Chapter 2: *Articulatory, Auditory and Acoustic Phonetics. Phonology*

2.1. **Phonetics and phonology**
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### 2.4. Acoustic phonetics

The branch of phonetics that studies the physical parameters of speech sounds is called *acoustic phonetics*. It is the most “technical” of all disciplines that are concerned with the study of verbal communication. The data it handles are the most concrete, palpable, easily measurable ones that can be encountered in the domain of phonetics in general. The most important principle of physics on which verbal communication is based is that vibrating bodies send waves that are propagated in the environment. Our articulatory organs produce a number of vibrations; these vibrations need a medium to be transmitted through. The medium through which speech sounds travel is usually the air. (Experiments have proved that if we try to communicate in vacuum the sounds that we produce fail to reach the addressee since they lack a medium through which they can propagate.) Classical prototypes of a vibrating body that are normally referred to in order to describe the way in which verbal communication is achieved include the pendulum or the tuning fork. When the former is set in motion or the latter is struck, they vibrate constantly. The pendulum or each of the prongs of the tuning fork move in one direction and then back to the starting point and then in the opposite direction to roughly the same extent and the movement is continued decreasingly until the vibration dies out completely. It is because friction with the environment that the movement eventually dies out. Ideally, if the vibrating body were placed in vacuum the energy of the initial impulse would be kept constant and the movement would continue for ever. However, as the vibrating body is surrounded by air, its movement is transmitted to the air molecules around, that vibrate accordingly. The vibration of the pendulum or of the prong of the tuning fork can be represented graphically by a sinusoidal curve. The vertical axis or the ordinate will measure the amplitude or intensity of the sound, while the horizontal one, or the abscissa will measure the duration in time of the vibration.

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8 If it is difficult to analyze in detail, to carefully observe the speech organs in the process of producing various sounds, the acoustic features of sounds are more easily observable. The sounds we produce can be recorded, their features can be analyzed, we can even provide graphics representing the sounds we articulate by means of special machines (see the discussion below)
If the distance from the point of rest is greater, we say the *amplitude* of the vibration is higher. This is related to the amount of energy that is transmitted through the air by means of the respective sound wave. The higher the amplitude is, the louder the sound. The conventional way in which we refer to the intensity or loudness or amplitude of sounds is that of using the *decibel scale*. The decibel scale does not express the absolute intensity of a sound, but the ratio between the intensity of a sound and a reference intensity. Thus, if we want to compare the intensity of two sounds, we take the logarithm to the base 10 of their ratio and multiply it by 10. For instance, if a sound is 1000 times more intense than another, it means that 10 has to be raised to the power 3 to get the ratio between them. If we multiply 3 by 10 we get 30, therefore the difference between the two sounds is of 30 decibels (dB). If a sound is a billion times more intense than another, this means that their ratio is 10 raised to the power 9, so the difference between them is of 9 multiplied by 10, that is of 90 decibels (dB). The reference value for the decibel scale is the standard intensity of a sound which has a fixed value close to the audible limit of sound. (This value is $10^{-16}$ watts per square centimetre). Therefore, if we say that a sound is 40 decibels it means it is ten thousand times more intense than the standard reference value.

A complete movement, that is one starting from the initial point, going as far as the maximum amplitude, then back to the point of rest and beyond it to the maximum amplitude in the opposite direction and finally back again to the point of rest is called a *cycle*. The higher the number of cycles per unit of time (second) is, the higher the *frequency* of the vibration is. The time it takes for a cycle to be completed is called the *period* of the vibration. Frequency is measured in cycles per second (cps) or Hertz. Sounds having a constant period (in other words sounds displaying a regular vibration) are called periodic sounds. The typical example for this kind of sounds are musical sounds. However, in the case of other sounds, successive periods vary and these sounds are called aperiodic. In reality, periodic vibrations are seldom simple, the vibration being of a more complex kind than that represented by the simple sinusoidal wave (or sine wave) described above. A vibrating body oscillates or vibrates at various intensities, the ensuing vibration of the entire body being a wave that is not sinusoidal and will differ from any of the simple sine waves of which it is the result. The sinusoidal components of any complex periodic sound are called the *harmonics* of the respective sound. The higher harmonics are integral multiples of the lowest harmonic which is called the *fundamental frequency* or the *fundamental* of the respective sound. Thus, if a sound has as its fundamental frequency 200 cps and one of its higher harmonics is of, say, 400 cps, we say that the latter is the 2nd harmonic of the sound since it is twice higher than the fundamental. A harmonic having the frequency of 800 cps will be the 4th harmonic of the sound, as it is four times higher than the fundamental. We should always specify therefore, in the case of periodic sounds, which are the frequency and amplitude of its fundamental and of its higher harmonics. It is also important to note that though the various rates of vibration will result in a given timbre (tonality) of the sound, which is different from any of the harmonics, it will always be the fundamental that essentially
defines (gives the quality of) a given sound. This kind of specification that includes the fundamental and the harmonics of a sound is called the spectrum of the respective sound.

An essential feature of any sound is its pitch. Pitch is, roughly speaking, the way in which we perceive the frequency of a sound, it is, in other words the perceptual correlate of the frequency of that sound. We can say that the higher the fundamental frequency of a sound will be, the higher the pitch of the respective sound is, or rather that we perceive the sound as having a higher pitch. This correlation is not, however, linear as there is not always a direct proportionality between the frequency of a sound and our perception of that frequency. Pitch has a very important role in intonation as we shall see later. Pitch differs a lot from one speaker to another. Women, for instance, have shriller voices than men, therefore the pitch of their utterances will be higher. How is it then that we recognize a sound as being “the same” even if it is pronounced by persons whose voices have very different pitches? The answer is that though the fundamental and the number of harmonics differ, obviously, in the two cases (the one with a lower pitch having a lower number of harmonics) the shape of the spectrum of the two sounds is pretty much the same in the sense that the harmonics with the greatest amplitude are at about the same frequency in both cases. While vowels and sonorants have spectra which resemble those of periodic sounds (of the kind musical sounds are), obstruents, and particularly the voiceless ones, are aperiodic sounds, which makes them pretty similar to pure noises.

Three are then the essential acoustic parameters that characterize a given sound (a sound having a certain quality): its amplitude or intensity – that we perceive as loudness; its frequency, that we perceive as pitch, and its duration. A given sound, therefore, say the vowel /e/, can be pronounced with various degrees of intensity, the amplitude varies therefore, but fundamentally the sound is the same. In spite of frequency variations (that we perceive as variations in pitch) in the pronunciation of the above-mentioned vowel by different persons, we will still identify the “same” sound. We can also vary the length of the vowel and we will still say that the sound hasn’t fundamentally changed its quality. The anatomy and physiology of both the articulation and audition processes drastically limit the range of sounds that we can produce and perceive, respectively. In other words we can only utter sounds within a certain range of intensity and loudness and their duration is also limited. Conversely, our auditory system is able to perceive and analyze sounds whose frequency and intensity are situated between certain values and whose duration is limited.

The vibrations of a body can be transmitted, often with a higher amplitude, by a phenomenon called resonance. Certain bodies have the property of transmitting vibrations in this way and they are called resonators. It is enough to think of musical instruments and this physical process becomes clear for everybody. If we take a violin, for instance, the strings play the role of vibrating bodies, while the body of the instrument acts as a resonator. And this is true not only for string instruments, but for wind

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9 The frequency of vocal cord vibration ranges, generally, between 80 and 200 Hz in men, while the vibration of women’s vocal cords can reach 400 Hz (see Ladefoged. 1975: 163)
instruments as well. If we take a flute or a bassoon, we shall easily see that the air that is pushed into the instrument when we blow it makes vibrate the air already existing inside the instrument and the body of the instrument plays again the role of resonator.

A similar process can be witnessed in the case of speech. Remembering our description of the main articulators above we shall again mention the glottis as the first essential segment of the speech tract that shapes the sounds that we produce. The vocal cords have the role of vibrating bodies while the pharynx, the oral and the nasal cavities, respectively, act as resonators. The versatility of these cavities (notably the oral cavity) that can easily modify their shape and degree of aperture, the mobility of the tongue and the complexity of the human speech producing mechanism enable human beings to articulate a remarkable variety of sounds in terms of their acoustic features. The initially weak vibrations of the vocal cords, having a wide range of frequencies, are taken over and amplified by the above mentioned resonators. The amplitude and frequency of the sounds that are further transmitted by the resonators depend very much on the size and shape of these resonators. Resonance does not characterize, however, only cavities that modify the acoustic features of a sound. Vibrating bodies themselves are characterized by various degrees of resonance. Resonators can amplify or damp the formants of the given sound, by enhancing or suppressing various frequencies. This accounts for the wide variety in the parameters of sounds different human beings are able to produce. Each of the features of the articulators of an individual has an impact on the types of sounds that individual utters. The musicality of the sounds that we produce largely depends on the characteristics of our phonatory system, too. Vowels, for instance, have distinct and constant patterns of resonance (the resonating cavities assume certain shapes whenever a given sound is uttered) and thus we can always recognize the respective sound by its distinctive mark. The various positions of the soft palate will direct the air through either the oral or the nasal cavity or through both of them. This will give the sounds we produce a nasal or an oral character. As pointed out above, the shape and degree of openness of the mouth can vary. The tongue, the lips, the teeth, the movement of the mandible can also influence speech production assigning various acoustic characteristics to the sounds we articulate. The qualities of the vibrating bodies themselves (in our case the vocal cords) largely influence the timbre of the sound that is produced. Speech perception also fundamentally relies on the vibrating characteristics of various membranes, on the possibility of transmitting these vibrations and converting them into neural impulses. Certain segments of the auditory system, too, act as resonators, amplifying the basic features of the sounds that reach our ear, or, on the contrary, damping these sounds, often in order to protect our auditory organs. (see the discussion of audition above).

As we have said, acoustic phonetics is the branch of phonetics where data are most liable to measurements, quantification, etc. If we can hardly think of apparatuses being used in other linguistic fields like syntax or semantics, for instance, the situation is different in the case of phonetics, as scientists have devised various instruments that are used to provide an “image” of the way in which people speak and graphics representing the sounds we produce. Such an instrument is the *acoustic spectrograph*, an appliance
similar in many ways to a seismograph, or to an electrocardiograph (devices that record seismic and heart activity respectively). It marks on paper the vibrations caused by speech sound production. The graphs they produce are called spectrograms and represent the frequency of the sound on the vertical and its duration on the horizontal. The darker bands in the spectrogram are called the formants of the respective sounds and they represent the frequencies at which a greater amount of energy is spent. Normally, two or three formants at the most are used to describe a certain sound. Formants are essential for the acoustic representation of sounds and all voiced sounds have a formant structure.

Different classes of sounds have, as shown above, different acoustic parameters. We have already mentioned the fact that, of the two major classes of sounds, vowels and consonants, the former are closer, acoustically speaking, to musical sounds, as their vibration comes closer to the ideal line of the periodic constant vibration. Vowels in their turn have distinct acoustic features. Front vowels, for instance, are acute sounds, displaying higher frequencies in their second formant (between 1800 and 2300 cps), while back vowels are, comparatively, graver sounds, their second formant ranging between 800 and 1000 cps. We can also distinguish between compact and diffuse vowels, depending on the way in which the main formants are close to each other or are wider apart in the spectrum of the sound. Thus, low or open vowels have their formants grouped towards the middle of the spectrum and are consequently compact, while high or close vowels are diffuse, the distance between their formants being greater. Consonants, on the other hand, can be clearly distinguished on the basis of their acoustic features. Non-peripheral (dental, alveolar, alveopalatal, palatal) sounds are acute, as their formants are situated among the upper frequencies of the spectrum, while peripheral consonants are grave, as their formants are situated among the lower frequencies of the spectrum.10

10 The distinction was made by Jakobson and Halle (1956), who introduced the respective features, acute/grave to differentiate between peripheral and non-peripheral consonants. Acoustic parameters of sounds played an important role in several notorious attempts made by various phonologists to establish a list of so-called distinctive features. Jakobson and Halle’s classification notably uses acoustic characteristics to describe the features. More details will be given in this book in the chapter discussing distinctive features.