was a significant effect of length contrast: as expected geminates were significantly longer than singletons ($F(1,4) = 47.292$, $p < .01$, eta-squared = .922; M = 320 ms and M = 163 ms respectively). Position in the word, however, did not affect consonant length significantly (word-initial = 252 ms, word-final = 231 ms on average).

Among the stress-related conditions pre-stress, post-stress, and not-adjacent to stress consonants were considered. Results of the statistical analysis of the perceptual data showed that there was a significant effect of target consonants' duration and stress location on participants' responses. In particular, the number of "long" responses increased as target consonants increased in duration ($F(1,24) = 466$, $p < .001$, eta-squared = 0.951). There was also a significant difference in the percentage of "long" responses between pre-stress, post-stress, and not-adjacent to stress consonants ($F(2,48) = 14.5$, $p < .001$, eta-squared = 0.376): the number of long responses was the highest in the post-stress context followed by the non-adjacent to stress context; the pre-stress context conditioned the lowest percentage of "long" responses (see Figure 2).

Statistical analysis of the acoustic measurements showed that in Russian,

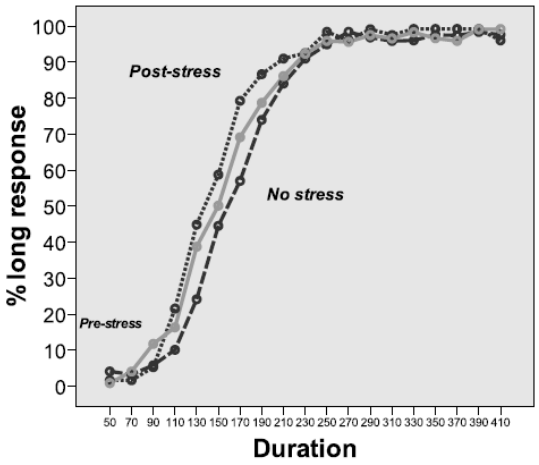

Figure 2. Perception of consonant length in stress-related contexts

consonants in pre-stress context were the longest in duration, while consonants in post-stress and not-adjacent to stress positions did not differ from each other (RM ANOVA: $F(1,8) = 15.074$, $p < .01$, eta-squared = 0.79; M = 196.3 ms, M= 168.5 ms, and M= 166.8 ms respectively). This suggests that context-invoked difference in acoustic duration can explain the curve misplacement for pre-stress consonants: they are longer in production and as a result the perceptual boundary between the short and the long consonants is shifted towards the higher end of the duration continuum. However, the identification curves for post-stress and not-adjacent to stress consonants do not coincide although their duration in production does not differ. There is a bias for "long" percept in post-stress condition.

Consonants in intervocalic environment were compared to those followed by another consonant. A Repeated Measures ANOVA showed that participants' responses differed significantly as a result of changes in target consonants' duration ($F(1,21) = 194.5$, $p < .001$, eta-squared=.903) but were not affected by the differences in immediate segmental environment (Figure 3). The tight overlapping of the two identification curves suggests an absence of the durational differences in production. However, the analysis of the durational measurements showed that intervocalic consonants were significantly longer than preconsonantal ones (($F(1,4) = 11.052$, $p < .05$, eta-squared = .734; M=268.6 and M=232 respectively). The mismatch between the production and the perception shows a bias for "long" perception in intervocalic context as compared to the preconsonantal one.

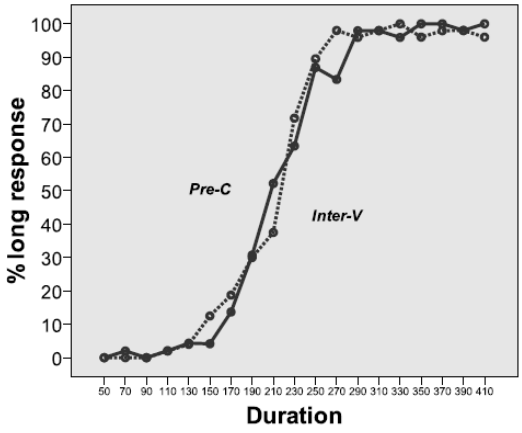

Figure 3. Perception of consonant length in segmental environment contexts

To summarize, the following perception-production asymmetries were established in Russian: there was a significantly higher percentage of "long" responses for consonants in word-initial position as compared to word-final position, although no significant differences in duration were detected between these two contexts in production. Post-stress position also conditioned a higher proportion of "long" responses, in particular in comparison to the not-adjacent to stress context. In production consonants in these two positions did not differ in duration. The two types of immediate segmental environment did not affect perception of length in target consonants. However, in production, intervocalic consonants were significantly longer than preconsonantal ones.

3.2. American English

There was a significant effect of both consonant duration and word-position on the perception of consonant length by speakers of American English: just as for Russian, the proportion of "long" responses increased as target duration increased ($F(1,8) = 45.056$, $p < .001$, eta-squared = .849). There was also a significant bias for "long" responses in word-initial position ($F(1,8) = 8.376$, $p < .05$, eta-squared = .511), with the identification curve misplaced to the left, as in Figure 1. At the same time, production data show that word-initial consonants in the stimuli produced by speakers of American English were significantly longer than word-final consonants ($F(1,6) = 17.787$, $p < .01$, eta-squared = .748; M = 136 ms and M = 107 ms respectively), which would

suggest, contrary to the previous finding, a later switch to the perception of length in the word-initial context.

Analysis of the perceptual data show that consonants in three stress-related positions differed significantly in terms of the percentage of "long" responses: the highest percentage were found for the pre-stress context, the lowest for the not-adjacent to stress context, with the post-stress context in the intermediate position ($F(1,29) = 6.711$, $p < .05$, eta-squared = .188). There was also a significant effect of target consonant duration ($F(1,29) = 201.365$, $p < .001$, eta-squared = .874). Acoustic measurements revealed that, similarly to Russian results, pre-stress consonants were significantly longer than post-stress and not-adjacent to stress consonants, while the latter two did not differ from each other ($F(2,8) = 4.810$, $p < .05$, eta-squared = .546; M = 92 ms, M = 69 ms, and M = 65 ms, respectively).

In accordance with the findings for the Russian group of participants, perception of length in intervocalic and preconsonantal positions by American participants did not show any context-driven biases, although as expected, there was an effect of target consonant duration ($F(1,25) = 142.963$, $p < .001$, eta-squared = .851). In production, intervocalic targets were longer than preconsonantal ones and this difference nearly reached significance ($F(1,8) = 4.877$, $p = .058$; M = 115 ms and M = 103 ms respectively). A reanalysis of the experimental data due to the different pronunciation of the stimuli by some of the American participants is in order, which I believe will provide decisive evidence of a significant statistical effect in the condition.

To summarize, the following perception-production asymmetries were established based on the results from the American participants: there was a significantly higher percentage of "long" responses for consonants in word-initial position as compared to word-final position, although in production word-initial consonants were longer than word-final ones, which would suggest an opposite trend in perception. Both post-stress and pre-stress positions conditioned a higher proportion of "long" responses relative to the not-adjacent to stress context. In production, consonants in post-stress and not-adjacent to stress positions did not differ in duration, and would be expected to condition a similar response on perception. Consonants in pre-stress were longer acoustically, and would be expected to condition a later shift to the perception of length, which was supported in relation to the post-stress consonants but not the not-adjacent to stress ones. The two types of immediate segmental environment did not affect perception of length in

the target consonants. However, in production, intervocalic consonants were near-significantly longer than preconsonantal ones.

3.3. Italian

For the Italian participant group, the results of the statistical analysis showed no significant effect of either target consonant duration or word-edge position on the perception of consonant length. In fact, both word-initial and word-final identification curves barely reached 50% of "long" responses around 350 ms. No statistical analysis of the production data was performed at this stage due to the small number of participants. Descriptive analysis showed that word-final consonants were marginally longer than word-initial ones (5ms difference).

Stress-related contexts, likewise, did not condition any difference in perception for the Italian participants: the three identification curves were completely overlapping. In this condition, however, there was a significant effect of target consonant duration: the listeners made a distinction between "long" and "short" consonants in a categorical fashion ($F(1,7) = 46.578$, $p < .001$, eta-squared = .869). In production, as for Russian and American groups of participants, pre-stress consonants were on average longer than post-stress and not-stress adjacent ones (24 ms and 26 ms respectively) - a potentially significant difference. The consonants in the latter two contexts differed only minimally in duration (2 ms).

Italian participants' responses in intervocalic and preconsonantal conditions showed a significant effect of target consonants' duration ($F(1,6) = 26.703$, $p < .01$, eta-squared = .817) but not of the segmental environment. There was a reliable discrimination of "short" and "long" consonants in this case, but no context-driven biases. Acoustic measurements demonstrated an average of 28 ms difference in duration between intervocalic and preconsonantal targets, intervocalic consonants being longer. This trend, if replicated with a higher number of participants, is likely to be significant.

To summarize, preliminary data for the Italian group of participants suggest a potential of the perception-production asymmetries of the type found for Russian and American participants in the intervocalic/preconsonantal condition, where the intervocalic context conditions an increase in acoustic duration but no shift in perceptual function. Similarly, in pre-stress context

consonants are on average longer than their post-stress and not-adjacent to stress counterparts, but do not differ from them in terms of the perceptual time-line. It is difficult to make assumptions based on the results of the length perception of word-initial and word-final positions because Italian participants showed a general reluctance to categorize consonants as long in these contexts, even at the extreme high end of the durational continuum.

4. Discussion and Conclusions

The results of the perceptual and acoustic investigation of the consonant length in three distinct languages show that, on the one hand, there are striking similarities between all three groups of participants, and especially Russian and American English. These similarities suggest that the mechanisms involved are universal rather than languages-specific. On the other hand, the Italian group of participants demonstrated differences in responses in a number of parameters, which will be discussed in more detail below. Both Russian and American participants showed a bias towards the perception of "long" consonants, which could not be justified by the differences in production, in the following environments: word-initial, post-stress, and intervocalic. This finding is especially important when considered in the context of the tendencies in the typological distribution of long consonants. As discussed in the introduction, long consonants are distributed asymmetrically across different word-positions and environments, occurring in most cases in intervocalic positions and after stressed vowels. No clear crosslinguistic preferences for word-initial or word-final position has been established by the previous researchers, although in Russian a context-driven variable degemination happens less frequently in word-initial position than in word-final position. There also exist languages that allow word-initial but not word-final geminates. (Chuukese; Muller 1999) Findings presented here indicate that perceptual considerations are among the factors deciding the location of consonantal length contrast in the languages. As long consonants are more readily perceived in such contexts as intervocalic, post-stress, and word-initial, they render the contrast more stable over time. In other environments, such as preconsonantal, emerging geminates are more likely to undergo neutralization on the perceptual grounds, although augmentations, as sometimes happens in detrimental to contrast positions, are not completely ruled out. An interesting case is represented by the pre-stress position. Russian data tell us that it is almost as good as the post-stress one: Russian long consonants degeminate in this context more often in post-stress position but

less often than in not-adjacent to stress position. Existing crosslinguistic investigations do not provide any information concerning the status of consonant length contrast in this environment. The results of the current study indicate an earlier perception of length in pre-stress context in relation to the not-adjacent to stress context for American participants. It is possible that not only preceding stressed vowels, but also following ones, increase the probability of the consonantal length contrast. The mechanisms underlying these perceptual differences are still unknown, although the answer probably lies in the direction sketched by those who addressed this question in the previous literature. In particular, as proposed by Padgett (2003), certain environments may be better suited for the detection of durational differences. Absence of clear segment boundaries, formant transitions, and similar cues normally provided by the vowels, in such contexts as consonantal clusters and word-edges, create difficulties in estimating the duration of the target segment. These difficulties promote uncertainty on the part of listeners as to whether the consonant they heard was long or short. As a result they choose to adhere a little longer to the "safe" choice of the unmarked member of the opposition - a singleton. In addition, certain phonetic environments may put the consonant in the position to obtain additional acoustic cues to its geminate nature, for example extra intensity. Since non-synthesized stimuli were used in this experiment, all the naturally present acoustic correlates of length were preserved and could have facilitated the perception of length. Word-initial and pre-stress position, in particular, are good candidates for increased intensity as an additional cue to geminacy.

While the advantages of intervocalic contexts are relatively clear, the privileged status of the stress-adjacent positions remains somewhat of a mystery. It is not immediately obvious what properties of stress can make the perception of duration easier, unless one considers the connection with the general ability of the stressed syllables to enhance the acoustic properties of its components. It is possible that in the presence of stress, differences in duration, just as other acoustic nuances, become more detectable to the listeners.

While Russian and American English results are in remarkable agreement, Italian participants bring in some diversity. Since only preliminary data are discussed here, they cannot be considered conclusive. However, one difference can be well justified: unlike Russian and American English, Italian has well-established phonemic geminates and, as a result, a language-specific influence on perception transpires in the results. In particular, Italian listeners

were very reluctant to categorize consonants on word-edges as long even when they reached 350-400 ms. This can be easily explained by the fact that Italian does not allow long consonants at the beginning and at the end of the words, apart from raddoppiamento sintattico (syntactic gemination of word-initial consonants after certain types of words, in particular those with final stressed vowels, see Borelli (2002)). In the remaining conditions Italian data show a potential to support the results from Russian and American English. There is a possible bias for the "long" perception in the intervocalic context as opposed to the preconsonantal one, due to longer duration of intervocalic targets in production. However, this effect, if found, could be attributed to the "short" bias in preconsonantal environment due to the absence of consonant-adjacent geminates in Italian. In stress-related conditions, preliminary results indicate a potential "long" bias in pre-stress position, but not in, contrary to the expectation, post-stress position. This is especially surprising given that Italian has been reported to contain more geminates following a stressed vowel than in any other environment (Esposito & Di Benedetto 1999), which suggests that the distribution of geminate consonants in Italian has been affected by the perceptual factors to some degree. This issue will be further clarified as more data from the Italian participants' group is analyzed. However, it is possible that perceptual factors discussed here are active on the synchronic level only in languages where consonant length contrast has not being fully phonologized. In languages like Italian, the phonemic status of the contrast in question and its currently established distribution may obscure the listeners' perceptiveness to the subtle acoustic differences that differentiate the consonants in different phonetic contexts.

To conclude, in this paper I have shown that the perception of consonant length is context-dependent and does not always rely on the context-invoked differences in duration. A specific type of the perception-production asymmetry is found in a number of contexts which, most importantly, are characterized by the highest instances of long consonants crosslinguistically. I propose that the relative perceptual advantage that long consonants receive in these contexts is responsible for the observed tendencies in crosslinguistic distribution of geminates.

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