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Neurophysiologic background in speech production -A review

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ABSTRACT:
Communication is the foundation of human interaction and speech is the heart of this process. The process of speaking involves a series of intricate steps that enable us to effectively convey our thoughts and ideas. It basically involves three major levels: conceptualization of ideas or thoughts and conversion of them into language by precise articulation of sounds. This article focuses on each level by exploring the neurophysiologic aspects behind speech production.

KEYWORDS: Neurophysiology, Phonation, Sound, Speech, Vocal Cord.

INTRODUCTION:

Every living thing, no matter how big or small, is connected in an endless ebb and flow of messages.[1] Communication is the mechanism that makes this relationship possible. Communication is a process rather than an entity. It has numerous forms, including written, heard, read, gestural, and nonverbal.[2] Speaking is the fastest, most efficient and convenient mode for humans to communicate. It is the ability to create, modify, and articulate sounds. Speech is a function that human learns, but we seldom stop to think about it since it is such an ingrained aspect of a man's makeup. According to Simon (1957), speech can be viewed as a learned behaviour, a social phenomenon, novel responses, and oral gestures and as a means of establishing interpersonal relation, maintaining emotional homeostasis and manipulating human behaviour.[3] Human speech is a complex motor act that requires a high level of coordination between the neurological, muscular, mechanical, aerodynamic, acoustic, and auditory systems.[4] Hence, the purpose of this article is to give a brief insight into the neurophysiology background and structures involved in speech production.

DISCUSSION

Levels of speech production[5-9]:

Speech production involves three intricate levels. From the earliest conceptualization of ideas to their development into language and the precise articulation of sounds, each stage is critical for effective communication. Understanding these levels allows us to comprehend the complexities of human speech.

1. **Conceptualization**:Conceptualization is the first stage of speech production in which ideas and thoughts emerge in the mind. At this step, a person determines the message they want to express, identifies vital points, and structures the information in a way that is coherent. It's a cognitive process involving accessing knowledge, memories, and emotions. Language centers like Broca's and Wernicke's play crucial roles in this process.
2. **Formulation:** The formulation stage involves transforming abstract ideas into linguistic forms. It uses the brain's motor cortex and language production areas, to convert intended messages into meaningful word arrangements and grammatically correct sentences and phrases.
3. **Articulation:**Is the final level in speech production, where the linguistic message is physically produced and delivered using articulatory organs like the tongue, lips, jaw, and vocal cords, with the brain continuously monitoring and adjusting movements.

Mechanism of speech production[3,4,7,8,9]

In humans, speech mechanism is governed by fivemajor speech subsystems that interact in a coordinated manner. The respiratory, phonatory, resonatory, articulatory system are responsible for the physical manifestations of speech, and the nervous system regulates these systems at conscious and unconscious levels.

1. Respiration: The Foundation of Speech

The respiratory system is responsible for air movement, enabling oxygen intake and carbon dioxide exhalation, which is crucial for speech production.The diaphragm and intercostal muscles help control the breath and produce spoken sounds. Normally, inhalation and expiration occur at equal intervals during respiration. However, while speaking, the inhalation phase is shortened and the expiration phase is extended. In normal function, upward movement of the diaphragm combined with contraction of the costal cartilage and surrounding musculature produces an intrapulmonary pressure greater than atmospheric pressure, allowing air to be evacuated from the lungs. The valve system throughout the laryngeal, pharyngeal, oral, and nasal components of the respiratory tract prolongs exhalation by impeding expired air and aiding in the production of speech signals.

2. Phonation: Generating the Sound Source

Phonation is the process of producing sound by the vibration of vocal folds in the larynx. When air from the lungs flows through the vocal folds, they quickly open and close, causing vibrations and sound waves. These sound waves subsequently resonate in the vocal tract, resulting in different speech sounds.

Process of Phonation: The vocal folds (vocal cords) are situated in the larynx and are composed of elastic tissues. They are divided into two pairs, of which the true vocal folds are responsible for phonation.The Space between these folds is called the glottis. When we exhale, we evacuate air from our lung, which causes the vocal folds to partially close. The building of air pressure beneath the closed vocal folds. This pushes them open, unleashing a blast of air. As the air departs, the vocal folds immediately shut, repeating the vibration cycle and producing a continuous sound stream during speech. This process is explained by the “glottic cycle”[10]

Closed phase: air pressure builds up beneath the closed vocal folds. .

Opening phase: When the subglottic pressure exceeds the muscular opposition, the glottic slit is forced open. They open posterior to anterior, with the posterior section of the glottis opening first. Additionally, they open from bottom to top.

Open phase: The voice cords are fully extended, allowing air to flow through them. This is where the sound wave begins.

Closing phase: Subglottic pressure decreases following the release of air, and the vocal chords re-approximate with each other.

The cycle is then continued.

This process causes a "voiced" sound, which starts off as merely a buzzing noise.After that, resonance and articulation systems are responsible forchanging this noise and forming words. Laryngeal sounds not only serve as the foundation for speech organization but also determine the pitch of phonated sounds.Vocal folds are thick and flaccid while producing low-pitched sounds and thin and tense in high-pitched sounds.

3. **Resonance: Amplifying the Sound**

Vocal fold sounds are not the final acoustic signals that our ears perceive during speech. The resonators are the ones that give a characteristic quality to a voice and add depth to it.The resonating structures are sinuses, organ surfaces, and cavities such as the chest wall, pharynx, oral cavity , nasal cavity. The nasopharynx, which leads to the nasal cavity, begins where the velum meets the pharynx. This location is referred to as the "velopharyngeal port."During breathing, the velum hangs down, connecting the nasal and oral cavities.This naso-oral connection is required for nasal resonance.The closure of the velopharyngeal port occurs when the velum is raised by muscular activity. This closed position causes oral resonance. In simple terms, the Velopharngeal mechanism proportions sound between oral and nasal cavities, influencing voice quality. Compromise in velopharangeal closure or structural integrity can compromise voice quality.

4. **Articulation: Shaping Speech Sounds**

The next step, after producing sound and its amplification, is to produce the specific speech sounds (phonemes) required for speaking that are meaningful. The articulatory system performs this function. Without this system, the sounds produced would only be variable in pitch, volume, quantity. Structures involved in this system are called articulators and are of two types: Fixed and movable.

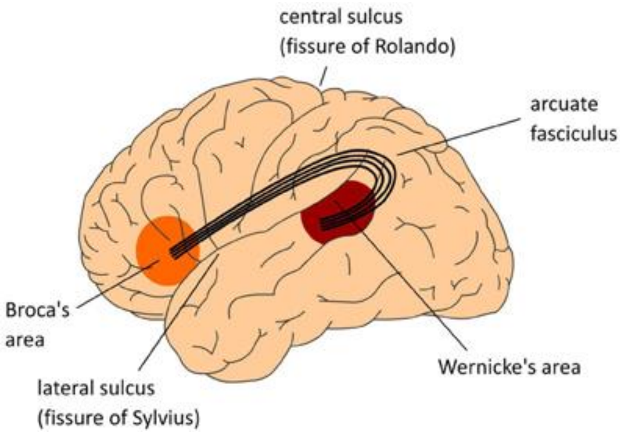
Movable/Active articulators: Movable articulators include the lips, tongue, pharynx, soft palate, and mandible. They take an active part in articulation by altering the shape of the vocal tract, which can change the physical characteristics of sound waves that are generated.

Fixed/Passive articulators: These are immobile and include bone structures like the alveolar ridge, hard palate, and incisors. They do not interact with sound waves and cannot be changed in a way that would change the final physical characteristics of the sound waves that are generated. They participate in articulation by offering an area for the active articulators to contact.

5. **Regulation: The Role of the Brain and Nervous System**[11]

An important function of the brain is to coordinate and govern the speaking process. Various speech and language functions are handled by different brain regions (fig 1)

Figure 1: Regions in brain involved in speech production



Broca's Area: The Seat of Speech Production

Broca's area, located on the frontal lobe of the left hemisphere, is responsible formotor planning for speech movements and speech production. This area is in charge of generating, organizing, carrying out the message transmission.

Wernicke 's area: Understanding Spoken Language

Located in the left temporal lobe in a right-handed person.This area is essential for understanding spoken language and interpreting its meaning.

Arcuate Fasciculus: Connecting Broca's and Wernicke's Areas

The arcuate fasciculus is a network of nerve fibers that links Wernicke's and Broca's regions, allowing the speech production and comprehension centers to communicate with one another.

Motor Cortex: Executing Speech Movements

The muscles used to produce speech are controlled by the motor cortex, which translates neural impulses into specific motor movements.

Cranial nerves

The command centers in the cerebral hemispheres receive information from the sense organ of hearing and transmit commands to the individual speech-producing muscle groups through the peripheral nervous system. This is accomplished by the cranial nerves. For the control of speech mechanism the fifth (trigeminal), seventh (facial), ninth (glossopharyngeal), tenth (vagus) and twelfth (hypoglossal) nerves play important roles. The eighth cranial nerve is the auditory nerve, which is responsible for hearing and balance.

The process of producing speech is controlled by a very intricate neuro-physiological system. Its molar regulation is mediated by an extensive range of oral mechano-sensitive sensors, both kinesthetic and tactile. The process of producing speech involves a multitude of inherent and acquired motor acts that are generated in rhythmic behavior in sequences of 12–16 sounds/sec. It has been proposed that when abilities become automatic, less cortical space is needed for their processing. Speech control localizes in certain regions, such as the pre-motor and motor cortex, when it is automated. The pyramidal motor system plays a major part in the precise movements used during speech production.

The majority of motor events, including the timing and sequencing of speech movements, are controlled by feedback, which is dynamic and flexible. Feedback appears to be a learned, subconscious kind of pattern recognition of afferent information that directs central pattern generators (CPGs) and central programs. As a result, the CGPs are crucial for the fundamental rhythmic production and timing of motor activity. Together with cortical input, proprioceptive mechano-sensitive afferents determine the timing of certain elements of the extremely rapid motor pattern and produce the final motor output and rhythm.

The motor innervations in speech involve three pathways: the pyramidal pathway, extra pyramidal pathways, and cerebellar pathways.The motor innervations in speech involve three pathways: the cortico-bulbar pathway, extra pyramidal pathways, and cerebellar pathways. The pyramidal tract controls precise movements, while the extra pyramidal tract regulates muscle tone, breathing, and tension of vocal fold. The cerebellar pathway, from the cortex to speech muscles, ensures automatic coordination and takes over speech after childhood.

Audition: Chierici and Lawson added audition, or the ability to hear sounds, to the above mentioned systems. Normal speaking requires audition, or the capacity to perceive acoustic impulses. Hearing enables the speaker to monitor and control speech production. Hearing loss can make it difficult to provide accurate feedback, which can impact speaking. Hence, Patients with hearing impairments have difficulties with speech therapy.

Speech sounds[3,4,9,12-15]

Sentences are created by joining words together in vocal communication. Various syllabus / speech sounds are combined to form the words. The process of producing speech is complex. The speech organs operate in coordination throughout this procedure. Numerous speech sounds, including vowels, consonants, and diphthongs, are generated during these motions.

Phonetics is a branch of linguistics that studies characteristics of speech sound.They are categorized into auditory, acoustic, and articulatory phonetics. The study of how speech organs produce sounds is known as articulatory phonetics.Speech articulation takes place when approximation or movement of the articulators constricts, impedes and diverts the air stream to produce a single sound. The single sound that this physiological airstream system are producing are wide variety and innumerable. Most of these sounds occur merely as noise and are unclassified, but those learned as speech are called phones. Many of the phones are extremely similar in nature that only a specialist or someone speaking very slowly and deliberately can distinguish them as distinct sounds. These similar related phones are combined to form recognizable sounds and are classified as phonemes.

Phonemes is further divided into four types: Vowels, Diphthongs, Consonants and Combinations

Vowels: these are voiced sounds produced in a relatively open vocal tract, that is, without any closure, or narrowing that will produce audible friction

Eg: A, e, i, o, u.

Diphthongs: these are blends of two vowels or vowel like sounds, spoken with in a single syllable without interruption of speech. here sound begins as one vowel and moves towards other.

Consonants: these are articulated speech sounds produced by closure or narrowing of the air passage so that the air stream is blocked completely or partially in the mouth.

Combination – is a blend of a consonant and a vowel spoken is such quick succession that they are identified as a single phoneme.

Eg: h-e in Hid

Classification of consonants:

Consonants can be classified based on place of articulation, manner of articulation and Voicing

(a) Place of articulation: the precise location where the air stream is modified in the vocal tract i.e lips, teeth etc. The names are assigned based on the articulators producing that particular sound. Table 1 describes the various the types of sound and articulators involved.

Table 1: Classification of consonents based on place of articulation

Articulation	Example

Bilabial	Produced by bringing both lips together	P, B, M, N
Labio-dental	Touching the bottom lip to the upper teeth	F, V
Linguo-dental	Placing the tip of the tongue between the teeth	Th
Linguo-alveolar	Raising the tongue to the alveolar ridge in some way	
	i) Tip of the tongue touching the alveolar ridge (or just in front of it)	T,D,N
	ii) Sides of the front of the tongue raised but the tip lowered to allow air to escape	S, Z
	iii) The tongue tip is raised while the rest of the tongue remains down so air can escape over the sides of the tongue	L
	iv) Air escapes through the central part of the mouth; either the tip of the tongue is curled back behind the alveolar ridge or the top of the tongue is bunched up behind the alveolar ridge	R
Linguo-palatal	Contact of tongue to some part of palate posterior to alveolar ridge	J
Linguo-vela	Contact of the middle of the tongue with the soft palate.	K, G, H

(b) Manner of articulation: the way the airstream is affected as it flows from the lungs and out of the mouth and nose (blocked, restricted, diverted, etc). Table 3 describes the various sounds and mechanisms involved.

Table 1: Classification of consonents based on manner of articulation

	Mechanism	Example
Stops	completely stopping the air flow in the oral cavity for a fraction of a second	P,B
Fricatives	Produced by a stop closure that is released with a lot of friction	S,V,F
Affricate	Produced by a stop closure that is released with a lot of friction	“j” and “ch”
Diversions	Characterized by stoppage of air stream at one point to permit escape at another	U, M
Glides	relatively very little impedance of the air stream	W (witch), Y (you)

(c) Voicing: Refers to whether or not a consonant is accompanied by laryngeal tone. Those produced with the vocal cords apart so the air flows freely through the glottis are voiceless consonants. Voiced is the term applied to consonants produced when the vocal cords are together and vibrate as air passes through them.

Milestones in speech production:

The cry of the newborn is the initial stage of sound development. While infants babble marks the initial stage of speech production, which gets converted to fully developed speech by the age of eight.Early infancy is when vowel sounds begin to emerge and are mastered or spoken well over the next several months. Consonants, on the other hand, take longer to develop in the proper order.[16] Table 3[17] shows the normal pattern of speech development

Table 3: Milestones in speech development

Age	Speech
0-3 months	Vegetative sounds (grunts, crying) coo, laugh, babble Smiles at people

4-6 months	Coos and babbles when playing alone or with you Makes speech-like monosyllables, like pa, ba, and mi, Giggles and laughs makes sounds when happy or upset
7-12 months	Babbles long strings of sounds (bisyllables), like mama, baba Uses sounds and gestures to get and keep attention Points to objects and shows them to others Uses gestures like waving bye, reaching for "up," and shaking his or her head to say no Imitates different speech sounds Says 1 or 2 words, like hi, dog, dada, mama, or uh-oh. This will happen around his or her first birthday but sounds may not be clear
1-2 years	Uses a lot of new words Starts to name pictures in books Asks questions, like "what's that?", "who's that?", and "where's kitty?" Puts two words together, like "more apple," "no bed," and "mommy book
2-3 years	Put 2–3 words together to talk about and ask for things, average talking vocabulary is 200–300 words
3-4 years	Speech is understood 76% of the time. Longer sentences, fluent speech, and more complex sentences
4-5 years	Speech should be 100% understood, might continue to have errors with s, r, l, v, z, ch, sh, and "th" and consonant blends (sl, str, bl, etc.) Produces long and detailed sentences Tells a short story Talks in different ways, depending on the listener and place

CONCLUSION

Speech is the superior characteristic that makes humans different from other members of the animal kingdom.[4] Speech development has been demonstrated to be highly complicated, with several factors that might affect it. A thorough knowledge of speech production, types and milestones is necessary for the physicians to screen for abnormalities in speech and provide proper care.

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