# NASAL COARTICULATION IN LEXICAL PERCEPTION: THE ROLE OF NEIGHBORHOOD-CONDITIONED VARIATION

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## ABSTRACT

Nasal coarticulation has been shown to vary systematically in words depending on the number of phonological neighbors: words with many neighbors are produced with a greater degree of vowel nasality than words with fewer phonological neighbors [9]. This study examines the effect of this systematic low-level variation on lexical perception. The degree of nasality in natural real and nonsense words from high and low density neighborhoods was manipulated to neutralize the neighborhood-conditioned differences, and these original and manipulated stimuli were presented to subjects in a lexical decision task and a forced choice preference task.

The findings of this study suggest that, for high neighborhood density words at least, listeners are indeed sensitive to this systematic low-level phonetic variation and that it has an influence on lexical perception.

**Keywords:** nasal coarticulation, lexical perception, neighborhood density

## 1. INTRODUCTION

Vowels adjacent to nasal consonants (either preceding or following) are at least partially nasalized in English. While this coarticulatory nasality is consistently present (and therefore predictable based on the presence of an adjacent nasal), the degree of nasality varies across tokens. Listeners, then, encounter varying degrees of vowel nasality when they perceive words containing nasals.

There are conflicting accounts of how this coarticulatory nasality should affect listeners. On the one hand, nasality might constitute variability in vowel quality that would have to be factored out in vowel identification and therefore be detrimental to perception e.g., [6], with reference to coarticulation more generally. On the other hand, because nasality is predictable in the context of nasal consonants, it might be systematic information that could be used to facilitate perception of the larger vowel + nasal unit, e.g. [2, 4]. In yet a third alternative in which specific encountered instances of words are stored in phonetically-detailed exemplar representations, e.g. [5, 8], nasality *per se*, insofar as it matches the nasality in the input the speaker has received previously and stored, should have no effect at all on perception as it is simply a part of the stored representations.

To further complicate predictions, however, some of the variation in degree of nasal coarticulation has been shown to be systematic as well, conditioned by the phonological neighborhood properties of the word. Vowels in words from neighborhoods with many neighbors show greater nasality than vowels in words from neighborhoods with fewer neighbors [9]. Do listeners notice this lower-level variation? Do they notice its systematicity? And what effect does this have on them?

The current study examines the effect of vowel nasality on lexical perception by means of a lexical decision task and a forced choice preference task performed with natural language stimuli manipulated to vary their degree of nasality by the small degree found in the difference between natural productions of high and low neighborhood density words. Based on the responses from these tasks, we can see the effect that fine-grained detail in coarticulatory nasality has on lexical perception and assess the degree to which neighborhood-conditioned adjustments in production influence perception.

## 2. METHODS

Listener participants took part in an auditory lexical decision task and a forced choice preference and rating task with manipulated more- and less-nasal low- and high-neighborhood density words.

### 2.1. Materials

There were 32 monosyllabic words containing a VN sequence (VNs) and 26 monosyllabic words containing an NV sequence (NVs) included in the study, plus an equal number of category-matched nonwords. The words and nonwords of each type were divided equally between high and low neighborhood density words.

#### *2.1.1. Lexical properties*

Frequency-weighted neighborhood density (henceforth, ND), defined as the summed log frequencies of a word's neighbors, was calculated for each monosyllabic VN and NV in the Hoosier Mental Lexicon [7]. Neighbors were considered to be words that differed from the target word by the addition, deletion, or substitution of a single phoneme. Frequencies were taken from CELEX [1]. Study words were selected from the top third and bottom third of these possible VNs and NVs, ranked by ND. All words were highly familiar (with familiarity ratings of 6 or greater on the 7 point Hoosier Mental lexicon scale) and were balanced by target word frequency, vowel height, coda size, and adjacent sonorant (if any) across neighborhood categories.

Possible phonotactically-plausible English-like nonwords were automatically generated from each selected real word by modifying the onset, vowel, or coda (but always preserving any nasal segments), and their neighborhood properties were calculated. Nonword tokens were chosen from this set to be phonetically balanced and to match as closely as possible the lexical properties of their real word pairs. Lexical properties of each group are summarized in Table 1**.**

**Table 1:** Mean frequency-weighted neighborhood density (ND) and number of neighbors (Neigh), by stimulus type.

| | Real VN | Real NV | Non VN | Non NV |
|---|---|---|---|---|
| Hi ND | ND: 45.4<br>Neigh: 17.9 | ND: 48.0<br>Neigh: 19.9 | ND: 43.3<br>Neigh: 16.7 | ND: 45.4<br>Neigh: 19.6 |
| Lo ND | ND: 8.9<br>Neigh: 4.0 | ND: 11.0<br>Neigh: 5.2 | ND: 8.7<br>Neigh: 4.3 | ND: 11.1<br>Neigh: 5.2 |

#### *2.1.2. Nasality manipulation*

Degree of vowel nasality was manipulated by combining the waveform of a nasal or oral "donor" vowel with the waveform of the target "recipient" token in varying ratios by formula using Praat. The recipient was one of the test words (VN or NV); the donor vowel was extracted from a monosyllabic word matching the recipient for vowel quality and surrounding consonant place of articulation but containing either an NVN sequence (to increase the recipient's nasality) or a CVC sequence (to decrease the recipient's nasality). The vowels from both words were automatically isolated and adjusted to match for duration and pitch contour using a Praat script. The vowel waveforms were then additively combined, with incrementally adjusted ratios from 0% donor:100% recipient to 30% donor:70% recipient. Each resulting vowel was spliced back into the original recipient word context.

A stimulus pair was then selected from this continuum of outputs for each target word and nonword. The "original" stimulus member was chosen based on the degree of nasality, measured acoustically by A1-P0 [3], expected for natural Hi and Lo ND words as produced by speakers in [10]. Often, this was the 0% donor:100% recipient token (though not always, due to natural variation in production). A "nasality-modified" counterpart was selected to correspond with respect to the degree of nasality to the "original" as shown in Table 2. (Note that this means that "original" and "modified" nasality stimulus pairs did not always correspond to more or less altered tokens, respectively.) These amounts of change in nasality were determined on the basis of the measured nasality differences for low versus high neighborhood density NV and VN words produced by speakers in [10]. Hi ND words (which naturally have more nasality) were modified to have the degree of nasality typical of Lo ND words (i.e., nasality was decreased), and Lo ND words (which naturally have less nasality) were modified to have the degree of nasality typical of Hi ND words (i.e., nasality was increased).

**Table 2:** Target changes in nasality.

| | VN | NV |
|---|---|---|
| Hi ND | A1-P0 ↑ by .99<br>Nasality *reduced* | A1-P0 ↑ by .98<br>Nasality *reduced* |
| Lo ND | A1-P0 ↓ by .99<br>Nasality *increased* | A1-P0 ↓ by .98<br>Nasality *increased* |

Recordings for stimulus generation were recorded from a single phonetically-trained male native speaker of English using an Earthworks M30 microphone in a sound-attenuated booth. Each donor and recipient word or nonword was spoken three times from a wordlist (with nonwords transcribed in IPA).

### 2.2. Participants

Eighteen native English-speaking paid volunteers participated in the study (13 female, 5 male; all right-handed).

### 2.3. Task

PsyScope X was used to present the prepared stimuli to participants for timed auditory lexical decision and a forced choice preference. In the lexical decision task, participants heard 26 NV and 32 VN words and an equal number of matched nonsense words, half from each group with an original ("natural") degree of nasality and half in their nasality-modified ("changed") version. The versions heard were counterbalanced between two groups of subjects.

Following the lexical decision task, participants were played both versions of each real word in pairs and instructed to indicate (at their own pace) which version (first or second) they felt was a better pronunciation of the word and their degree of preference (on a scale of 1-3).

Participants listened to the stimuli over headphones in an acoustically controlled environment and recorded their responses on an iOLabs response box.

## 3. RESULTS

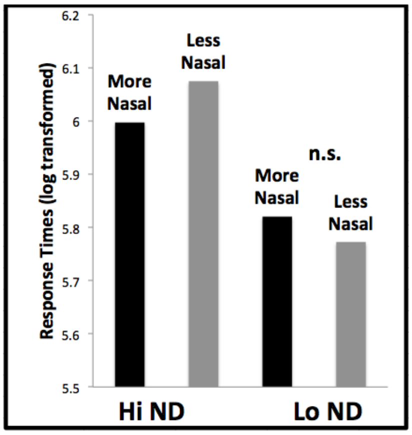
### 3.1. Lexical decision

Response times (RTs) from correct responses to the lexical decision task were log-transformed and analyzed. A four-way repeated-measures ANOVA tested listeners' response times for effects of neighborhood density (Hi ND, Lo ND), word reality (real word, nonword), syllable type (NV, VN), and degree of nasality (original degree of nasality, changed degree of nasality). A second four-way RM ANOVA tested RTs with the factor degree of nasality recoded with the factor of nasality (more nasality, less nasality).

The first analysis revealed main effects of neighborhood density [$F(1,17)=33.34$, $p<.001$] and word reality [$F(1,17)=29.89$, $p<.001$], indicating that listeners responded faster to Lo ND words and nonwords (422 ms) than to Hi ND words and nonwords (485 ms) and that they were faster responding to real words (380 ms) than to nonwords (532 ms). There were also main effects of degree of nasality [$F(1,17)=5.54$, $p=.03$] and syllable type [$F(1,17)=6.21$, $p=.02$]. These main effects revealed that listeners responded faster to words with an original degree of nasality (440 ms) than to words with a changed degree of nasality (465 ms) and that they were faster responding to NV words (433 ms) than VN words (469 ms). There was also a significant interaction of reality by syllable type [$F(1,17)=9.61$, $p=.007$]. The second analysis revealed a significant interaction of nasality by neighborhood density [$F(1,17)=5.54$, $p=.03$]. No other main effects or interactions were significant in either analysis.

Fig 1. illustrates the interaction between nasality and neighborhood density. Post hoc t-tests showed faster RTs to more nasal Hi ND items (real and nonsense) than to less nasal Hi ND items but no difference in RT between more or less nasal Lo ND items. These results indicate that listeners found it easier to correctly accept words (and reject nonwords) with the attested relative level of nasality for Hi ND words: more nasality when the word has many phonological neighbors.

**Figure 1:** Lexical Decision Task: Average log RTs by neighborhood density (Hi ND, Lo ND) and nasality (more nasal, less nasal).



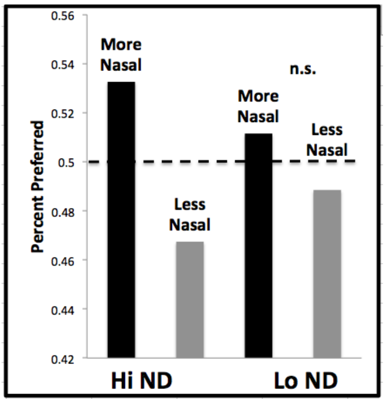

As noted in section 2.1.2 above, Hi ND tokens (both words and nonwords) with a "more natural" degree of nasality (in this case, greater nasality) are not uniformly less altered than Hi ND tokens with a less natural degree of nasality, due to natural variation in production and the process of stimulus selection. Thus, we can attribute this result to the difference in the naturalness of the degree of nasality without concern about a confound between degree of nasality and degree of modification.

### 3.2. Forced choice preference

The forced choice preference task elicited listener preferences in original-changed nasality real word pairs. These responses are summarized in Fig. 2.

Binomial tests showed that relative Hi ND more nasal and Hi ND less nasal preferences differed significantly from chance, but the Lo ND preferences did not differ significantly from chance. Note that the pattern of data seems to mirror the results from the lexical decision task in that listeners tended to prefer Hi ND words with natural (greater) nasality but again the Lo ND results were inconclusive.

**Figure 2:** Percentage of preferred responses to more nasal-less nasal stimulus pairs, by ND.




## 4. DISCUSSION

This study examined the perceptual consequences of the details of nasal coarticulation, which are conditioned in natural speech by the phonological neighborhood properties of a word (where Hi ND words exhibit greater degrees of nasal coarticulation than Lo ND words [9]). We systematically decreased the degree of nasality in Hi ND words and increased the degree of nasality in Lo ND words, effectively neutralizing the natural neighborhood-conditioned differences, and we presented original nasality and altered nasality stimuli to subjects in a lexical decision task and a forced choice preference task.

Our results suggested that speakers are sensitive to this low-level phonetic variation and that it does affect perception. For Hi ND words, we take these results as demonstrating that perception mirrors natural production: speakers produce Hi ND words with more nasality and listeners both respond faster to and systematically prefer tokens that conform to these patterns.

The lack of significant differences among the Lo ND words, however, invites speculative hypotheses about the roles of vowel nasality as a predictive cue and stimulus naturalness (or closeness to produced norms) in lexical perception. One possibility is that increased nasality (as in Lo ND modified tokens) and naturalness (as in Lo ND original tokens) are similarly weighted perceptual cues, with the perceptual advantage of the one balancing out the perceptual advantage of the other. Alternately, listeners may be less reliant on (and sensitive to) such cues as degree of nasality in the easier Lo ND words, since such detailed analysis of the signal may not be necessary for the identification of these words in the absence of competition from many neighbors. Evaluation of these hypotheses awaits results from further experimentation now in progress.

Whether or not neighborhood-conditioned effects are produced explicitly *for* listeners [9, 11], our results show that listeners are sensitive to and make use of subtle, systematic neighborhood-conditioned variation in the speech signal, showing better perception when the effects of such variation are present – at least for Hi ND words – and critically, when they are present to the same degree that they are in natural production.

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