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A Strong Connection between Hand Gestures and Tongue Movements

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Abstract

Speech and gestures are impeccably coordinated, and tongue movements and hand movements are interrelated. The purpose of this article was to review articles related to tongue movements, hand movements, speech and gestures. All studies including case studies, cohort studies, experimental studies and reviews, which explained the relationship between hand and mouth, hand and tongue, hand gestures and speech during the period between 1998 and 2019 were included in the study. A total of 36 articles that met the inclusion and exclusion criteria were finally included in this review. A number of experiments have established the relationship between tongue area and hand area, and hand gestures and speech. Thus, tongue movements and hand movements are coordinated and Broca's area controls not only the speech but also hand gestures. This concept can be used to rehabilitate the hand in cases of damage to cortical area representing hand.

Keywords: *Speech, Gesture, Hand movements, Broca Area.*

Introduction

Substitution is a hall mark of human activity. There have been proven substitutions with many parts of the body such as right- and left-hand substitution, hand and leg substitution, etc. Although a number of established neural pathways explain the relationship between different parts of the brain, a number of associations still need to be explored and used as a substitute for inducing neuroplasticity in neuro rehabilitation.

While we speak, nearly 100 muscles are engaged to move our lips, jaw, tongue, and throat in a controlled manner to create fluent sequences of sounds that form our words and sentences. (Sawczukl et al., 2001)[(1)]. Hand movements and gestures are controlled by different parts of the brain (Fig 1). Dick and his colleagues (2009) suggested that the premotor cortex and more posterior cortical regions are involved in comprehension of action and the inferior frontal gyrus is involved in top-down integration or determination of actions as potentially relevant or irrelevant to the accompanied speech [(2)].

Several studies have established the relationship between gesture and speech, and hand movements and mouth. The purpose of this review is to review all the articles that explains the relationship between hand gestures and speech as well as the relationship between hand, tongue and brain. A number of articles have been reviewed in a systematic way to find out the meaningful relationship between tongue area and hand area.

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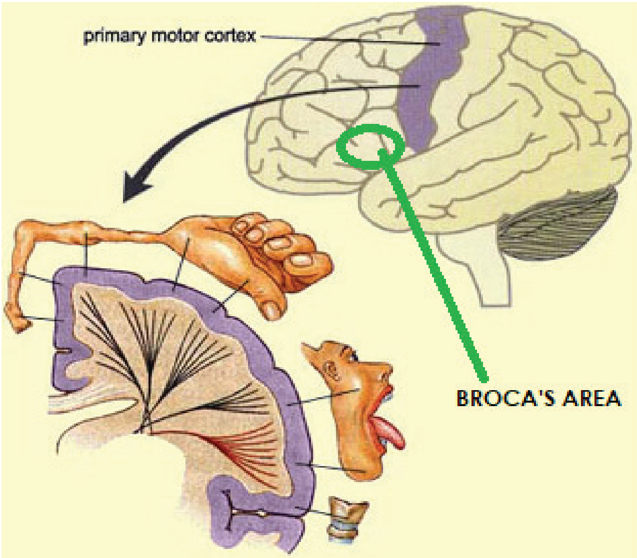

Figure 1. Primary motor cortex representing various parts of the body. Broca's area lying adjacent not only controls speech but also gesture.

Methods

Eligibility Criteria

Inclusion Criteria: All studies including case studies, cohort studies, experimental studies and reviews, which explained the relationship between hand and mouth, hand and tongue, and hand gestures and speech were included in the study.

Exclusion Criteria: Studies done on animal subjects, poor quality studies and studies where only abstracts are available were excluded for the review.

Information Sources

Search: Literature searches for case studies, cohort studies, experimental trials and reviews on the relationship between mouth and hand, speech and hand, tongue movements and hand gestures were performed in the following online databases: PubMed, EMBASE, The Cochrane Library, and Scopus. Three of the authors independently screened all research articles and abstracts for relevance. The article was finally review by an independent author.

Outcome Measures: Relationship between hand and mouth, hand and tongue, and hand gestures and speech were the primary outcome measures.

Critical Appraisal: The included papers were critically evaluated using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, formerly QUOROM) Statement before the data was extracted. The PRISMA Statement comprises an evidence-based 27-item checklist for reporting in systematic reviews and meta-analyses.

Study Selection: The experimental studies and reviews were included during the period between 1998 and 2019. (Fig 2).

Results

A total of 36 articles have been screened and reviewed which includes 20 experimental studies and 16 review articles. Summary of the findings of the experimental articles has been discussed in detail, which explains the relationship between tongue, hand and speech. (Refer to Table 1).

Data Collection Process:

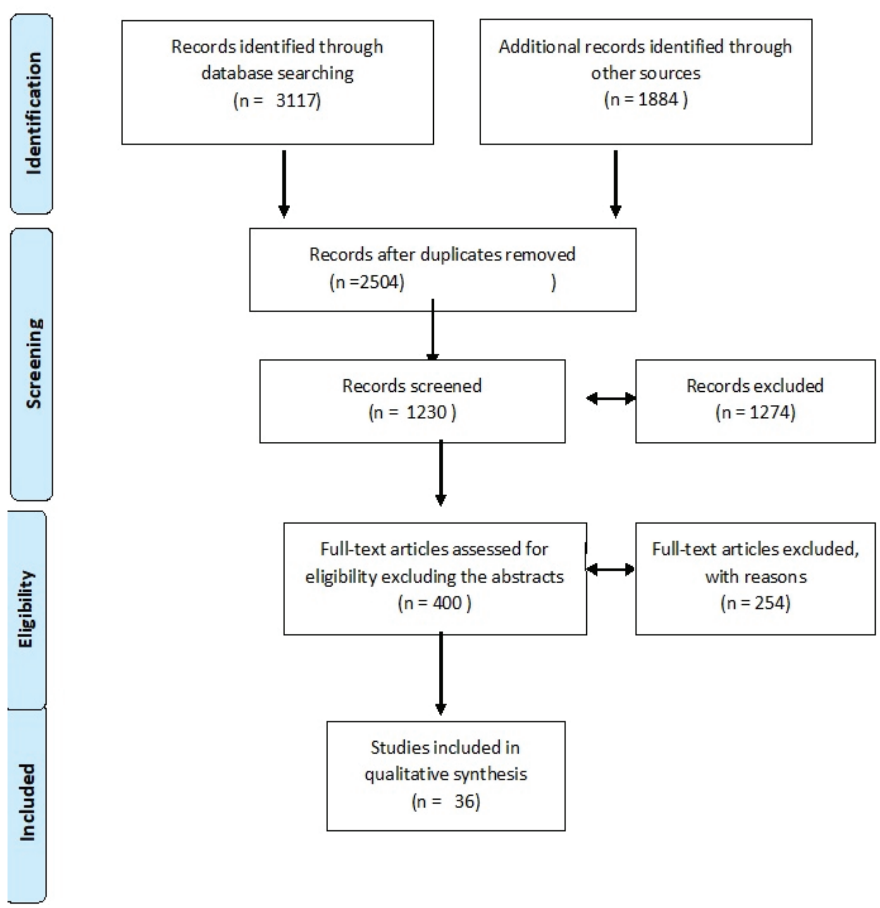

Table I: Studies on relationship between mouth and hand, speech and hand gestures.

Authors (Year)	Study Protocol	Number of Subjects	Outcome Measures	Results	Conclusion	Quality / Level of Evidence
S. Knecht, 2000.(3)	Relationship between language dominance and handedness in healthy subjects were studied	326	Functional Transcranial doppler sonography	The incidence of language dominance in the right hemisphere was observed to increase linearly with the degree of left handedness	The relationship between handedness and language dominance is not an artifact of cerebral pathology but a natural phenomenon.	2b
Maurizio Gentilucci, 2001 (4)	In a set of experiments, healthy subjects reached and grasped with the hand an object of different size while opening the mouth, or extending the other forearm, or the fingers of the opposite hand.	72	Velocity of Movements	The results of the present study suggest that grasping with the hand or with the mouth can affect movements of other distal effectors.	Broca's area derives phylogenetically from the monkey premotor area where hand movements are controlled.	2c
H. Henrik Ehrsson, 2003 (5)	Subjects imagined and performed repetitive movements of the right fingers or right toes, or horizontal movements of the tongue	7se	Functional Magnetic Resonance Imaging	Imagery of action engages the somatotopically organized sections of the primary motor cortex as well as activates some body-part– specific representations in the nonprimary motor areas	Direct relationship between the type of movement that is being imagined and the activation patterns of somatotopically organized motor areas	3b
Paolo Bernardis, 2006 (6)	In four successive blocks of trials, the participants were required to provide different responses at the end of stimulus presentation.	28	Voice Spectra Recording and 3D optoelectronic recording of movements	The same reinforcement in the voice spectra as during simultaneous emission	Two types of communication signal, word and gesture, are related at the levels of execution and processing	1b
Filippo Barbieri, 2009 (7)	The participants were required to respond to the speaking and or / gesturing actress by producing the same communication signal(s) (word, gesture or both).	34	Video Recording (3D optoelectronic SMART system)	There is an increase in voice parameters (and in particular F2) increase and decrease in gesture kinematics parameters while the communicative words and the gestures related in meaning are concurrently produced.	The social intention recorded by the gesture was transferred to the mouth, inducing a change in the tongue motor pattern.	2b
Maurizio Gentilucci, 2009 (8)	Participants observed power grasp of large fruits and precision grasp of small fruits	73 (15, 16, 10, 12, 14, 9)	Transcranial Magnetic Stimulation	Observation and execution of grasp actions guided by differently sized objects influence voice spectra parameters	Grasp observation activated motor commands to the mouth as well as to the hand.	2b

Authors (Year)	Study Protocol	Number of Subjects	Outcome Measures	Results	Conclusion	Quality / Level of Evidence
Spencer D kelly, 2012 (9).	Subjects viewed short video clips of gestures and speech (e.g., a person telling ''chop'' or ''twist'' while doing a chopping gesture) and had to determine whether the two modalities were congruent or incongruent	22	Video Recording	Gesture videos were designed to stimulate the parvocellular or magnocellular visual pathways by filtering out high or low spatial frequencies (HSF versus LSF) at two different levels of degradation severity (moderate and severe). Participants were less specific and slower at processing gesture and speech at severe versus moderate levels of degradation.	Hand gestures use a wide range of spatial frequencies, and depending on what frequency carries the most motion energy, different visual pathways (i.e., parvocellular and magnocellular) are likely maximized to quickly and optimally extract meaning.	1b
Ashley N Johnson, 2012 (10)	Subjects performed rapid and slow goal-oriented movements of hand and tongue with and without a associated motor (hand or tongue) or cognitive (memory and arithmetic) task.	13	Changes in reaction time, completion time, speed, correctness, accuracy, variability of displacement, and variability of time due to the inclusion of a concurrent task were compared between hand and tongue.	Rapid goal-oriented hand and tongue movements were more influenced by concurrent motor and cognitive tasks, respectively, compared with the other movement.	Hand movements and tongue movements are related.	2c
Benjamin Straube, 2013 (11)	Participants were presented with videos of an actor either speaking sentences with an abstract-social or concrete-object-related content, or performing meaningful abstract-social emblematic or concrete-object-related tool-use gestures	20	Functional Magnetic Resonance Imaging	Modality specific activations were found in bilateral occipital, parietal, and temporal as well as right inferior frontal regions for gesture (G > S) and in left anterior temporal regions and the left angular gyrus for the processing of speech semantics	Gestures referring to abstract concepts are processed in a predominantly left hemispheric language related neural network.	2b
Claudia L. R. Gonzalez, 2014 (12)	Children of two different ages (4–5 and 8–9) completed two grasping tasks and a test of speech articulation.	35	Video and audio recording	Children (4–5 years old) who are more right-hand lateralized in picking up small food items for consumption show enhanced differentiation of the “s” and “sh” sounds	Left hemisphere control of hand-to-mouth gestures may have provided an evolutionary platform for the development of language	2b

Authors (Year)	Study Protocol	Number of Subjects	Outcome Measures	Results	Conclusion	Quality / Level of Evidence
Naeem Komeilipoor, 2014 (13)	Subjects observed videos of bimanual hand movements associated or not associated with nouns	10	Transcranial Magnetic Stimulation induced motor evoked potential of tongue and hand	Higher motor excitability in the tongue area during the presentation of meaningful actions as compared to meaningless ones, while the excitability of hand motor area was not differentially affected by action observation.	Tongue area is excited even during hand gesture.	2c
Amanda Elias Mendes, 2015 (14)	Tongue force was evaluated using the Iowa Oral Performance Instrument and grip strength using the Hand Grip in 90 normal individuals	90	Iowa Oral Performance Instrument and Grip Strength	A reduction in tongue force and grip strength, as well as an increase in the time required to drink 200 ml of liquid, were noted with increasing subject age.	There was an association between the measures of tongue force and grip strength in the different age groups.	2b
LariVainio, 2016 (15)	The participants had to perform either forward or backward hand movement and simultaneously pronounce different vowels or consonants.	58 (20, 19, 19)	Vocal and Manual Reaction time	The results revealed a response benefit, observed in manual and vocal reaction times, when the responses comprises of front vowels and forward hand movements. Conversely, back vowels were associated with backward hand movements	Movements of tongue body share the directional action planning processes with hand movements	2c
Mikko Tiainen, 2018 (16)	Participants were presented with visual stimuli specifying articulations to be uttered (e.g., A or I), and they were required to produce a manual gesture simultaneously with the articulation.	40 (19, 21)	Reaction time	Results for the vocal responses also revealed an interaction of tongue position and grip, where letters were uttered more quickly when the grip was a power grip than when the grip was a precision grip $p < 0.001$	This reflects interaction between processes that plan articulatory gestures and hand movements	2c
Claudia Mazzuca, 2018 (17)	Participants were tested individually, and were instructed to respond as quickly and accurately as possible to each trial with the help of a response box connected to a pedal and a button for lexical decision task and recognition task	80 (40, 40)	Response time	In the lexical decision task abstract words were processed slower than emotional words and more slower than concrete ones, proving the well-established concreteness effect	Abstract words were processed slower than both concrete and emotional words	2b

Authors (Year)	Study Protocol	Number of Subjects	Outcome Measures	Results	Conclusion	Quality / Level of Evidence
Caitlin Hilverman, 2018 (18)	Participants learned novel label-object pairings while producing gesture, observing gesture, or observing without gesture. After a short delay, recall and object recognition were assessed.	27	Recall Response	Unsurprisingly, amnesic patients were unable to recall the labels at test. However, they correctly identified objects when they produced a gesture at encoding.	Gesture production may support word learning by engaging nondeclarative (procedural) memory.	2b
Caitlin Hilverman, 2018 (19)	Participants viewed the video of the adult native English speaker who narrated four stories about a cartoon man named Carl who experienced a variety of unfortunate events	27	Recall Response	Patients with amnesia were significantly more likely to include supplementary information from gesture in their retellings than healthy comparison participants	Functioning hippocampus is not necessary for gesture-speech integration	2b
Anthony Steven Dick, 2009 (2)	The BOLD response was recorded while subjects listened to stories under three audiovisual conditions and one auditory-only (only speech) condition. In the first audiovisual condition, the narrator produced gestures that naturally accompany speech. In the second condition, the narrator made semantically unrelated hand movements. In the third condition, the narrator kept her hands still.	24	Functional Magnetic Resonance Imaging	In addition to inferior parietal and posterior superior and middle temporal regions, bilateral posterior superior temporal sulcus and left anterior inferior frontal gyrus activated more strongly to speech when it was further accompanied by gesture, regardless of the semantic relation to the speech.	Listeners attempted to find meaning, not only in the words speakers pronounced, but also in the hand gestures that accompany speech.	2c

Table Explanation: Table explains the various studies which explains the relationship between tongue movements, hand movements and speech.

Abbreviations: HSF- High Spatial Frequency; LSF – Low Spatial Frequency; BOLD – Blood Oxygen Level Dependent.

Non – Neural Networks Explaining the Relationship between Tongue, Mouth and Hand.

Gentilucci and his colleagues (2001) suggest that there exists anclose functional relationship between mouth and hand in primates as well as in humans[4].

Rapid tongue and hand movements are more constantly influenced by concurrent cognitive and motor tasks respectively, compared with the other task [20].

Walker (1998) stated that the articulatory organs (tongue, jaws, lips, larynx) are also used in eating and there exists a coordinated relationship between actions that involve the hand and actions that involve the mouth [12].

LariVainio (2013, 2017) proposed thatthe horizontal tongue movements for vowel production share the movement planning processes with the reach-related hand movements, whereas the tongue articulators of dorsum (related to arching of the tongue body) and the apex (related to tongue tip movements) share the action planning processes with the power and precision grasp respectively [21, 22].

It has been also noted that young children and chimpanzees tend to perform mouth movements, like tongue protrusions, in imitative synchrony with fine-motor hand manipulation [23].

We are also aware of the concept that while doing a manual task that involves high precision manual dexterity, like threading a needle, tongue tip is held between the lips or the protruded tongue is moved in coordination with the manipulative hand movements[24].

Salmelin and Sams (2002) have shown magnetoencephalography evidence that the hand motor cortex is significantly involved in non-verbally produced lip movements (lip protrusion) as well as tongue (touching the upper teeth with the tip of the tongue) movements (Viano et al., 2019) [24].

Mirror neurons are present in different cytoarchitectonic areas and their unique properties are connected not only to the type of effector involved (hand or mouth) but also to different anatomical pathways (Ferrariet al., 2017) [25].

Speech and Hand Gestures are Inter-related.

Gesture–speech synchrony re-stabilizes when hand movement or speech is disrupted by a delayed feedback manipulation, suggesting strong bidirectional coupling between gesture and speech (Dick et al., 2009; Goldin-Meadow et al., 2013) (2, 16).

The brain circuits involved inprimitive communication signs with hand gestures were now controlling the mouth articulation system which supports the hypothesis that Broca's area derives phylogenetically from the primatespremotor area where hand gestures are controlled(Gentilucci et al., 2001)[4]. Neuroimaging studies found that left motor cortex controls semantic processing of speech and hand gestures. (Xu et al., 2009; Straube et al., 2012, 2013) [11].Younger children with speech disorders such as developmental dyspraxia or phonological disorder also present with problems in manual dexterity. Neuroimaging studies have shown that Broca's area (in the frontal lobe) is involved in both speech production and non-linguistic motor tasks (Gonzalez et al., 2014) [12].

Hilverman et al (2018) concluded that the absence of a functioning hippocampus does not affect memory and learningand speech and gesture processing and integration plays animportant role in memory mechanism [17, 18].

Functional MRI study conducted by Erhard et al., (1996) to find out whether brain areas activated by motor tasks overlap with those activated during language tasks. Twelve healthy, right-handed subjects performed a series of motor functions (toe movement, random tongue movement, complex instruction-guided finger tapping, and aping of displayed hand shapes) and a language task. There was activation of Broca's area not only during the language task but also during each of the motor tasks involving hands (Iverson et al., 1999) [27].

Behavioral data reported a reciprocal influence between symbolic gestures and words, and neuroimaging studies and transcranial magnetic stimulation techniques suggest that the system governing both gesture and speech is located in Broca area. The articulate language evolved from manual gestures has been proposed several times (Corballis et al., 2003; Gentilucci et al., 2008) [28, 29].

The posterior part of the motor speech area in primatescontrols jaw and mouth movements in chewing (Luschei & Goldberg 1981), and stimulation of the homologous area in humans induces chewing movements (Foerster 1936) which have suggested (MacNeilage 1998) that speech itself would have evolved from the repetitive movements involved in chewing (Corballis et al., 2003)[28].

Studdert-Kennedy (1998) has suggested that speech involves both phonetic segments (consonants and vowels) as well as gestures, which is composed of coordinated movements of six different articulators, namely, the lips, the body of the tongue, the blade of the tongue, the root of the tongue, the velum (or soft palate), and the larynx. Liberman and Whalen (2000) argued that the same gestural system underlies the production of speech as well as perception, presumably through a system resembling the "mirror-neuron" system(Corballis et al., 2003) [28].

Neurophysiological and behavioral evidence suggest that manual gestures and vocal language share the same control system. Studies of premotor cortex in primates and humans, suggest the existence of a dual hand/mouth motor command system involved in ingestion activities (Gentilucci et al., 2008) [29].

Corina and McBurney found that in deaf singers, Broca's area of the dominant hemisphere was specialized for sign production by using cortical stimulation mapping. (Gordon, 2004) [30]. However, hand gestures may not be well suited for learning novel phonetic distinctions at the syllable level within a word, and thus, gesture-speech integration may break down at the lowest levels of language processing and learning (Kelly et al., 2014) [31].

Broca's area comprises of partly overlapping subsystems that support various functions, ranging from motor imagery to object manipulation and grasping, to motor preparation, and to planning (Nishitani et al., 2005[32].

Speech-related gestures and speech production are connected to such a degree that they have been considered as outlets of the same thought process, a view supported by the finding that hand and orofacial gestures are supported by the speech production area, i.e., Broca's region (Nishitani et al., 2005) [32].

Broca's area encompassing Brodmann's areas 44 and 45 in the left hemisphere, with representations of face, head, and hands—but not of foot—may have evolved into a special communication area relying on hand movements and orofacial gestures (Nishitani et al., 2005) [32].

Summary of Evidence

In summary, a body of evidence from electrical stimulation, behavioural and neuroimaging studies of healthy individuals and patient populations is consistent with the view that gesture and speech form a tightly coupled system. The strength of the coupling between speech and gesture is further emphasized by preliminary findings indicating that spontaneous gesture production occurs even in the face of damage to brain regions involved in motor control (Iverson et al., 1999) [18].

We reviewed evidences that the transition from primarily manual to primarily vocal language was a gradual process, and is best understood if it is assumed that speech is a gestural system rather than an auditory system, an idea captured by the motor theory of speech perception and articulatory phonology. Studies on premotor cortex of primates, and, in particular, of the so-called ''mirror system'' suggest a double mouth/hand command system that may have evolved initially in the context of ingestion, and later formed a platform for combined vocal and manual communication (Gentilucci et al., 2003) [33].

Whishaw I Q et al., (2010) described that the hand gestures associated with speaking have a similar structure to functional hand movements.[34] The relationship between gesture and functional hand movements has three implications. First, it is consistent with the view that there is evolutionary link between functional hand movements used by species ancestral to humans and humans themselves. Second, it is consistent with the idea that there is link between functional hand movements in humans and the hand gestures associated with speech. Third, it is consistent with the idea that the neural circuitry, e.g., the motor cortex, involved in controlling functional hand movements participates in language through hand gestures. Functional neuroimaging have also revealed that parietal cortex is responsible for visuomotor action like reaching, grasping and eye movements [35].

Broca's area also becomes active in stroke patients who have recovered from subcortical infarctions when they are asked to use their paralyzed hand (Rizzolatti et al, 1998) [36].

Limitations: We have included only available full articles for this review article.

Conclusion

Various studies have established that there exists a relationship between tongue movements and hand movements, speech and gesture. Moreover, Broca's area controls the hand movements in addition to speech. Thus, this relationship can be used in neurorehabilitation for inducing neuroplasticity. Further studies can be done to train hand functions in conjunctions with the speech or oral functions for patients whose hand motor cortex is damaged.

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