Acoustics of nasal consonants

Based on the main points from Johnson, Chap. 8 “Nasals and Laterals”

(When reading this text refer to the three figures at the end of the document. They compare the acoustics of bilabial **[m]** and uvular **[N]** as sonagrams and spectra.)

Consider a **uvular nasal** as the simplest case of a nasal consonant.
It can be regarded as a (fairly) neutral tube extending from the glottis via the pharynx and nose to the nostrils.
Since this tube is longer than the neutral tube for schwa (extending from the glottis via the mouth to the lips) we expect **lower resonance frequences** (Johnson p. 144; he estimates a total tube length from glottis to nostrils of about 21.5cm).
This can be seen very clearly in the sonagram of the sequence schwa - uvular nasal - schwa for F1 and F2 (Fig. 1 below).

A second feature of nasals is that (compared to oral vowels) the **formants are more strongly damped**. Damping is related to the fact that the soft vocal tract walls absorb acoustic energy. The overall area of the vocal tract walls is probably larger in nasals.
Increased damping corresponds to larger bandwidth of the formants (Johnson p. 141-143; see handout on ‘Bandbreite’ from previous session).
This is not so easy to see in the sonagram in Fig. 1, but for the sound on which this sonagram is based Praat reports a bandwidth of F1 of about 60Hz in the schwa and about 200Hz in the uvular nasal (the bandwidth of F2 is also larger overall, though less consistently).
This is one reason that nasals appear less prominent in sonagrams compared to vowels.

A second major reason for the weaker signal in nasals is that these sounds are always accompanied by **anti-resonances**. Observe the very low intensity in the uvular nasal in the frequency region around 1500-2000Hz. This is probably due to an anti-resonance caused by one of the nasal sinuses. The nasal sinuses act as **side-tubes** branching off the main tube (Johnson p. 146 and p. 151).
Side-branches in effect take energy out of the main tube at the resonance frequency of the side-branch (a more detailed example of this phenomenon is given below).
This in turn explains why (unlike F1 and F2) F3 does not appear to lower at the transition from schwa to the uvular nasal. Let us assume that like schwa the uvular nasal has roughly equally spaced resonances (our typical schwa has resonances at about 500, 1500, 2500 ... Hz). Because of the longer tube for the nasal the resonances will be closer together. F1 and F2 in the uvular nasal in Fig. 1 are about 700Hz apart. So we expect F3 at about 700Hz above F2, i.e at about 1600 to 1700Hz. However, it has probably been cancelled by a nearby anti-resonance and is simply invisible in the sonagram (it may be just visible in Fig. 3 showing overlaid spectra of **[N]** and **[m]**).

Summarizing so far, in a nasal consonant we expect:

- Overall low resonance frequencies (compared to schwa)
- Larger bandwidths (greater damping compared to oral vowels)
- Frequency regions of very low intensity caused by anti-resonances (so not all resonances of the system may actually be visible)

Let us now turn from the uvular nasal to a **bilabial nasal** (see sonagram in Fig. 2 below; see also Johnson p. 146-147). This will show that anti-resonances actually have an even more important role to play in nasals.

The key difference between the uvular and bilabial nasal is that for the bilabial the whole of the mouth cavity forms a side-branch branching off from the main pharynx-nose tube system. Thus we can expect additional anti-resonances to be introduced. And once again this is very easy to see in the sonagram: for **[m]** compared to **[N]** there is a clear decrease in the acoustic energy around 1000Hz and again at around 3000Hz. The decrease in energy around 1000Hz means that now not only F3 but also F2 is more or less cancelled out.

For the anti-resonances related to the mouth cavity it is also much easier to work out a rough estimate of their expected frequencies than it is for the side-tubes formed by the nasal sinuses. The mouth cavity can be considered as a tube closed at one end (the lips) and open at one end (at the opening into the pharynx near the uvular). The resonances of this tube system will appear as anti-resonances in the output signal. The formula for calculating the resonances is exactly the same as that used for calculating the resonances of a neutral tube as for schwa (c/4l, 3c/4l ....). Assuming a length of the mouth tube of about 8cm, this gives (very roughly) about 1000Hz and 3000Hz for the first two resonance frequencies. Thus we expect very little energy in the output signal at these frequencies. And indeed, these are the frequencies at which we have just observed the major differences between **[N]** and **[m]**.

An important further consequence of this basic principle is that the **location of these anti-resonances will move upwards in frequency as the place of articulation of the nasal moves back in the mouth** from bilabial to e.g alveolar or palatal (i.e the length of the mouth-cavity side-branch gets shorter).

Figure 3 provides a summary of all the above remarks by overlaying the spectra of [N] and [m]: The strongest differences between the two sounds are in the region of 1000 and 3000Hz, caused by additional anti-resonances for [m]. Both sounds have a very strong minimum around 2000Hz: This makes sense if this is due to an anti-resonance from the nasal sinuses since such an anti-resonance will be independent of the place of articulation of the consonant.

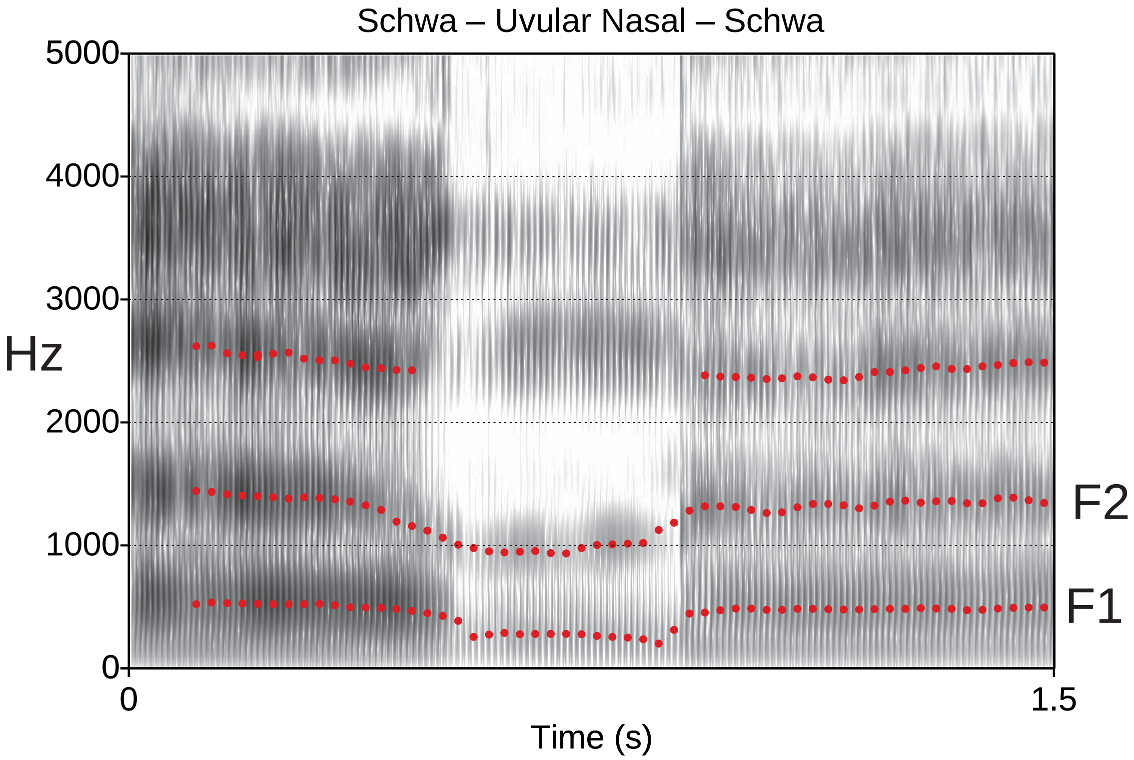

Figure 1

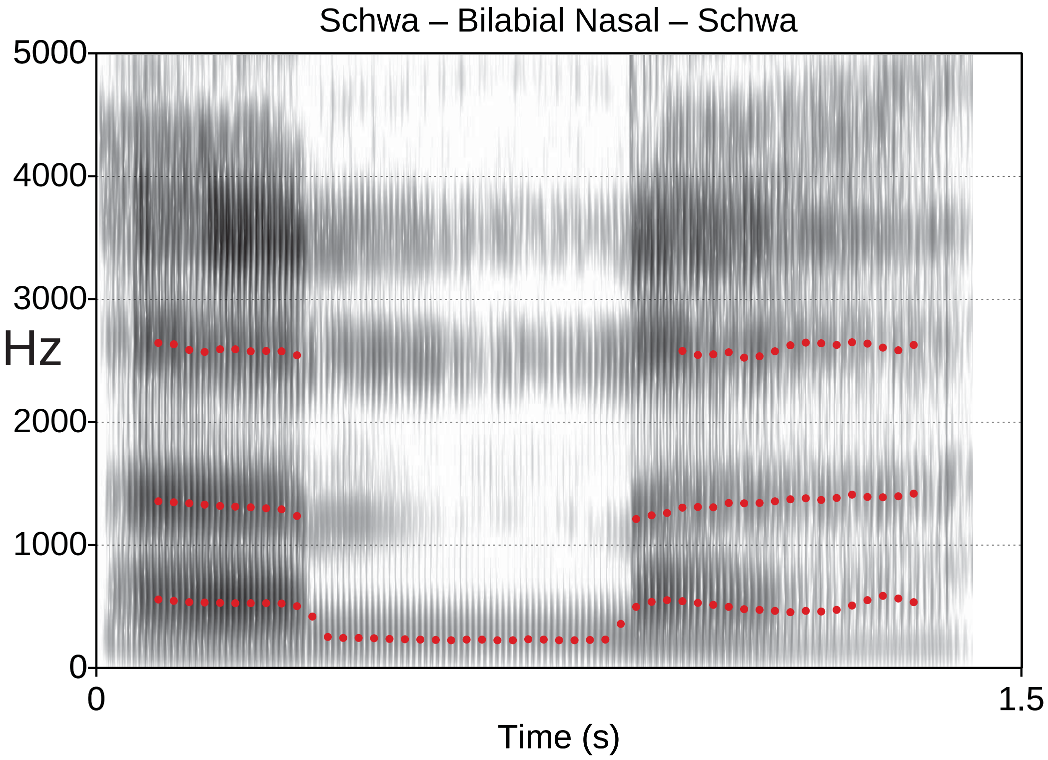

Figure 2

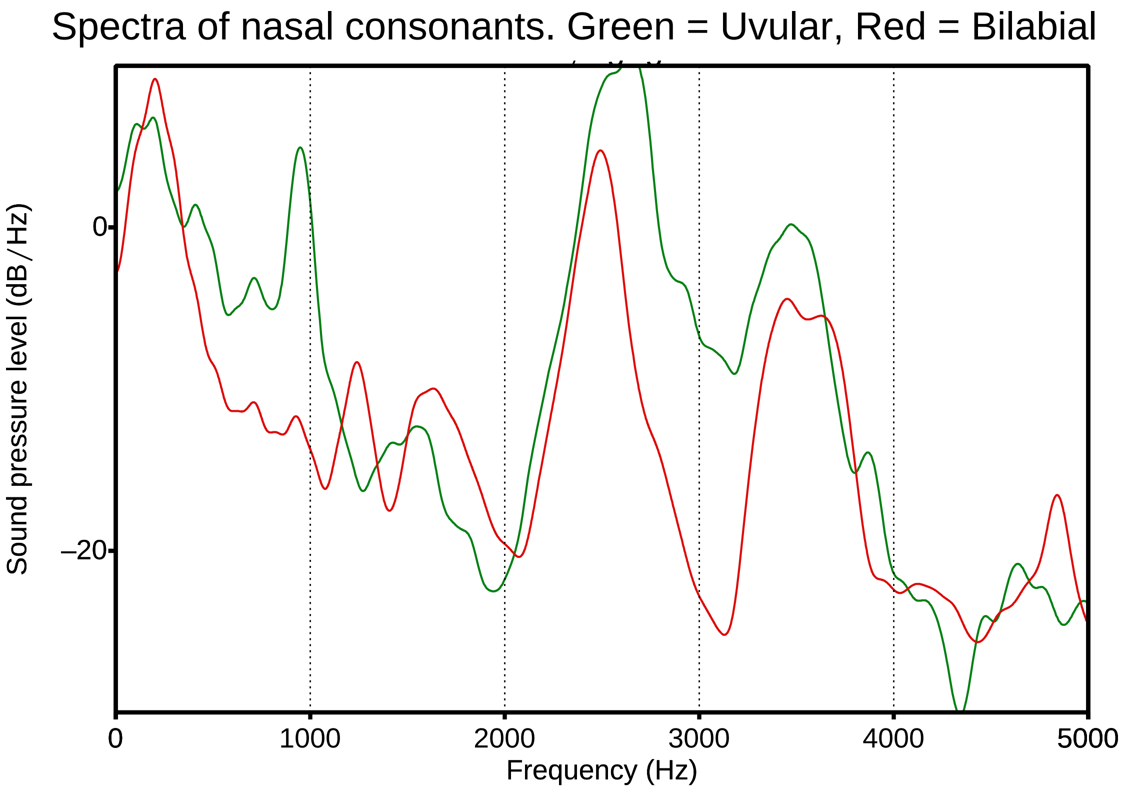
Spectra of nasal consonants. Green = Uvular, Red = Bilabial

Figure 3