SUPPLEMENTARY INFORMATION*:

"What Garcia got right: understanding cortical signaling of the glottis"

*Note: this information is not peer reviewed
nor officially authorized by the Journal of Singing.
It is my personal supplement to clarify some terminology).

There is a hazard of shared terminology between disciplines. Measurement observations can also differ in terms of order and timing (at the millisecond level) when coordinating fine motor skills. To that end, there are important clarifications to add. This supplemental document will further articulate some of these issues.

First, The definition and context of the term "declination": in many spoken languages, F0 values tend to decline in an utterance, particularly in declarative sentences (Fujisaki, 1984). When we are not phonating, the lungs are going through natural pressure differentials: this is what makes the influx and outflow of air in respiration possible (Figure 1). When we phonate, those differentials change because we are adding resistance in two planes: at the glottal source and with various accessory muscles and recoil mechanisms. These processes helps stabilize equilibrium and subglottal pressure. There have been many hypotheses as to the physiological rationale behind the drop in F0 over the course of a phrase (i.e. Lieberman, 1967; Titze, 1989; Strik and Boves, 1995). The Fujisaki model (Figure 2) attributes the phenomenon primarily to the natural decrease in air pressure becoming disequilibrated at the glottal level. In singing, this process becomes even more apparent given the demands required from pitch, volume, and other laryngeal dynamics. The glottis as a valve must adapt to these changes in pressure rapidly and efficiently to sustain vocal fluency.

On the other hand, the more common term in vocal pedagogy,"maximum flow declination rate" (MFDR) refers to the fastest airflow pressure drop possible in each vibratory cycle (Figure 3). This is a different use of the term 'declination'. For laryngeal efficiency, we want to get from a lot of airflow through the vocal folds to zero as quickly as possible ("snappy folds")Singers desire MFDR but also work to counter any natural declination rate from pressure changes through the exhale. One can perceive the former as macro phenomena and the latter being micro in terms of basic valve behavior. There are inter-relationships of course, but the ideas are different in terms of what is desired vocally.

From the respiratory standpoint, Hixon has described the mechanics of pressure maintenance in great detail (Respiratory function in Singing, 2006.) There are many accessory muscles and recoil mechanisms involved in assisting the glottis in maintaining equilibrium. In the brain, all respiratory elements must travel through the respiratory center (Figure 4) and calculations are made whereby homeostatic needs take priority. However, in phonation these respiratory muscles are actually being coordinated by the laryngeal motor cortex (LMC), not traditional cortical areas involved in normal breath management. In a 2021 paper, Belyk also observed this shift of respiratory control in phonation.

When we phonate, we don't observe the pressure differentials seen in normal exhalation because the LMC is coordinating both the glottis and the respiratory elements to maintain equilibrium for vocalization. The system counters the natural declination that would happen ordinarily in an exhale through a tightly coupled sensorimotor loop. That's the epiphany. The laryngeal motor cortex is much more than a laryngeal motor cortex!

This phenomenon aligns with the auditory cortex suppression story: as the article shows, the dLMC takes over auditory pitch processing. The reason is that proximity in the sensorimotor cortex breeds speed and efficiency. For something as fine-tuned as singing and speech, those neurons need to be highly coordinated in a constant, fast, feedback loop so that adjustments can be made with precision. Clustering them together in the motor cortex facilitates the fine motor control necessary for nuanced speech and singing.

The motor elements for vocalization are also predictive. The initial calculations are made without any feedback and in the absence of any respiratory signal: all of the muscles necessary for phonation are signaled ahead of time. The declination and respiratory elements are initially recruited after those decisions have already been made about 'what and how to sing'. This emphasizes the importance of the audiation step. As we go through a phrase in singing or speech, feedback is rapid to adjust both glottal and respiratory events accordingly (articulators also, as we will see in a future

Minding the Gap installation). Interestingly, signals for "loud and fast"— even during covert speech — more accurately recruited proper respiratory volume than any other predictive vocal signal (Hoole, 1997). Everything is then balanced accordingly via the rapid feedback process. This all occurs very rapidly at the millisecond level.

In conclusion, the neuroscience aligns with observed measurements of both respiratory and glottal behavior. However, surprisingly the entire system is coordinated in the LMC (Figure 5). As pedagogues, we can use this information to design more targeted protocols.

Figure 1: pressure changes in normal respiration

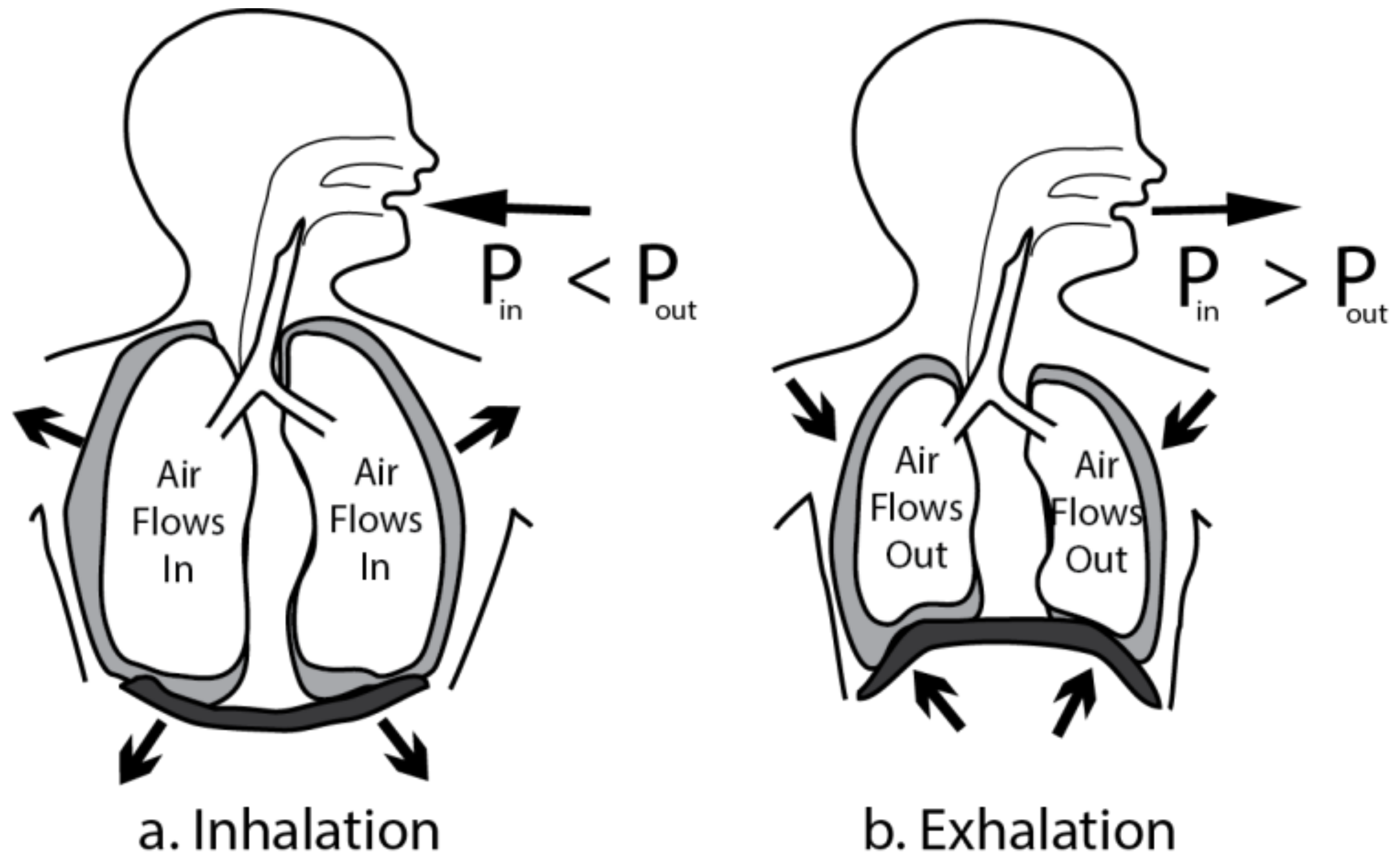
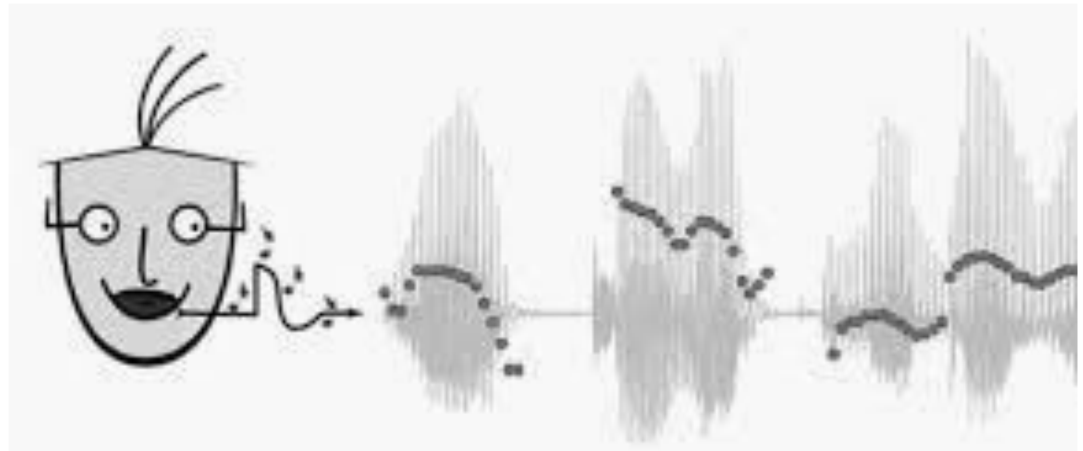


Figure 2

Fujisaki model

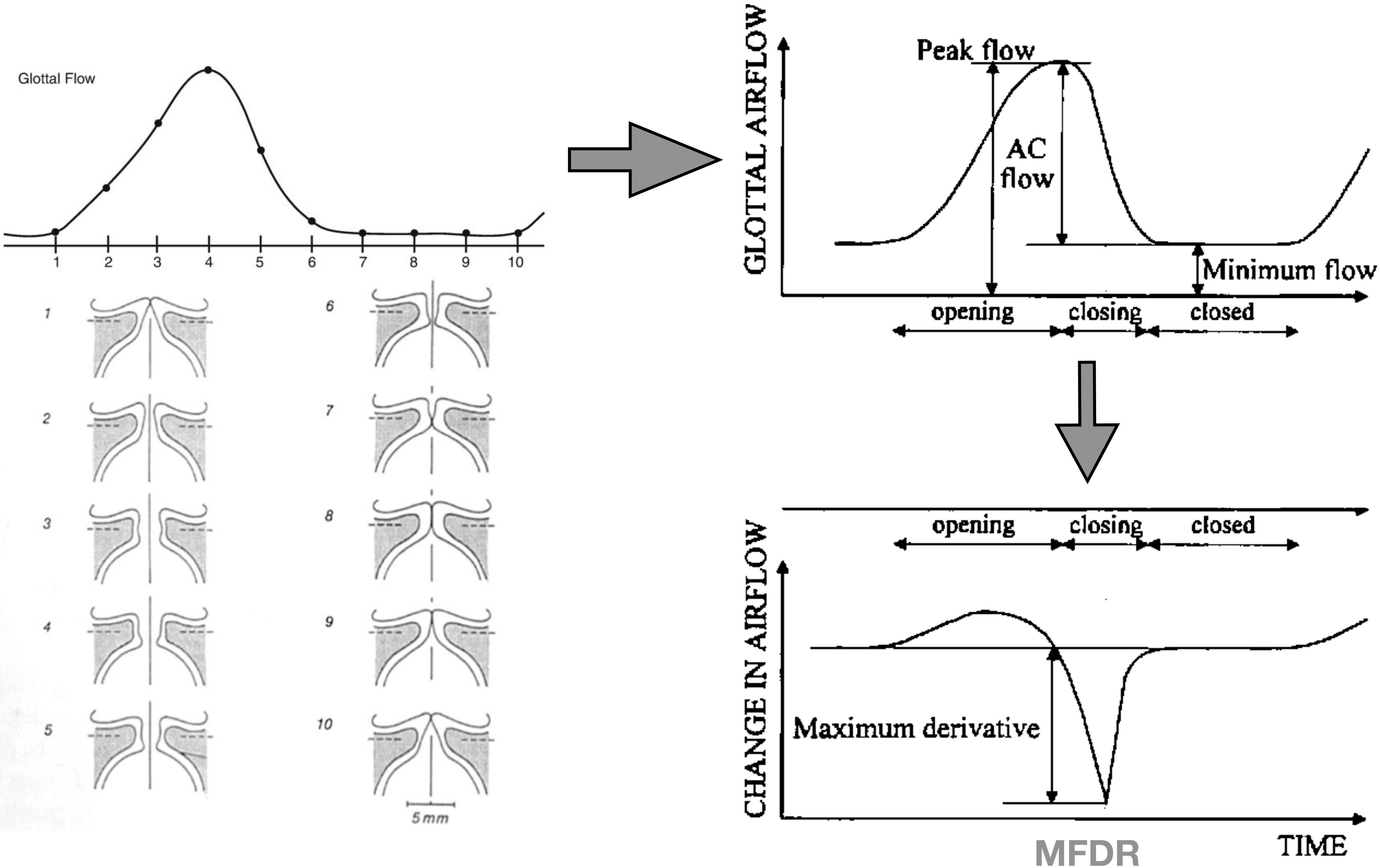


- 1) **a fast, accent contour** which indicates *emphasis* of a word or syllable
- 2) **a slow phrase component** which is the *declination of a pitch over a phrase*.*

There are *independent vs overlapping* brain representations of:

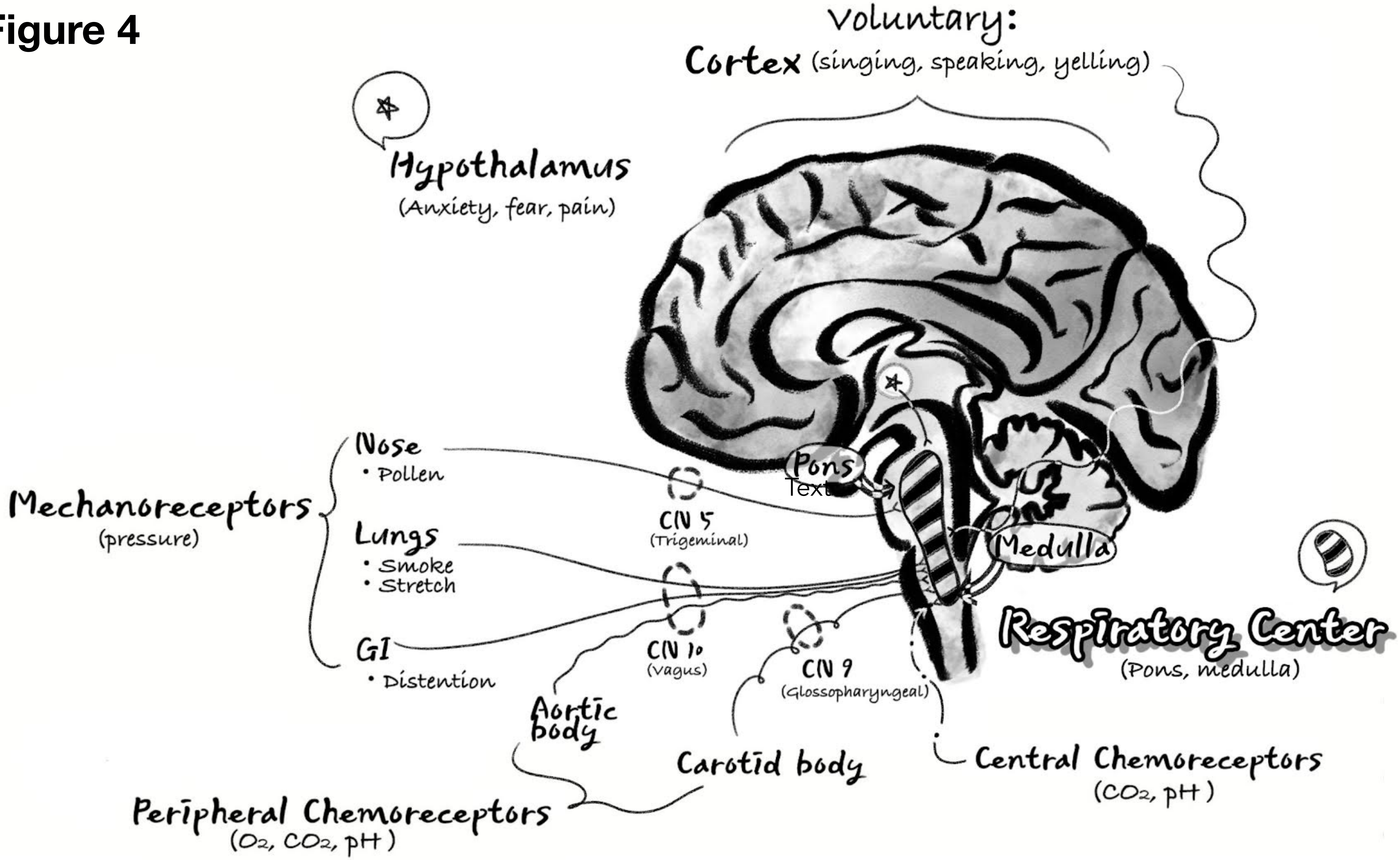
- **phrase** =declination over the course of a phrase which is indicative of the potential *(when it is not maintained by glottal equilibrium)* AND actual (which happens at the very end of an exhalatory cycle) drop in subglottal pressure as we exhale.
- **accent** = which indicates the change in pitch.
- **voicing** = which is basically the folds' onset behavior.

Figure 3: Glottal phases and MFDR



From: Khosla and Born, “Laryngeal Physiology.”

Figure 4



Human respiratory center in the brain (Pons and Medulla) indicating the various inputs. (Image created by Kang Kang and designed by Heidi Moss Erickson)

Figure 5

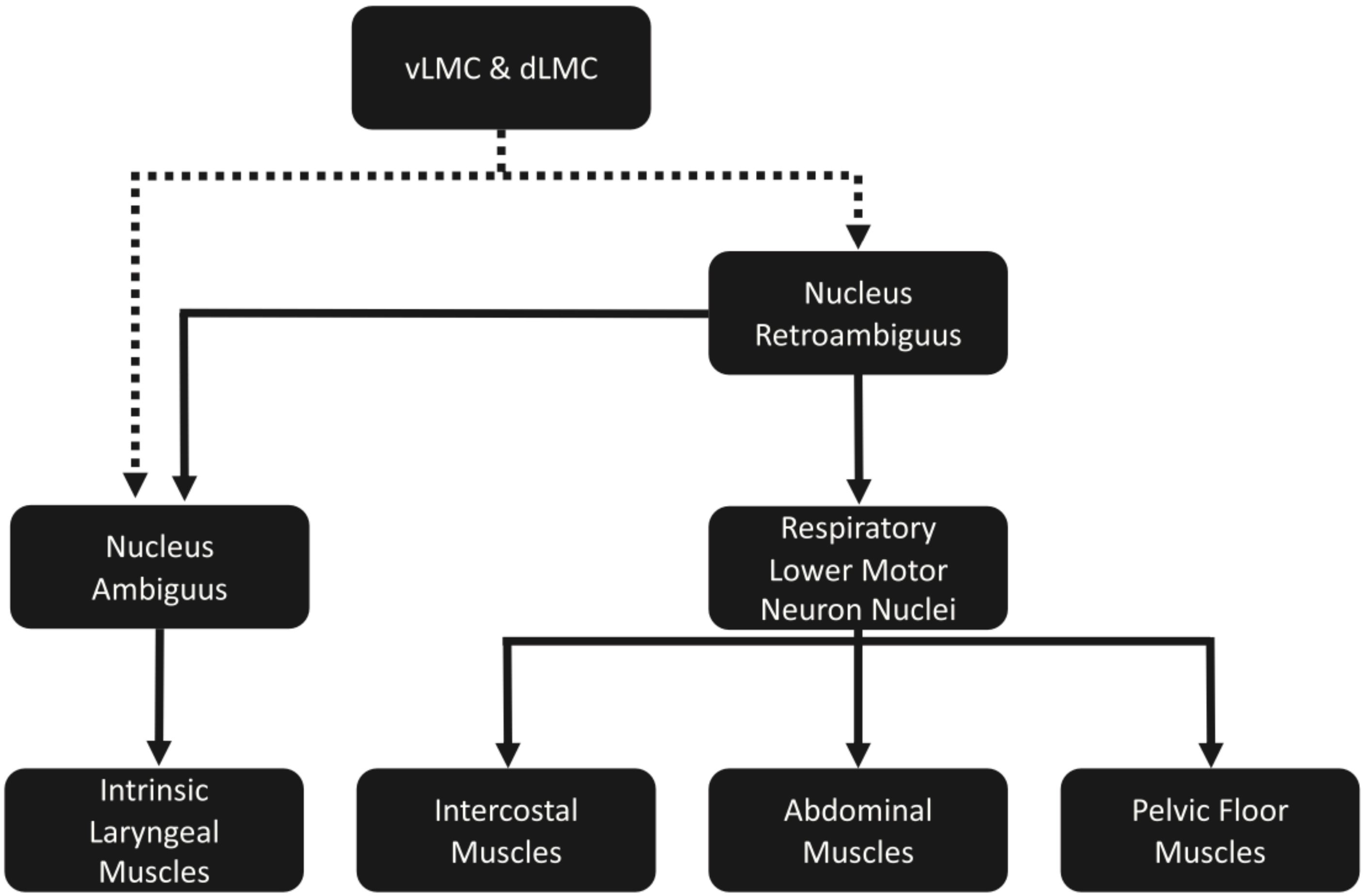


Fig. 3. Schematic of descending motor pathway. Cortico-bulbar pathways (dotted line) have been observed projecting to the nucleus ambiguus though it is not presently known whether these axons originate from the vLMC, the dLMC or both. We have hypothesized that both areas project to the nucleus retroambiguus as well.