# A PROBLEM OF ASSIMILATION BETWEEN NASAL VOWEL AND PRECEDING NASAL CONSONANT, A PERCEPTUAL EXPERIMENT

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## ABSTRACT

On the basis of mainly articulatory data it was concluded in Van Reenen [1] that a nasal vowel consists of a nasal part preceded by an oral part. The results of the experiment reported below show that the increase in nasality from the oral to the nasal part is relevant for the perception of the vowel as nasal, even when the vowel is preceded by a nasal consonant. The result explains a paradox with respect to assimilation.

## THE PROBLEM

### Assimilation

When two phonemes (or underlying segments) are realized adjacently, assimilation may occur, i.e. the realizations of these phonemes (or segments) may become more like each other. When the underlying sequence of phonemes (or segments) /na/ is perceived as [nã], the /a/ has been assimilated to the /n/ with respect to nasality, a case of progressive assimilation. However, if the sequence /na/ is perceived as [na], there is no (or hardly any) assimilation. This is essentially the view of assimilation in structural and generative phonology.

In diachronical studies it is commonly claimed that if [na] > [nã] (whatever the underlying segments) there has been progressive assimilation. However, this kind of change is not common. Much more common is the change [an] > [ãn] > [ã] or [nan] > [nãn] > [nã]. The formation of the [ã] is usually the consequence of regressive assimilation by the following nasal consonant. However, no explanation is provided for the asymmetry in behaviour of the vowel preceded or followed by nasal consonant.

In both views is it assumed (although often implicitly) that assimilation concerns both coarticulation and coperception. If the [ã] in [nã] is more like the [n] than the [a] in [na] the resemblance concerns both the position of the velum and the nasal quality of the two sounds. We will refer to these views as the Assimilation Hypothesis.

In the following we will provide an explanation why there is an asymmetry between the nasalisation of a vowel preceded and a vowel followed by nasal consonant. In particular we claim that with respect to articulation the [ã] in [nã] has not become more like the [n] than the [a] in [na], although in both forms some coarticulation occurs.

### The articulatory structure of a nasal vowel

In Van Reenen [1] it was found that vowel nasality is better defined in terms of the articulatory notions nose coupling and mouth coupling than in terms of nose coupling alone. The amount of nose coupling N was defined as the opening in $mm^2$ of the nasal port measured in a cross-section perpendicular to the airstream at the point of greatest constriction between the velum and the pharyngeal wall. The amount of mouth coupling MC was defined as the opening in $mm^2$ of the mouth passage, measured in a cross-section perpendicular to the airstream at the point of greatest constriction in the mouth. Articulatory evidence showed that rather than in terms of N the nasality of vowels may be expressed in terms of the proportional relationship N% between N and MC, as in formula (I):

$$N\% = N/(N+MC) \cdot 100\% \qquad (I)$$

It follows from (I) that an increase in N% is produced by means of an increase in N and/or a decrease in MC.

A second finding in Van Reenen [1] was that there is an increase in N% during the production of a nasal vowel and that this increase in N% is an intrinsic property of this vowel. This conclusion was mainly based upon the fact that the lack of N% in the first part of the vowel appeared to be not simply a case of coarticulation with a preceding nonnasal consonant, since the increase in N% was present in nasal vowels preceded by a nasal consonant as well. Between the central phase of the nasal consonant - during which MC=0 and N% is 100%, see formula (I) - and the central phase of the nasal vowel, a dip in the amount of N% occurred. In terms of N this dip was sometimes present as well. In other cases there was an increase of N from the end of the central phase of the nasal consonant to the central phase of the vowel. This increase in N may correspond to a dip in N% as well, on the assumption that the MC of the vowel is arrived at early in the vowel and is more or less steady until its central phase. We will refer to this conclusion as the Increase in N% Hypothesis.

### A paradoxical result of a perceptual experiment

A perceptual experiment carried out by Linthorst [2] provided some indirect evidence that the increase of N% during the nasal vowel was perceptually relevant. In the experiment, Linthorst manipulated the vowel

in French même "self" [mɛm] to which we will refer as [$e_n$], since it may be assumed that it was produced with a considerable amount of NZ from the beginning to the end, and the vowel in words like baie "bay" [be] to which we will refer as [$e_o$], since it may be assumed that it was produced with NZ being 0. Linthorst found that speakers of French perceived the vowel [$e_n$] as nonnasal. In one speech sample offered to the listeners the second [m] had been cut off as in [$me_n$] and in another the vowel [$e_n$] had been added once again as in [$me_ne_n$]. However, when the same vowel [$e_n$] was added to [$be_o$] as in [$be_oe_n$] the speech samples were perceived as containing nasal vowels, although in the first part of [$e_oe_n$] it may be assumed that NZ was 0.

In order to account for the results found by Linthorst, the following explanation was proposed in Van Reenen[1]. On the one hand, the increase in the amount of NZ during the [$e_oe_n$] preceded by **oral** consonant made the listeners perceive the vowel as nasal. On the other hand, the more or less constant amount of NZ in [$e_ne_n$] and [$e_n$] preceded by **nasal** consonant, made the listeners perceive [$e_ne_n$] as nonnasal. In other words, the listeners interpreted implicitly the off-glide of the [m] as still present during the articulation of the vowels [$e_n$] and even [$e_ne_n$].

**A first experiment**
In order to test this explanation a preliminary experiment was carried out in which a direct link was laid between articulatory properties of nasal vowels and their perception. Artificial nasal vowels were produced by means of a plexiglass model in which NZ could be calculated on the basis of the articulatory properties N and MC. Listeners judged vowels in which NZ increased as being more nasal than vowels in which NZ was equally distributed over the vowel for the same amount of NZ. Since the result showed that the increase in NZ is more important for the perception than the total amount of NZ, the increase in NZ hypothesis was confirmed. The details of the first experiment are presented in Van Reenen and Groen [3].

**Implication**
The explanation in Van Reenen [1] of the experiment in Linthorst [2] has an implication which can be tested. If it is correct, it follows that a nasal vowel preceded by a nasal consonant should contain an increase in NZ in order to be perceived as nasal. A perceptual experiment was devised in which this implication was examined in order to make a choice on this point between the Assimilation Hypothesis and the Increase in NZ Hypothesis.

Figures 1 through 4 illustrate the two hypotheses to be tested from an articulatory point of view. In these figures C=oral consonant, N=nasal consonant, V=oral vowel, $\tilde{v}$=nasal vowel. The amount of NZ is represented from the end of the central phase of the consonant until the end of the central phase of the vowel.

With respect to perception the two hypotheses predict that [$\tilde{v}$] in [C$\tilde{v}$] will be perceived as nasal and [V] in [NV] as oral (see figures 1 and 2). Figures 3 and 4 represent forms of coarticulation. Instead of following down the broken lines, NZ stays high in figure 3. Figure 4 represents another, less outspoken form of coarticulation. Here NZ decreases until it crosses the line of increase of the vowel. According to the Assimilation Hypothesis figure 3 represents [N$\tilde{v}$], whereas figure 4 is nonexistant. According to the Increase in NZ Hypothesis figure 3 represents [NV] and figure 4 [N$\tilde{v}$]. The experiment reported below shows that figure 4 represents [N$\tilde{v}$], thus providing confirmation of the Increase in NZ Hypothesis.

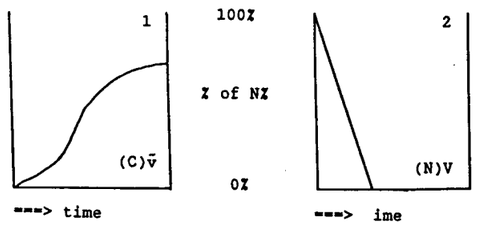


Fig. 1 and 2. Schematic representation of the amount of NZ on the basis of articulatory data.

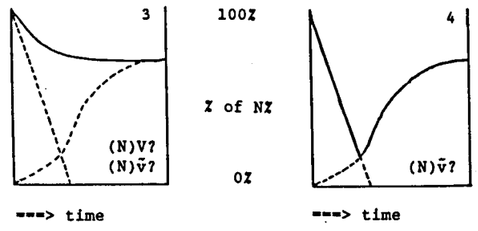


Fig. 3 and 4. Schematic representation of the amount of NZ during the vowel on the basis of articulatory data.

## THE EXPERIMENT

**Test words**
In the experiment the properties of the vowels of four Dutch words of type [Cvs] and [N$\tilde{v}$s] were tested perceptually. The words are:

[pɑ̃s, pɪ̃s, mɑ̃s, mɪ̃s]

They occur in low standard Dutch pronunciation, in which the [n] - present in the standard language forms - is absent and the vowel is nasal. The words with [ɑ̃] are possible French words as well.

**Speech samples**
The series of four words was pronounced five times by the first author and registered on Revox A77 by the second author. The words were pronounced slowly and clearly, as much as possible at the same frequency (150 Hz) and equally loudly. The most regular set was selected for further treatment.

The [p], [m] and [s] were cut off the words by means of the computerprogram SESAM. As the borderline between [p] and vowel we took the transition from non-periodic to periodic. As the borderline between [m] and vowel the change in amplitude. In the case of [p] and [m] these borderlines correspond almost exactly to the end of the central part of the consonant during which the mouth canal is blocked. As the borderline between the vowel and [s] we took the transition from periodic to non-periodic. The vowel length of the two [ɑ̃] sounds was 420 ms, of the [ɪ̃] in [pɪ̃] 368 ms, in [mɪ̃] 394 ms.

For the [p$\tilde{v}$] words we expected a perceptual score corresponding to figure 1. These items served as a control. The scores with respect to the vowels in [mɪ̃s] and [mɑ̃s] made it possible to check the reality of figure 4.

Five times two periods were selected from each of the four vowels. The two periods were chosen at 0, 50, 100, 150 and 200 ms from the beginning of the vowel. Since a period has a length of 8 ms the selected vowel periods were situated at 0-16 ms, 50-66 ms, 100-116 ms 150-166 ms and 200-216 ms. We may assume that the nasality during each selected vowel fragment of two periods was (almost) constant.

Each fragment of two periods was lengthened to a vowel of 196 ms by means of a computer program (GHEVU). These vowels will be called: 1 to 5, where 1 refers to the first, and 5 to the last selected vowel segment. We refer to the artificial vowels as (p)$V_3$, (m)$i_5$ i.e. the third lengthened vowel segment in the word starting with [p], and the fifth segment of [i] preceded by [m].

The ten artificial [ɑ̃] sounds were grouped into pairs and the pairs were put on tape in random order. Each pair was compared to itself and to the other [ɑ̃] sounds, just as the ten artificial [ɪ̃] sounds. The test is of the type A-B and B-A. So, for instance, [(p)$i_1$] formed a pair with [(p)$i_4$] and [(p)$i_4$] formed a pair with [(p)$i_1$]. The test started with ten supplementary pairs which did not count in the score.

**Subjects**
Altogether 33 subjects listened to the tape, 18 of whom were known to be trained listeners. They were asked to score which of the two vowels was more nasal. The results have been calculated for the two groups separately and together. Since we were not interested in the question whether Dutch listeners are able to hear vowel nasality, but in the question whether listeners who are able to perceive vowel nasality judged our artificially lengthened vowels, we consider the results of the trained group as more relevant and report them in detail. The data of the untrained listeners - showing the same trends but less clearly - are presented in an Appendix.

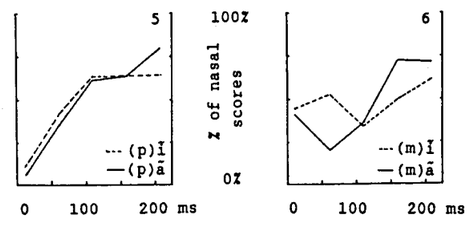


Fig. 5 and 6. Nasal scores by trained listeners.

**Results**
The results of the trained listeners are reproduced in figures 5 and 6 as percentages of more nasal scores. They show that trained listeners hear the vowels preceded by [p] as consisting of a minimal nasal part, followed by increasingly more nasal parts. In the case of [(p)$i_3$], [(p)$i_4$] and [(p)$i_5$] no increase in nasality was perceived. Apparently the maximal nasality is reached early in this vowel, earlier than in the [ɑ̃].

The [(m)$\tilde{v}$] vowels offer a different picture. During the central part of the nasal consonant NZ is 100%. As soon as the vowel starts (in terms of periodic waves or increased amplitude) the perceptual correlate of NZ decreases sharply until the second vowel to increase sharply again until the 5th. In the case of [ɪ̃] there are two increases at the beginning of the vowel. The second and most serious increase is situated later in the vowel than in the three other words.

**Agreement of scores**
In order to check the agreement of the scores of the trained listeners, the Friedman rank analysis was applied. The higher the $X^2$, the better the agreement among the listeners. As appears from table 1 (for the untrained listeners see Appendix), the agreement of the scores of the trained listeners was high. It was always significant at the .01 level, and, except in one case, at the .001 level. We may conclude that the scores of the trained listeners are highly reliable.

| | $X^2$ | Df | a=.05 at | a=.01 at | a=.001 at |
|---|---|---|---|---|---|
| (p)ɑ̃ | 51.19 | 4 | 9.49 | 13.28 | 18.47 |
| (m)ɑ̃ | 33.30 | 4 | 9.49 | 13.28 | 18.47 |
| (p)ɑ̃+(m)ɑ̃ | 94.06 | 9 | 16.92 | 21.67 | 27.88 |
| (p)ɪ̃ | 38.52 | 4 | 9.49 | 13.28 | 18.47 |
| (m)ɪ̃ | 14.74 | 4 | 9.49 | 13.28 | 18.47 |
| (p)ɪ̃+(m)ɪ̃ | 95.34 | 9 | 16.92 | 21.67 | 27.88 |

Table 1. Agreement of the scores of trained listeners in terms of the Friedman rank analysis. Agreement was always significant at the .01 level, and, except in one case, at the .001 level.

## DISCUSSION

**Confirmation of the Increase in NZ Hypothesis**
Although we have not examined the question whether the speech samples were articulated with an increase in NZ during the nasal vowel, the way the listeners perceived the succeeding parts of the original nasal

vowels suggest that such an increase was present. The perceptual results represented in figure 5 closely parallel the articulatory representation in figure 1. Apparently the increase in NZ brought about by the amount of N and MC is perceived as an increase in nasality. The perceptual results in figure 6 closely parallel the articulatory representation in figure 4. Apparently, the dip in NZ between the nasal consonant and the central part of the vowel is perceived as a relative lack of nasality. It would be difficult to imagine how these perceptual results correspond to an articulation without such a dip. Therefore we consider the perceptual results represented in figure 6 as evidence in favour of the Increase in NZ Hypothesis. It follows that both figure 2 and figure 3 represent [NV].

It may be the case that the results found do not even represent the dip in its most outspoken form. As we have seen above, the vowels 1 through 5 were produced on the basis of 16 ms samples from the original vowel. In between every two succeeding samples fragments of 50-16=34 ms were not examined. It is possible that if the two periods had been chosen from these 34 ms, the NZ and the perceived nasality might have been even (slightly) less than what has been found. This would have made the results even more convincing.

**Differences concerning [Ĩ] and [ã]**

There is less agreement among listeners concerning [(m)Ĩ] than concerning [(m)ã] and on an average the increase in NZ in the [Ĩ] is less clearly perceived than in the case of [ã]. Apparently, the role of the dip is less important in the case of [(m)Ĩ]. We have have seen that in the case of [(m)Ĩ] the dip falls later in the vowel than in the case of [(m)ã]. Does the amount of nose coupling N during the first part of the [Ĩ] ([(m)$i_1$]) increase slightly? The palatoglossus - which is responsible for the closing movement of the velum - is a relatively slowly reacting sphincter and since MC is relatively low the influence of such a slow reaction may be noticeable where it is not in the case of [ã].

**Assimilation, coarticulation and coperception**

A nasal vowel preceded by a nasal consonant will not easily become nasal. The NZ will be interpreted as part of the off-glide of the nasal consonant. Even if a nasal vowel is formed by means of a dip between the central phase of the nasal consonant and the central phase of the nasal vowel, this vowel is not as easily perceptible as a nasal vowel in isolation, since the increase will be less outspoken.

Coarticulation between [m] and [V] implies that the vowel is produced with a considerable amount of NZ during its first part, which may go on during its central phase. The result is perceived as an oral vowel. In order to perceive such a vowel as nasal this coarticulation should be avoided and a dip in NZ should be created.

If assimilation is considered to concern both coarticulation and coperception, we may conclude that the succession of a nasal consonant and a nasal vowel is characterized by coperception but not by coarticulation. Coarticulation between nasal consonant and following nasal vowel is not more outspoken than between nasal consonant followed by an oral vowel.

If this conclusion is accepted there is no specific coarticulation between a nasal consonant and a following nasal vowel. This would explain why in language change progressive assimilation of a nasal vowel is less common than regressive assimilation.

## APPENDIX

Data concerning the group of untrained listeners.

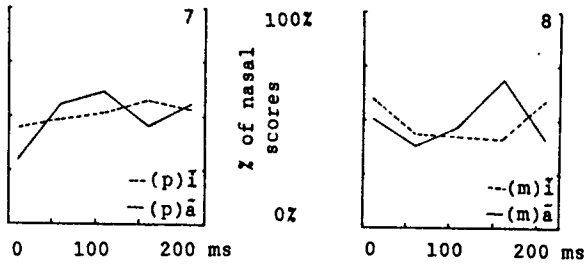


Fig. 7 and 8. Nasal scores by untrained listeners.

| | $X^2$ | Df | a=.05 at | a=.01 at |
|---|---|---|---|---|
| (p)ã | 15.56 | 4 | 9.49 | 13.28 |
| (m)ã | 9.67 | 4 | 9.49 | 13.28 |
| (p)ã+(m)ã | 33.89 | 9 | 16.92 | 21.67 |
| (p)Ĩ | 4.04 | 4 | 9.49 | 13.28 |
| (m)Ĩ | 13.48 | 4 | 9.49 | 13.28 |
| (p)Ĩ+(m)Ĩ | 15.63 | 9 | 16.92 | 21.67 |

Table 2. Agreement of the scores of untrained listeners in terms of the Friedman rank analysis. The agreement among untrained listeners was less than among trained listeners, although, except one case, significant at the .05 level and, except two cases, at the .01 level.


## ACKNOWLEDGEMENTS

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## REFERENCES


[1] Reenen, P. Th. van, **Phonetic feature definitions, Their integration into phonology and their relation to speech, A case study of the feature NASAL**, Dordrecht/Cinnaminson: Foris, 1982.

[2] Linthorst, P., **Les voyelles nasales du français, Etude phonétique et phonologique**, Thesis University of Utrecht, 1973.

[3] Reenen, P. Th. van and M. Groen, **The relation between the articulatory properties of nasal vowels and their perception**, in prep.