



## A General Explanation of How and Why Articulation Modeling Works: Illustrated by an Analysis of a Brief Sample of Fluent Speech Recorded at 55 fps in rtMRI

### Linguistics

John W. Oller, Jr. Ph.D. University of Louisiana

### ABSTRACT

This paper looks into the amazing depth of the sort of articulation that we take for granted in our most mundane and ordinary uses of language. It explores why and how articulation modeling is necessary to language acquisition and it shows how cross-modal transfer from vision, and motoric information, for example, can inform speech perception and production. It also shows how such information can be used in therapeutic interventions. As a process, *articulation* is most naturally, and most appropriately, associated with speech, but it also applies with essentially the same pragmatic value to writing, typing, reading written symbols, reasoning, thinking, and to planning and producing complex sequences of actions or of signs in general. Examined closely, there are no meaningful sequences of signs representing corresponding arrangements of entities, events, relations, or combinations of them that are not articulated in a manner analogous to the articulation of sequences in everyday speech. The spoken sequence used in this paper to assess the foregoing assertions is a recorded message welcoming visitors to the Science Gallery of the Max Planck Society in the Gendarmenmarkt of Berlin. The "Welcome Message" to be examined was recorded at the Max Planck Institute of Biophysical Chemistry in Göttingen, Germany, at approximately 55 fps with real-time Magnetic Resonance Images (rtMRI), adjusted to about 60 fps with Adobe Premier. The fluent sequence of articulations can be roughly transcribed in the International Phonetic Alphabet as [wɛlkɑmtuðisajntsɔælɪjəvðimæksplæŋksosajitij]. To show the importance of modeling, I also refer to the extreme case of "locked-in syndrome" as experienced by Victoria Arlen who lost all of her capacity to move her body or articulators and yet against all odds recovered enough to make it to the semi-final round on *Dancing With the Stars* in the 2017 season ("Victoria Arlen/Dancing with the Stars," 2017).

### KEYWORDS

articulation, fluent speech analysis, real time Magnetic Resonance Imaging, visible phonetics

#### Background and Introduction

Recently, in preparing a talk for speech-language pathologists and audiologists that was delivered in Los Angeles at the Annual American Speech Language and Hearing Association in 2017, it struck me yet again (J. W. Oller, 1972) how the articulation of speech is far deeper than it appears to be on the surface. Speech-language pathologists and audiologists especially tend to focus a great deal of attention on the surface aspects of speech articulation, just as many linguists also have in the past (notably by Bloomfield, 1933; Bloomfield, Barnhart, Pooley, & Faust, 1961; Harris, 1969), and yet upon closer inspection it turns out that the meaningful articulation of signs of any kind requires connections that reach deeply into the entities, relations, events, and combinations of them that occur in ordinary experience (J. W. Oller, Sales, & Harrington, 1969). We tend to overlook the many layers of the dynamic systems involved in the articulation of speech, and of other sign systems as well, because we are naturally inclined to look right through all of the dynamic layers involved in articulation. We tend to go directly from the superficial elements that we perceive to what we understand (conceive) to be the intended meaning (Bergelson & Swingley, 2012; Ferguson & Waxman, 2016; J. W. Oller, 1975; S. D. Oller, 2005).

In this paper I want to examine closely the first sentence of the "Welcome Message" which can be heard, with or without machine noise in the background, by clicking either of the respective hyperlinks in the caption to Figure 1. I have also produced a publicly accessible YouTube containing a frame by frame analysis of the of the articulatory movements involved in producing "Welcome Message" (just click the link in this sentence to view it). It shows the visible movements involved in producing the audible segments as represented in the transcription [wɛlkɑmtuðisajntsɔælɪjəvðimæksplæŋksosajitij] of the rtMRI recording.

That YouTube analysis, incidentally, addresses only the surface segments. It says nothing about the layers in between those superficial forms and the meanings to which they direct our consciousness. And yet, it is easy to prove that all of the content of even the most transparent of meaningful signs is, for practical purposes, infinitely extended in its connections with space-time-matter. Those other layers, as I will show in this paper, are unfathomably deep with respect to the entities, events, and relations that connect with the articulated meanings even in such a short stretch of fluent speech. Strangely, although "articulation" seems to produce the very most superficial surface forms of speech, as we examine *articulation itself* more closely, it turns out that even *the most mundane meaningful articulations* actually connect to the world of common experience, and, thus, to the abstract essence of ordinary meaningful content. What is more, this same sort of multi-layered connectedness to the world of

experience seems always to be present in meaningful sign sequences in general. Even the most fantastic of fictions, errors, and deliberate lies, are without exception tied to real persons, times, and places though their producers and interpreters. However, in this discussion, it is the process of *articulation itself* on which I wish to focus attention.

#### From Surface Form to Actual Content

It is, of course, true, as linguists have been emphasizing, at least since the beginning of the Chomskyan revolution (Chomsky, 1957, 1959), but especially since the advent of his distinction between surface and deep structures (Chomsky, 1965), and his subsequent investigations of phonology (Chomsky & Halle, 1968), that the dynamic systems involved in articulated speech, and in languages (and later in language-like sign systems without exception; see J W Oller, 2014a), are deeper and more complex than they appear to be at the surface. Chomsky attributed much of his thinking (Chomsky, 2007; Chomsky, Ronat, & Viertel, 1979, p. 71) mainly to Charles Sanders Peirce [born 1839-died 1914] – ("Charles Sanders Peirce," 2016). Among Peirce's ideas about language and related sign systems, as discussed at some depth by Redondo-Dominguez (2009, 2017), was the fact that meaningful, articulated signs, are always deeply layered somewhat in the manner of an onion. This layering can be discerned in the most superficial forms and it penetrates to the deepest layers of meaning connecting directly or indirectly to the entities, relations, and events of the space-time universe where the ultimate material content of meaningful signs seems to reside, and yet is only known conceptually through abstract representations.

Among the most quoted of Peirce's remarks about the nature of meaningful articulated strings of signs is the following (also quoted by Redondo-Dominguez, 2017):

To try to peel off signs & get down to the real thing is like trying to peel an onion and get down to the onion itself, the onion per se, the onion *an sich* (MSL387, 1905).

To understand Peirce's meaning, it is necessary to realize that he was not speaking so much of the surface forms of signs as of their "real" content at the deepest level of comprehension. It comes out, if we examine articulated meaningful sign systems closely, including everything from biosignaling systems to human languages, we discover that all of them without exception depend for their significance as meaningful signs on connections with the material world as known to us through our senses. Peirce proved in general that all meaningful signs depend on their valid associations with the material world (Peirce, 1877, 1878, 1897), and Tarksi — (1949, 1956), later, argued that case from the point of view of ordinary truth. The upshot of their proofs is that there cannot be any meaningful signs

whatsoever that are so completely removed from the material world as to be entirely dissociated from it. That kind of entity would be an abstraction beyond any hope of the slightest bit of significance. No such signs, therefore, can exist. This means that the only kind of meaningful signs that can exist are the kind that we find in natural language systems, ones that are, to a greater or lesser extent, always associated with the common “real” world of ordinary experience where living humans generally seek to maintain their existence in spite of the risks that invariably and persistently threaten to terminate it.

It is invariably, therefore, in such an “at risk” context that the articulation of meaningful strings of signs must take place. For skilled language users who have devoted their early years of life to acquiring one or more language systems, the perception of a fluent stream of articulated speech, for example, in any of the languages that we know well, seems deceptively straight-forward, even simple, so much so, that we are unimpressed with the process of understanding what is without question an exceedingly complex arrangement of systems within systems within systems. It comes out upon closer inspection that meaningful articulated strings of signs are deeply layered. In fact, they are so richly interconnected that missing, damaged, or mistaken parts of the surface forms can often be filled-in or corrected by an intelligent interpreter. Yet the distinct layers of interconnected systems in an articulated stream of speech are hardly repetitive in the manner of a cauliflower as seen in Figure 2, for instance. But they do involve many cross-linked “redundancies” in the phonology, morphology, lexicon, syntax, semantics, and pragmatic systems of the language (Leydesdorff, Johnson, & Ivanova, 2014; Pinker & Morey, 2014). Those “redundancies” engender incredibly rich and often highly efficient “expectancies” enabling far more fluent and accurate processing (Díaz-Galaz, Padilla, & Bajo, 2015) than is possible when they are systematically corrupted (Bachman, 1982, 1985; Cziko, 1984; Cziko, 1981; Jonz, 1987, 1989, 1990). If those redundancies are completely removed, of course, we end up with an arrangement that cannot even be described as “chaos”. If all traces of articulate signs in any string are removed, so also, is the last vestige of anything resembling information or meaning. Even a chaotic arrangement of just the surface forms of signs is a step up from complete erasure of those forms.

### Something to Talk About

With all the foregoing in mind consider that fact that fluent articulation in speech, for example, in the “Welcome Message” for the Science Gallery of the Max Planck Society, begins with something to talk about. Setting aside many details about the backgrounded thought processes (some known but most of them remaining yet to be discovered; see Carson, 2008), from the global architecture of the cerebrum, we can infer the general outlines of the neurological processes leading from the intention to utter the “Welcome Message” to the necessary articulatory movements to produce it in English. From Roger Sperry's work with patients whose corpus callosum was cut, ostensibly to reduce the likelihood of recurrent life-threatening seizures, we know that speech articulation can only come under the control of the dominant hemisphere of the brain whereas the subordinate hemisphere specializes in handling holistic images of entities and the like (Sperry 1964, 1981).

Presumably, therefore, the producer of the “Welcome Message” knows and has in mind the fact that the Science Gallery of the Max Planck Institute is a real place in Berlin (Figure 3). Although the recording was not actually made there, but rather in Göttingen, about 200 miles mostly east and a little south of Berlin, the person uttering the “Welcome Message”, along with those assisting in the creation of the rTfMRI recording, had to have in mind the actually existing Science Gallery of the Max Planck Society. The inner workings of the mind of the producer of the message might be summed up as shown in the brief video hyperlinked to Figure 4. Subsequently, any consumer of the message must to some extent work in the opposite direction, from the surface form to the meaningful material content. Observers such as ourselves, who are neither the producer, nor any of the on site consumers of the message at the Science Gallery itself, must rely on our knowledge of English and our ability to draw reasonable inferences about the world of experience to complete the pragmatic mapping of the surface forms of the “Welcome Message” all the way to the entities in the real world that are referred to. The indispensable phrase that must be deciphered appropriately is the name, *Max Planck*. With that in mind, let us next consider the layers of signs within which this phrase is embedded as well as at least some of the systems of signs underlying and constituting it.

### Articulated Speech Is Deeply Layered

The underlying meaning of the “Welcome Message” can be distinguished from its surface form as suggested in Figure 5. The segmental surface forms are shown in symbols from the

International Phonetic Alphabet (InternationalPhoneticAlphabet.org, 2016) in red lettering at the top of Figure 5. Beneath that “surface form” of the message, even the word *welcome* considered all by itself, must be addressed to some consumer (or plurality of them) who has (or have) arrived in some sense (perhaps virtually) at the Science Gallery of the Max Planck Society. It can be argued that the deeper meaning must involve that person (or those persons) addressed in the abstract proposition underlying the sentence, *you are welcome*, which has an understood complementary propositional meaning that can be expressed in the sentence, *we are glad you have come to the Science Gallery of the Max Planck Society*. Much more is contained within the “deep structure” (to use Chomsky's 1965 term) that is easily understood by reasonably mature and well-informed speakers of English. Intelligent consumers will also know, or be able to infer, that Max Planck was an important German scientist of the past, in whose honor the Max Planck Society was established in order to sponsor and create the Science Gallery referred to. With a little investigation, consumers would easily discover a great deal more about Max Planck himself – (“Max Planck,” 2017), about the Science Gallery of the Max Planck Society (Max Planck Society, 2017), and about its connections with the 83 Max Planck Institutes funded throughout Germany at an estimated cost of about €1.7 billion in 2015 (“Max Planck Society,” 2016).

They would also find that the Max Planck Institute for Biophysical Chemistry in Göttingen, Germany is the flagship institution located, as noted, about 200 miles east and a little bit south from the Science Gallery of the Max Planck Society in Berlin. Students of the sciences, especially in chemistry and physics, would be likely to know that Max Planck, in addition to essential scientific contributions of his own, was also instrumental in enabling Albert Einstein to publish his *annus mirabilis* papers on special relativity (“Annalen der Physik,” 2017; “Annus Mirabilis papers,” 2017; “History of special relativity,” 2017). In 1913, Einstein wrote:

The attention that this theory [special relativity] so quickly received from colleagues is surely to be ascribed in large part to the resoluteness and warmth with which he [Max Planck] intervened for this theory (“Annus Mirabilis papers,” 2017).

Much more could be said along that line, but the connections with historical facts and present-day happenings would prove to be absolutely inexhaustible. As Peirce explained, we cannot by any means of cutting, digging into, or teasing apart the layers of a well-formed articulated sequence of signs, ever arrive at something that might be thought of as the actual essence of that articulated sequence itself — the “onion” *as such* (Peirce, 1897; Redondo-Dominguez, 2017).

### Proving the Reality of Underlying Conceptual Meanings

Although we cannot actually dig our way down to the very essence of the meaning of any string of well-formed articulated signs, we can easily prove both empirically, and by strictly necessary mathematical reasoning along the lines Peirce's “exact logic” (Peirce, 1982), that the underlying meaning of the “Welcome Message” (or pick any other well-formed articulated string of signs) is very real in spite of the fact that it is exceedingly abstract and ultimately only *conceptual* in nature as Peirce took a great deal of trouble to explain (Peirce, 1878).

To prove the existence of the abstract propositional meaning of the Welcome Message, we can paraphrase it in many different ways in English, and/or translate it into any one of more than 7,000 other extant languages (Paul, Simons, & Fennig, 2016), and we can paraphrase it in countless ways in any one of those other languages as well. We can, for instance, paraphrase the “Welcome Message” in English in many different ways. We can make it even more succinct, as in, *Welcome to the Max Planck Science Gallery*, or more elaborate as in, *This is the Science Gallery of the Max Planck Society and you are welcome here*, or *The material found at this web site belongs to and is maintained by the Max Planck Society, and you are welcome to browse around and see what you can find here, and on behalf of the Society, we want you to realize that we are glad you came here*, and so on.

Or, we can translate the “Welcome Message” into any other language

we may know, as in *Bien venido a la galería de la ciencia de la sociedad Max Planck* (Spanish), *Bienvenue à la galerie de la science de la société Max Planck* (French), 歡迎來到馬克斯·普朗克社會科學館 (Chinese), Χαλωσορίζω στην επιστήμη γκαλερί του Ινστιτούτου Max Planck (Greek), *Bi xweşî hatî ferhenga gallery zanist ji civaka Max Planck bi xêr hatî* (Kurdish), and so forth. Also, as noted, paraphrasing can be applied in any language, so the number of ways we could express the propositional meaning of the “Welcome Message” is unlimited, and, although the conceptual basis of the message is very abstract, it really exists. And, of even greater importance, that conceptual basis connects with the whole of the common world of experience in the present tense which also happens, necessarily to be connected to all the rest of that common world past and future without any discernible boundaries or limits.

Thus, when we look to the Chomskyan “deep structure” — the Peircean conceptual meaning underlying any articulated sequence of signs — it comes out that the “real onion *an sich*” is the whole of the material world insofar as we are able to conceptualize whatever particular parts or aspects of it may be signified by interpretable sequences of signs. Looking in the other direction to the Chomskyan “surface forms” — the aspect of the moving articulations that we can perceive, transcribe, or record in some way, as in the rtMRI of the “Welcome Message” hyperlinked to Figure 1 with both visual and auditory tracks — many theoreticians have been reluctant to admit that parsing such strings to show their dynamic “structure” requires appeal to our knowledge of the material world (J. W. Oller, 1970; Reichling, 1961; Uhlenbeck, 1967). But, the truth is that to decipher fluent speech in any language of the world, we absolutely must take account of the bounded entities, events, and relations of the “real” material space-time world to which the elements of that particular language refer, or signify, in order to differentiate the distinct articulatory movements that constitute the “surface forms” of that language (Caza & Knott, 2012; J. W. Oller, 2005). If those entities, events, and relations of the “real” material space-time world are not taken into account the deciphering of the “surface forms” of any language will not be just difficult, it will be impossible — (J. W. Oller, 2010, 2013, 2014a, Peirce, 1877, 1878, 1897, Tarski, 1949, 1956).

The fact is that language users cannot decipher languages or acquire them without calling on the kinds of meaningful content that enable paraphrase and translation. As de Saussure noted more than a century ago,

The main characteristic of the sound chain is that it is linear. Considered by itself it is only a line, a continuous ribbon along which the ear perceives no self-sufficient and clear-cut division, to divide the chain we must call in meanings (Saussure, 1959, p. 103).

It has been demonstrated logically that the segmentation of significant units within a sequence of articulated linguistic (or other signs) depends on the discovery of bounded entities, relations, and events in experience (Caza & Knott, 2012; J. W. Oller, 2013), and the distinct referring terms and phrases that single out certain of those entities, relations, and events from the stream of experience. Even the decipherment of Egyptian hieroglyphics (“Jean-François Champollion,” 2017) and of the “genetic code” depended entirely on identifying one or more entities referred to by some portion of the articulated sequence at issue (“Phenylalanine,” 2017). For the decipherment of hieroglyphics it was the articulation of certain “cartouches” referring to particular individuals also referred to in the corresponding Rosetta Stone translations, and in the genetic material of an *E. coli* bacterium, it was replication of a certain codon, UUU, in ribonucleic acid that enabled the discovery of the first “word” in the “genetic code” (M. Nirenberg et al., 1965; Nirenberg & Matthaei, 1961; Nirenberg, 2004).

With de Saussure's caveat in mind that articulated speech is like a “ribbon” without obvious breaks to define its distinctive units, from the rtMRI recording we can show that the speech articulators are constantly moving during the planning and construction of the “Welcome Message”. As seen in the hyperlinked videographic analysis of Figure 6, even in the break between the “Welcome Message” itself and the sentence that tells where the rtMRI recording was made, and during the greater part of the silence that follows the last audible part of the recording, the speaker's tongue, velum, and pharynx, continue to move.

#### Intelligibility Is Essential

Except for the importance of discovering some determinate part of the meaning of an articulated sequence in order to parse it into units and to decipher the whole sequence, it could almost go without saying that the point of articulation is to make our speech (or other strings of signs) intelligible to interpreters. In natural spoken languages, those interpreters are typically other users of the same language. In biosignaling systems, the active “articulators” and “interpreters” of any given string in some portion of a DNA, RNA, or a protein message are the layered systems above and beneath the one in question that must make sense of it in the deeply interconnected genetic, epigenetic, and proteomic processes (Di Ieva, Grizzi, Jelinek, Pellionisz, & Losa, 2014; J. W. Oller, 2010; Pellionisz, 2012).

In the “Welcome Message” focused on in this paper, a key phrase is *the Max Planck Society* which can be parsed into phonetic segments and syllables as shown in Figure 7. In fact, it is easy to see in the example translations across languages given above that the embedded NP, *Max Planck*, is pivotal. It is the element that cannot be omitted from any fully adequate translation. For instance, in the Chinese translation, this name appears in the written form in more or less homophonous characters transliterating “Max Planck” into the Chinese character sequence 马克斯普朗克 which can be represented phonetically in IPA symbols as [mākèsī pǔ lǎng kè]. Without that critical name referring to a particular German physicist who lived from 1858 until 1947 — (“Max Planck,” 2017), an adequate translation of the “Welcome Message” is not possible in any language. But, of course, the fluently articulated “Welcome Message” is not adequately understood by merely connecting the NP *Max Planck* with a particular physicist. More is required.

If we examine any part of the message in English, for instance, we discover that it can be parsed not only into phonetic segments that can be roughly transcribed in IPA symbols, but that each syllable has a syntax of its own, a phonotactic structure, that resembles the sort found in a phrase or even a whole sentence. For instance, we can analyze the syllables of the phrase *the Max Planck society*, as in Figure 8 showing that each syllable has a tactical structure not unlike that found in a NP or a whole sentence as seen in Figure 9.

The parallels across such radically different layers of articulated linguistic sequences are striking, and yet we have not yet discerned the most superficial elements of the articulated segments. They can be further analyzed into more or less simultaneously occurring phonetic “features” as suggested in Figure 10. There, reading down the columns, we find segments that share all but one phonetic feature in each instance. By contrast, reading across the three rows, the highlighted phonetic feature in each case is common to all three segments. For example, on the first row, [b] differs from [p] by the *voiced* versus *voiceless* contrast, as do [d] and [t], and [g] and [k], respectively. Similarly, on the second row, [p], [t], and [k] share the *voiceless* feature and yet, like [b], [d], and [g], as well as [m], [n], and [ŋ], they differ from each other according to the place of constriction owing to an approximation of the lips, the tongue tip to the alveolar ridge, or the tongue blade to the velum, respectively, reading left to right.

Finally, reading across the last row of segments, all of them share the feature of *nasality* and *voicing* but differ as already noted in the place where the oral cavity is obstructed by an articulatory movement of the lips, the tongue tip, or the tongue blade, respectively.

But we can go much further with our analysis of the phonetic features that must be articulated distinctly in order to differentiate the sound classes depicted in Figure 10. The most common phonetic feature throughout the “Welcome Message” in English (and across all natural spoken languages in general) is *voicing*. However, given the fact that the vocal folds of a typical male speaker produce about 120 cycles per second while the average female voice produces about 220, 55 fps is too slow a rate to adequately represent the rapid turning on and off of the voice in fluent speech. *Voicing* also involves production of sufficient pulmonic pressure by tensing muscles of the abdomen, intercostals between the ribs in the thorax, and the upper and lower serratus muscles in the back, along with the cricoarytenoid and cricothyroid muscles of the larynx. The coordinated innervation of all those muscles is also exceedingly complex and daunting to any would-be analyst.

Turning *nasality* on and off, by contrast, in order to produce the three *nasal* consonants in the final row of Figure 10, is simpler. It evidently

involves only the *vagus pair* of cranial nerves (numbered X), and the pair of muscles highlighted in the left hand drawing in Figure 11 from Gray (1918). As can be seen, these muscles serve to lift the soft palate, the *velum*, from a relaxed curve, as highlighted in the yellow oval at the right hand side of Figure 11, to an almost perfect right angle as seen in the elements highlighted inside red squares inside the vowel trapezoid of Figure 12 showing the corner vowels [i], [u], and [ɛ] along with the mid-central vowel [ə] and the near open front vowel [æ].

The nasopharyngeal closure is almost complete in the vocalic elements of Figure 12 with two exceptions where the speaker is anticipating a *nasal* segment to follow. The exceptions are [i], where this vocalic element appears as a transitional semi-vowel in front of [n] in *Science*, and [æ], which appears just ahead of the nasal [ŋ]. From this analysis, with the aid of the rtMRI recording examined a frame at a time, we infer that in fluent speech, the opening of the *nasopharyngeal* passageway begins before the speaker's tongue hits the targeted point of constriction for the *nasal* in question. All this can be seen in more detail in the videographic analysis of only the nasal segments [m], [n], and [ŋ] hyperlinked in the caption to Figure 13.

### Extending and Applying the Foregoing in Therapy

All of the foregoing might seem unnecessarily abstract and theoretical if it had no practical applications. But there is much to be learned from such analyses that can be applied in language learning, teaching, and in therapeutic modeling in many contexts. To bring out a general application in therapeutic contexts, it is useful to consider how speech-language pathologists often apply modeling of articulatory movements in therapeutic interventions. It can be shown that modeling of articulatory movements has long been a central component in the clinical practice of speech pathology. In this section, we consider how modeling actually works in many therapeutic applications, why it is essential to language acquisition, and how it works in normal speech perception.

Whereas some speech-language pathologists have used what are called “non-speech oral motor exercises” (NSOMEs) aiming to strengthen the muscles and thus to increase motor control of those involved in speech production, the research shows that such NSOMEs in general do little or nothing to improve speech articulation (A. S.-Y. Lee & Gibbon, 2015). By contrast the modeling of highly articulated movements in speech, manual signing, dance choreography, gymnastics, and the like, seems to work across the board according to the relevant research (Sigrist, Rauter, Riener, & Wolf, 2013).

Evidently, NSOMEs for articulation therapy are like strength training for a gymnast or a dancer. While some muscular strength is necessary, it is not sufficient to produce fluent speech articulation. Muscular strength training cannot ensure the hundreds of muscle innervations that must take place each second in fluent speech production (Green et al., 1997; Moore & Ruark, 1996; Ruark & Moore, 1997). From the research just cited, and references contained in those papers, we know that the complex muscular movements required for chewing and swallowing are many times slower than those involved in ordinary fluent speech. For that reason, the speculative claims of Davis and Macneilage (1995) that the rapid movements of speech articulation emerge from the movements of the articulators in consuming food and liquid, seems implausible. Moreover, if their theory were correct, why is it that all animals, or at least all primates, that chew and swallow do not also produce canonical babble and then go on to develop fluent human speech capacities? Evidently, more than sufficient muscle strength and an agile tongue (as seen in many “talking” birds, for instance) is required to connect strings of linguistic signs with the entities, events, and relations of the common material world as known in human experience.

Therefore, it appears that Chomsky's claims (Chomsky, 1965, 1968, 1975, 2006) about a “unique” human language capacity involving “special design” (Chomsky, 1975, p. 27) have been correct all along. In 1975, he wrote:

... some intellectual achievements, such as language learning, fall strictly within biologically determined cognitive capacity. For these tasks, we have “special design”, so that cognitive structures of great complexity and interest develop fairly rapidly and with little if any conscious effort (p. 27).

More specifically, we can argue that the deeply layered dynamic

structures universally found in fluently articulated human languages depends on By contrast modeling of the highly articulated movements involved in fluent speech — or in other complex sequences as found in gymnastics or in dancing choreography — seems to work across the board (Sigrist et al., 2013).

### Motor Modeling in the Extreme Case of Victoria Arlen

Sometimes modeling is perhaps the central component in therapy enabling dramatic recoveries of articulatory capacities and motor skills. Such was the case with Victoria Arlen. She had lost all of her articulation capacity with complete paralysis described as acute demyelinating/disseminated myeloencephalopathy (ADEM). Bearing in mind that ADEM is one of the most extreme demyelinating conditions linked to biosignaling injuries coming from certain toxins such as mercury and aluminum (Attar et al., 2012; Dórea, 2015; Giacoppo et al., 2014; Haley, 2005; Hybenova, Hrdá, Prochazkova, Stejskal, & Sterzl, 2010; Kennedy et al., 2016; Mutter, Naumann, Schneider, Walach, & Haley, 2005; Shaw, in press; Shaw, Seneff, et al., 2014; Shaw, Li, & Tomljenovic, 2014), pathogens (Baba et al., 2006; Buchanan & Bonthuis, 2012; Fisher, Defres, & Solomon, 2015; Har-Even, Aichenbaum, Rabey, Livne, & Bistrizter, 2011; Ludlow, McQuaid, Milner, de Swart, & Duprex, 2015; Nardone, Golaszewski, Trinka, Tezzon, & Zucconi, 2011; Seki et al., 2011; Sips et al., 2007), and to animal derived myelin basic protein coming to human beings mainly through injections (Agmon-Levin, Hughes, & Shoenfeld, 2012; Barilaro et al., 2016; Esposito et al., 2014; Luján et al., 2013; Perricone et al., 2013; Shoenfeld & Agmon-Levin, 2011).

Whatever the cause of demyelination in the case of Victoria Arlen, by 2005, she had slipped from being an athletic nine-year old to the state described as “locked-in syndrome” (Deussing, 2008; Haan, 2013; Laureys et al., 2005; Raoul, Canam, Onyeoziri, Overboe, & Paterson, 2001). All she had left of her former motoric capacities was the volitional eye-blink. Presumably it was a well-informed speech-language pathologist who was able to discover that Victoria was still understanding everything said in her presence even when she could not move anything other than her eyelids. In the meantime, her parents refused to believe the doctors who said she could not recover. They never gave up on her, and with the eye-blink discovery, they were encouraged to believe she could recover against all odds.

Central to the therapies helping Victoria learn to speak again, to stand up again, and to walk again, were various forms of modeling and assisted motor training. After years in a wheel chair, she was able to compete in the 2010 Special Olympics, and more recently, in 2017, on *Dancing With the Stars*, given extensive modeling and assistance from her partner Val Chmerkovskiy, she progressed all the way to the semi-finals. Crucial to her recovery of motor skills, including speech, but especially the use of her limbs, were passive exercise with the assistance of various therapists, and a great deal of modeling.

With her case in mind, especially taking into account her amazing recovery from the complete loss of articulatory capacities and all of her bodily motor skills, consider the role of modeling. For dance movements, once she had recovered movement in her legs and the capacity to stand and walk, because of her lack of sensations in her lower extremities, she depended at first on seeing her dance partner perform movements; then, on performing some of those movements with his assistance while observing herself in the mirrors of the dance studio; and, finally, she became able to perform complex sequences of choreographed movements on her own. Early in the dancing competitions, as the judges often commented, she depended on looking down to see what her feet and legs were doing because she could not feel them. Later, however, she was able to rely on motor memory and could perform exceedingly complex choreographed sequences without looking down. Critical to the learning of the complex choreography was repetitive modeling of the requisite movements, first by her partner, then, by herself with his assistance, later, by relying on motor memory and visual self-monitoring of her own movements, and, finally, by relying on motor memory of practiced movements.

### How Modeling Impacts Speech Perception

In speech articulation, modeling is essential to acquisition of the rhythms, intonations, and articulatory movements of whatever language someone may be learning to understand (Aldridge, Braga, Walton, & Bower, 1999; Aldridge, Stillman, & Bower, 2001; Campbell & Yunusova, 2017; Fox-Boyer, Salgert, & Clausen, 2016;

Kaye & Bower, 1994; J. W. Oller, 2014b; Walton & Bower, 1993). It has been argued that acquisition of particular varieties of any language requires synchronization of the rhythms and movements of the learner with those of the community of speakers who use that particular dialect (Ejiri, 1998; Nazzi, Bertoni, & Mehler, 1998; Provasi, Anderson, & Barbu-Roth, 2014). We cannot just invent our own rhythms and articulatory movements by deciding, say, to speak a particular dialect of Russian in our own special way. We need to do it the way Russian speakers of that dialect do it, or we won't really be speaking that language at all. For this reason, modeling of fluent articulatory movements is crucial for persons of any age seeking to acquire fluency and native-like proficiency in any language.

Modeling of actual articulatory movements, and in fact kinesthetic sensations of the motor signals themselves, as hypothesized half a century ago by (1967), is apparently essential not only to the acquisition of the ability to produce fluent sequences of articulatory movements by learners, but is also involved more or less directly in ordinary speech perception (Galantucci, Fowler, & Turvey, 2006; Liberman et al., 1967; Liberman & Mattingly, 1985; "Motor theory of speech perception," 2016). The theory that the motoric signals that are necessary to produce articulatory movements are involved in the perception of those same articulatory movements was somewhat tentatively proposed as a "theory" but was dramatically demonstrated to be largely correct in a little less than a decade after it was clearly stated. However, before experimental evidence would show that knowledge of articulatory movements perceived through vision radically influences the perception of, for instance, the initial consonants associated with recorded syllables, it seems that an unexpected result would have to emerge from what seems to have been an error in matching up audio and video recordings of syllable-level utterances.

The strikingly relevant result was evidently achieved by McGurk and Macdonald (1976) when video recording of syllables were mismatched with audio recordings. The outcome of the mismatches is dramatically demonstrated in the YouTube recorded by Lawrence Rosenblum hyperlinked to Figure 14. Persons who watch the articulatory movements of the speaker while listening to the audible syllables (provided only that they have a normal brain and an intact corpus callosum) report hearing the syllables [ba], [va], [ða], and [da]. However, if the listener/viewer looks away from the video, it becomes obvious that the only syllable recorded in the audio portion is [ba]. That single syllable is repeated four times in the audio track, while the video track shows the articulatory movements necessary to the production of the syllables [ba], [va], [ða], and [da]. What the demonstrations show is that ordinary speech perception is greatly influenced by the articulatory movements that we can see the speaker making and is almost oblivious to the audio portion of the recording once the visual part has been perceived. We hear, in these instances, what we see the speaker doing in terms of modeled articulatory movements, and the auditory impression that comes later is completely obliterated by the visual information.

It is not too much to say that normal language users are all "lip-readers", much more than is commonly realized. The McGurk effects at the segmental and syllable levels show that visually perceived articulatory movements outrank the much slower perception of auditory signals. In the demonstration associated with Figure 14, it is safe to say that we hear what we see rather than what is actually recorded in the audio portion of the demonstration. Evidently, seeing outranks hearing in perception because we see articulatory movements well before any sound can reach our ears. Part of the explanation is purely physical on account of the fact that light travels so much faster than sound.

A more complete explanation of such "McGurk effects" must also take account of the fact that motoric signals also outrank sensory signals in general. This fact can be seen in the anatomy of the nerves and even in the sensory systems undergirding speech perception where the number of motor synapses, for instance, in the inner ear, exceeds those dedicated to sound detection by a ratio of about 10 to 1 and where it has been discovered that the motoric protein, prestin, is involved in a way that can amplify a given auditory signal by about 40 decibels. Thus, the inner ear can increase the volume of certain auditory signals to about 100 times the level that is available without the amplification provided by prestin to the so-called "outer hair cells" which actually function like specialized nerve cells inside the amazing Organ of Corti (Dallos,

Santos-Sacchi, & Flock, 1982; Santos-Sacchi, 2003). They are many times smaller and far more sensitive than any actual hair follicles (J. W. Oller, 2018; Seikel, Drumright, & King, 2016).

An interesting likelihood is that these delicate instruments inside the "Spiral Organ" become differentially tuned to the phonetic features and transitions between them that are peculiar to the language(s) an individual may acquire. The tiny tube containing the "Organ of Corti" (also known as the "Spiral Organ") is contained within the scala media which is sandwiched between the scala vestibuli (associated with our sense of balance) and the scala tympani. It responds dynamically to sound pressure level fluctuations originating at the tympanic membrane but communicated (and amplified) by the lever actions of the ossicles in the middle ear. The movements of those tiny bones, as they are set in motion by the sound pressure fluctuations impacting the tympanic membrane, are further transformed at the oval window located at the distal end of the scala tympani. There the pressure fluctuations magnified by the lever actions of the ossicles are again transformed from mechanical movements into an almost unbelievably broad range of vibrational frequencies transmitted to the fluid endolymph inside the scala tympani. As those vibrations are transmitted through that fluid they differentially stimulate the "inner" and "outer hair cells" distributed throughout the cochlea on both sides of the head. Depending on contrasts in signal strength distributed more or less horizontally between the two ears and vertically in the space within which sounds are captured by the auricles and directed into the auditory canals on both sides of the head, the hearer can with a fair degree of accuracy tell where the source of a stream of speech is located and will typically look in the direction of the speaker to deploy the additional resources of the vision in processing the stream of speech.

As sound pressure level fluctuations are being processed, frequencies and bands of harmonics are distributed across the range to which the individual "hair cells" respond. The ensuing analysis not only enables triangulation of the approximate coordinates of multiple distinct sources of sounds at distinct frequencies within the more or less half sphere of space-time-matter that constitutes our dynamic field of perception, but also seems to be uniquely suited to the processing of any stream of speech to which we may attend deliberately, or, which we may incidentally happen to overhear.

Because of the remarkable sensory and motoric capacities of our integrated hearing systems which are obviously, based on observed consequences of McGurk effects (some of which were illustrated by Lawrence Rosenblum in the video hyperlinked to Figure 14 above), richly integrated with our visual and other sensory-motor systems, perhaps it should not surprise us that our sense of hearing itself, and our sense of vision also, become tuned up for articulatory movements that are characteristic of our primary language. That sort of tuning, naturally associated with primary language acquisition, can also accommodate one or more secondary language systems provided sufficient exposure and attention to the secondary system(s) may take place. What we learn from the cross-modal McGurk-type transfer effects, ones plainly linking motor systems with sensory ones and showing the differential ranking of signaling systems — with vision outranking hearing and motoric signals outranking sensory signals (J. W. Oller, 2018) — is that articulatory movements *must be modeled* in order to be acquired at all. Also when such modeling occurs and is attended to sufficiently over time to engender language acquisition, the normal integration of sensory-motor systems of production and perception are enhanced and increasingly fluent processing of speech in the acquired language(s) becomes possible.

Research with prenatal humans shows that the rhythms of modeled articulations are first noticed through the sense of touch and hearing in the womb (Spitzer, 2001). Later, at birth, the neonate will observe the speech of more mature individuals both by seeing and hearing. Typically, the synchronized movements of the baby's mother (usually as she talks (or possibly sings) to the baby with cadences and vocal articulations that are familiar to the child from prenatal experience will enable the mapping of mother's familiar voice to her until birth unfamiliar face (Sai, 2005). At birth, research shows that the baby tends also to "entrain" (synchronize) its own bodily movements with the rhythms of the mature speech of others who happen to use the baby's primary language(s) within its range of hearing (Chartrand & van Baaren, 2009; Condon & Sander, 1974; Dodd, 1979; Provasi et al., 2014). Within about six months, the baby will have not only

differentiate many words and phrases in the primary language(s) of the baby's primary language community (or communities), but will have mapped many of those distinct forms onto the entities, relations, and events which they are commonly used to signify or refer to (Bergelson & Aslin, 2017; Bergelson & Swingley, 2012, 2013b, 2013a). By about that same time the infant will begin what is known as canonical babbling where one or more familiar syllables such as [dadada], [mamama], [bababa] and the like are repetitively produced with a speech-like rhythm (Ejiri, 1998; C.-C. Lee, Jhang, Chen, Relyea, & Oller, 2017; Lohmander, Holm, Eriksson, & Lieberman, 2017; D. K. Oller, 1980; D. K. Oller et al., 2013).

A little later on, usually after about six months, the child at about the time of the first birthday will be able to control learned and practiced articulatory movements well enough to produce a "word" or "holophrastic" utterance at will on an appropriate occasion that more mature users of the baby's primary language will be able to recognize and understand. From there forward, the child's articulatory movements will, normally, become more sharply differentiated and better synchronized with the rhythms, intonations, and articulatory distinctions that are conventionally used by the child's primary language community. In some instances, the child with appropriate opportunities and exposures may acquire more than one "primary" language used by distinct communities (Byers-Heinlein, 2017; Farrell, 2011; Harley, Hart, & Lapkin, 2008; Kunnan, 1994; J. W. Oller, Chesarek, & Scott, 1991; Paradis, 2003).

Along the way, as the child is acquiring fluency in the articulation of one or more linguistic systems, the research shows that the McGurk-type cross-modal connections are always at work. For instance, Aldridge et al. (1999, 2001) showed that even neonates already know that in order to produce an [u] sound, the lips of the speaker must be rounded whereas an [i] sound requires flattened lips. The surprising thing, however, is that neonates evidently also have cross-modal knowledge about sounds they have never heard. For instance, newborns who have been exposed only to English know that the French rounded front vowel [y] sound can only be produced with rounded lips and that the peculiar and rare high back unrounded vowel of Mandarin [u] requires unrounded lips. But much more has been discovered about cross-modal transfer and the integration of the sensory and motor systems.

Not only do infants have advance expectations informing them that the sound [I], for example, requires a relatively closed jaw position and flat lips and that an [a] sound requires a more open mouth and lower position of the mandible, they also learn very soon after birth that females generally have higher fundamental frequencies (a higher pitched voice) than males (Bristow et al., 2009). Not only are very young infants puzzled (as indicated by sucking behaviors, heart rate changes, and the like) by mismatches of, say, a visible facial posture for [i] linked to an audible [a] sound, they are also perplexed by a mismatched audible male voice associated with a synchronized visible female speaker and vice versa. More importantly still, MRI scans of the brains of normal infants presented with the respective types of mismatched visual and auditory signals just described, also show increased activity in the dominant (left) hemisphere for the linguistic mismatches and increased activity in the subordinate (right) hemisphere for the mismatched gender of the visible speaker and the audible voice (Bristow et al., 2009). What these differences evidently show is that the division of labor that will later characterize the adult cerebrum according to the research of Roger Sperry (1964, 1976, 1979, 1981) is already in place in the infants studied by Bristow, et al. (2009).

### Can Visual Modeling Enable Detection of Flexing the Levator Veli Palatines?

Given the evidences reviewed above concerning cross-modal linkages and the integration of sensory and motor functions, it is a relatively straightforward inference to suppose that seeing, for example, the movement of the velum in response to the flexing or relaxing of the levator veli palatine muscles in the fluent articulation of non-nasal sounds which requires flexed levators pulling the velum upward into a right angle blocking the nasopharyngeal opening, versus the intermittent incorporation of a nasal consonant by relaxing the levators to open the nasopharyngeal passageway. If modeling assists language learners to gain more awareness and motor control of their articulators, will the visual modeling of actions of the levator veli palatine muscles, not help speech-language pathologists (and anyone who views the

rtMRI showing the actual movements of those muscles) to become able to perceive when they are themselves flexing or relaxing the levators? Normally, even expert phoneticians confess that they must hear the nasals to know when the levators are being relaxed and the need to hear non-nasal sounds to know when the levators are flexed. However, if modeling through rtMRI can raise awareness and create the capacity to feel the movements of the levators — movements which are usually undetectable by expert phoneticians — this change can help show in a subtle experiment how modeling works. It can help SLPs and language teachers, for instance, to see how and why modeling of articulatory movements in general is apt to help clients, students, and especially persons with so-called "articulation disorders" to improve both their ability to perceive their own articulatory movements and also to overcome symptoms described variously as "lisping", "nasopharyngeal insufficiency" (meaning inadequate closure of the nasopharyngeal passageway) resulting in "hypernasality", or inadequate opening of the nasopharyngeal passageway resulting in "hyponasality", reduction in vowel space, failure to adequately differentiate articulatory targets, omission of syllables or of one or both of their consonantal margins, perseveration resulting in rapid fire repetition of segments, syllables, or even whole words or phrases (known as "stuttering", "cluttering"), prolonged hesitations at syllable, word, phrase, and other boundaries, and so forth for the vast range of so-called "articulatory disorders".

As a final test of the explanation offered in this paper of how modeling of highly articulated movements actually works — ranging from the macro-level dance choreography undertaken by Victoria Arlen after her acute disseminated encephalomyopathy robbed her of all movements except the volitional eye-blink — the question is whether persons who view and contemplate the relaxation of the levators as seen in the rtMRI recording of the fluent speech examined in this paper, will be better able to actually detect the movements of their own levator veli palatines. Because the levators are gradually beginning to relax as the speaker of the rtMRI recording begins to anticipate a nasal to follow whatever vowel happens to be the nucleus of the syllable under construction (for instance, note the partly nasalized [I], or [j], preceding the [n] of "Science" and the [æ] of "Planck" preceding the [ŋk] marginal cluster closing that syllable, in Figure 12), we may suppose that the relaxation phase is going to remain difficult even for an expert speech-language pathologist or phonetician to perceive. However, because the transition from the nasal margins of a syllable to a non-nasalized vowel, requires the sudden flexing of the levator veli palatines, it should therefore be more easily perceived than the more gradual relaxation of them in anticipation of a nasal margin to follow.

The author has tested this theory with a audiences up to 40 persons and the result is that over half of them report that they can actually feel the flexing of their levator veli palatines after seeing the visual action in the rtMRI images. This is remarkable because for many listeners, the levators are muscles they did not know they had before viewing and discussing the rtMRI recording of the "Welcome Message" examined in this paper. The greatest level of success at detecting the actions of the levators is at the transition between, for example, the initial nasal and the following vowel in the syllables, [ma], [na], and [ŋa] spoken very deliberately at about one-third speed. Readers can test the theory for themselves. The question is, can the reader perceive the flexing of the levators when hitting the transition points just described for the syllables [ma], [na], and [ŋa]? If so, the test provides empirical evidence that a visual presentation through an rtMRI recording of articulatory movements — specifically pointing out the results of flexing and relaxing the levator veli palatines, movements that cannot normally be perceived in fluent speech, either by the speaker or the listener, nor even by expert speech-language pathologists and phoneticians — can be brought to consciousness and can become, for many people, detectable by tactile motoric (kinesthetic) feedback.

### Conclusions

With all the foregoing in mind, we may tentatively conclude that modeling of rapid sequences of movements in speech, or even in complex dance choreography, seems to be essential to learners and thus to consumers and producers of those same, or very similar, sequences of fluent movements. We may also infer that the ability to sense the articulatory movements of other persons — their rhythms, intonations, synchronies between articulatory movements with facial expressions, gestures, and bodily posture changes, and possibly also with music produced on one or more instruments possibly also with song lyrics, and so forth — depends on modeling. All that being said, it

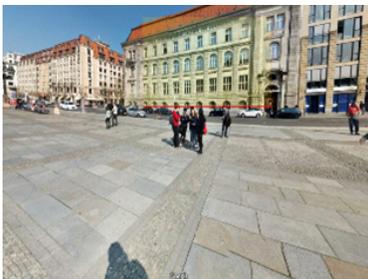
is hoped that this paper and the information that it contains, helps to explain how the modeling of the articulatory movements in speech works in language acquisition, perception, and therapies. It may also help to explain why articulatory modeling is important to learners, parents, teachers, and therapists working with persons who seek to sharpen and further develop or to recover articulatory capacities.



**Figure 1.** A still picture from the beginning of the “Welcome Message” recorded in rtMRI at 55fps at the Max Planck Institute of Biophysical Chemistry in Göttingen, Germany, by Jens Frahm and Aren Joseph. To hear the original recording click this link with machine noise included, or to hear the version with the machine noise mostly filtered out click this link.



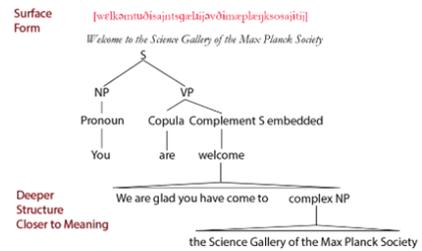
**Figure 2.** A cauliflower where the smallest parts, no matter where we cut into it, seem to contain the same patterns seen in the larger whole, only in smaller proportions.



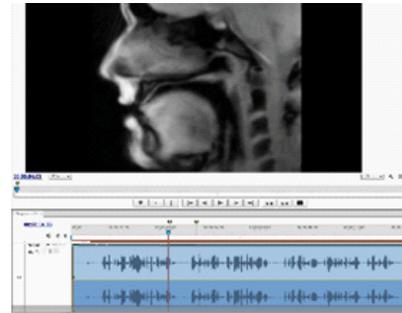
**Figure 3.** A Google maps shot of the building, highlighted in the red-outlined rectangle, where the Science Gallery of the Max Planck Society is located in the Gendarmenmarkt plaza in Berlin. Click this link to see a bit of what’s inside.



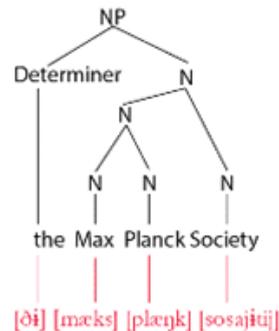
**Figure 4.** Click this link to see an imagined summary of what takes place in the mind of the producer of the “Welcome Message” in articulating it.



**Figure 5.** Contrasting the surface form of the “Welcome Message” with its deeper meaning.

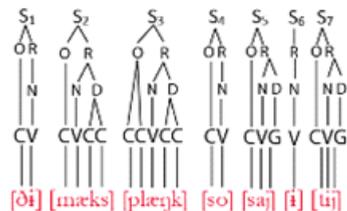


**Figure 6.** A videographic analysis (just click the link) showing that articulators move even in the “silent” parts (see the flat lines in the left and right stereo recording shown at the bottom of this figure in blue).

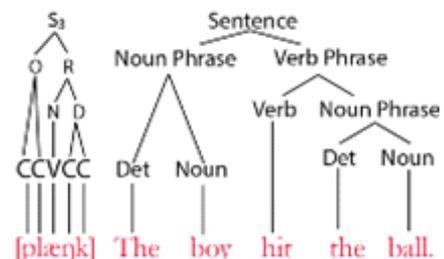


**Figure 7.** Segments and syllables in the NP, *the Max Planck Society*.

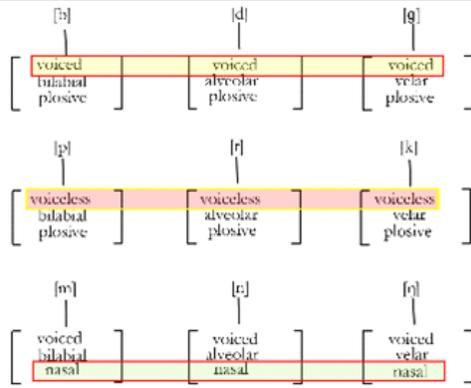
Let S stand for Syllable, O for Onset, R for Rhyme, N for Nucleus, and D for Coda (or Offset); V for Vowel, C for Consonant, and G for Glide.



**Figure 8.** Seven distinct syllables of the phrase, *the Max Planck Society*.

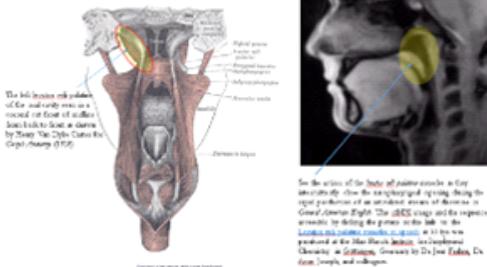


**Figure 9.** Compare the tactical structure of the syllable *Planck* with the tree structure of the transitive sentence *The boy hit the ball*.

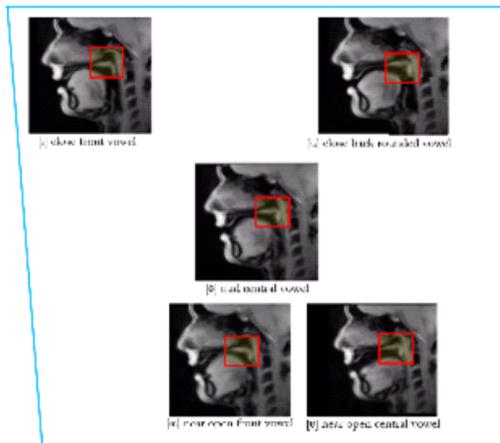


**Figure 10.** An analysis of phonetic features associated with certain segments of speech forms.

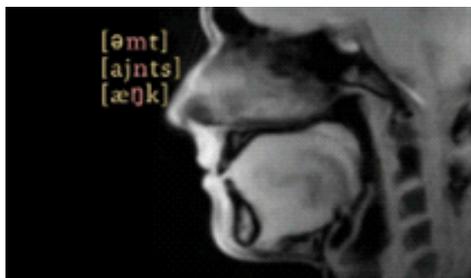
**But nasality requires just one pair of muscles**



**Figure 11.** The *levator veli palatinae* highlighted in the drawing at the left from Henry Vandyke Carter and the relaxed soft palate, or *velum*, highlighted in the yellow oval at the right from a still taken from the rtMRI sequence.



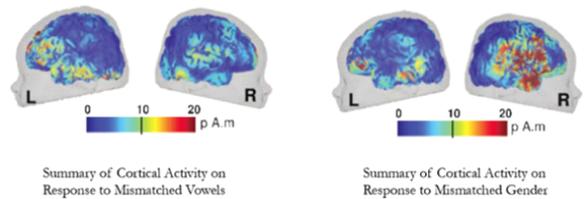
**Figure 12.** Result of flexing the *levator veli palatinae* muscles in order to close the *nasopharyngeal* passageway and thus to turn off *nasality*.



**Figure 13.** A videographic analysis of nasals in the rtMRI recording (just click the link) of the flexing or relaxing of the *levator veli palatinae* in the turning off or on, respectively, of the *nasality* feature associated with English nasals [m], [n], and [ŋ] in fluent speech.



**Figure 14.** Lawrence D. Rosenblum, Professor of Psychology at the University of California, Riverside, demonstrates certain “McGurk effects” in the initial consonant on a single syllable (click the link to see and hear the demonstration). This image was created at <http://www.faculty.ucr.edu/~rosenblu/lab-index.html> (visited September 19, 2016).



**Figure 15.** Findings from (Bristow et al., 2009, p. 913, Figure 4) showing greater involvement of the left (dominant) hemisphere of the cerebrum in responding to mismatched vowels versus the greater involvement of the right (subordinate) hemisphere in responding to mismatched gender.

1. “Nuanced Dynamics of Articulation Seen in ‘Real Time Magnetic Resonance Images’ Shot at 55 FPS”, presented at the American Speech-Language Hearing Association Annual Meeting at the Los Angeles Convention Center on November 9, 2017.
2. The author relied on Google Translator at <https://translate.google.com/> for the Chinese, Greek, and Kurdish and cannot fully vouch for the adequacy of those translations. But that is beside the point because fully adequate translations could easily be obtained from competent persons who know English and the other language at issue.

**References**

1. Agmon-Levin, N., Hughes, G. R. V., & Shoenfeld, Y. (2012). The spectrum of ASIA: “Autoimmune (Auto-inflammatory) Syndrome Induced by Adjuvants.” *Lupus*, 21(2), 118–120. <https://doi.org/10.1177/0961203311429316>
2. Aldridge, M. A., Braga, E. S., Walton, G. E., & Bower, T. G. R. (1999). The intermodal representation of speech in newborns. *Developmental Science*, 2(1), 42–46. <https://doi.org/10.1111/1467-7687.00052>
3. Aldridge, M. A., Stillman, R. D., & Bower, T. G. R. (2001). Newborn categorization of vowel-like sounds. *Developmental Science*, 4(2), 220–232. <https://doi.org/10.1111/1467-7687.00167>
4. *Annalen der Physik*. (2017, September 13). In Wikipedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Annalen\\_der\\_Physik&oldid=800419881](https://en.wikipedia.org/w/index.php?title=Annalen_der_Physik&oldid=800419881)
5. *Annus Mirabilis papers*. (2017, November 30). In Wikipedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Annus\\_Mirabilis\\_papers&oldid=812849276](https://en.wikipedia.org/w/index.php?title=Annus_Mirabilis_papers&oldid=812849276)
6. Attar, A. M., Kharkhaneh, A., Etemadifar, M., Keyhanian, K., Davoudi, V., & Saadatnia, M. (2012). Serum mercury level and multiple sclerosis. *Biological Trace Element Research*, 146(2), 150–153. <https://doi.org/10.1007/s12011-011-9239-y>
7. Baba, Y., Tsuboi, Y., Inoue, H., Yamada, T., Wszolek, Z. K., & Broderick, D. F. (2006). Acute measles encephalitis in adults. *Journal of Neurology*, 253(1), 121–124. <https://doi.org/10.1007/s00415-005-0923-8>
8. Bachman, L. F. (1982). The trait structure of cloze test scores. *TESOL Quarterly*, 16(1), 61. <https://doi.org/10.2307/3586563>
9. Bachman, L. F. (1985). Performance on cloze tests with fixed-ratio and rational deletions. *TESOL Quarterly*, 19(3), 535. <https://doi.org/10.2307/3586277>
10. Barilaro, G., Testa, C. S., Cacciani, A., Donato, G., Dimko, M., & Mariotti, A. (2016). ASIA syndrome, calcinosis cutis and chronic kidney disease following silicone injections. A case-based review. *Immunologic Research*, 64(5–6), 1142–1149. <https://doi.org/10.1007/s12026-016-8871-1>
11. Bergelson, E., & Aslin, R. N. (2017). Nature and origins of the lexicon in 6-mo-olds. *Proceedings of the National Academy of Sciences of the United States of America*, 114(49), 12916–12921. <https://doi.org/10.1073/pnas.1712966114>
12. Bergelson, E., & Swingle, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences*, 109(9), 3253–3258. <https://doi.org/10.1073/pnas.1113380109>
13. Bergelson, E., & Swingle, D. (2013a). The acquisition of abstract words by young infants. *Cognition*, 127(3), 391–397. <https://doi.org/10.1016/j.cognition.2013.02.011>
14. Bergelson, E., & Swingle, D. (2013b). Young toddlers’ word comprehension is flexible and efficient. *PLoS ONE*, 8(8), e73359. <https://doi.org/10.1371/journal.pone.0073359>
15. Bloomfield, L. (1933). *Language* (Reprint edition). Chicago: University of Chicago

- Press.
16. Bloomfield, L., Barnhart, C. L., Pooley, R. C., & Faust, G. P. (1961). *Let's Read: A Linguistic Approach*. Detroit, Mich: Wayne State University Press.
  17. Bristow, D., Dehaene-Lambertz, G., Mattout, J., Soares, C., Gliga, T., Baillet, S., & Mangin, J.-F. (2009). Hearing faces: how the infant brain matches the face it sees with the speech it hears. *Journal of Cognitive Neuroscience*, 21(5), 905–921. <https://doi.org/10.1162/jocn.2009.21076>
  18. Buchanan, R., & Bonthuis, D. J. (2012). Measles virus and associated central nervous system sequelae. *Seminars in Pediatric Neurology*, 19(3), 107–114. <https://doi.org/10.1016/j.spen.2012.02.003>
  19. Byers-Heinlein, K. (2017). Bilingualism affects 9-month-old infants' expectations about how words refer to kinds. *Developmental Science*, 20(1), e12486. <https://doi.org/10.1111/desc.12486>
  20. Campbell, T. F., & Yunusova, Y. (2017). Cutting-edge technology for speech rehabilitation. *Journal of Speech Language and Hearing Research*, 60(6S), 1798. [https://doi.org/10.1044/2017\\_JSLHR-S-17-0073](https://doi.org/10.1044/2017_JSLHR-S-17-0073)
  21. Carson, B. (2008). *Take the Risk: Learning to Identify, Choose, and Live with Acceptable Risk*. Grand Rapids, MI: Zondervan.
  22. Caza, G. A., & Knott, A. (2012). Pragmatic bootstrapping: a neural network model of vocabulary acquisition. *Language Learning and Development*, 8(2), 113–135. <https://doi.org/10.1080/15475441.2011.581144>
  23. Charles Sanders Peirce. (2016, September 24). In Wikipedia, the free encyclopedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Charles\\_Sanders\\_Peirce&oldid=740914766](https://en.wikipedia.org/w/index.php?title=Charles_Sanders_Peirce&oldid=740914766)
  24. Chartrand, T. L., & van Baaren, R. (2009). Human mimicry. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology*, Vol 41 (Vol. 41, pp. 219–274). San Diego: Elsevier Academic Press Inc.
  25. Chomsky, N. A. (1957). *Syntactic Structures*. The Hague: Mouton. Retrieved from [https://www.amazon.com/Syntactic-Structures-Noam-Chomsky/dp/1614278040/ref=sr\\_1\\_1?ie=UTF8&qid=1478110531&sr=8-1&keywords=chomsky+1957](https://www.amazon.com/Syntactic-Structures-Noam-Chomsky/dp/1614278040/ref=sr_1_1?ie=UTF8&qid=1478110531&sr=8-1&keywords=chomsky+1957)
  26. Chomsky, N. A. (1959). A review of B. F. Skinner's *Verbal Behavior*. *Language*, 35(1), 26–58.
  27. Chomsky, N. A. (1965). *Aspects of the Theory of Syntax*. Cambridge, MA: MIT Press. Retrieved from [https://www.amazon.com/Syntactic-Structures-Noam-Chomsky/dp/1614278040/ref=sr\\_1\\_1?ie=UTF8&qid=1478110531&sr=8-1&keywords=chomsky+1957](https://www.amazon.com/Syntactic-Structures-Noam-Chomsky/dp/1614278040/ref=sr_1_1?ie=UTF8&qid=1478110531&sr=8-1&keywords=chomsky+1957)
  28. Chomsky, N. A. (1968). Linguistic contributions to the study of mind (future). In *Language and Mind*. Harcourt Brace Jovanovich, Inc. Retrieved from <https://www.marxists.org/reference/subject/philosophy/works/us/chomsky.htm>
  29. Chomsky, N. A. (1975). *Reflections on Language*. New York: Pantheon.
  30. Chomsky, N. A. (2006). *Language and Mind* (3 edition). Cambridge ; New York: Cambridge University Press.
  31. Chomsky, N. A. (2007). *Of minds and language*. *Biolinguistics*, 1, 9–27.
  32. Chomsky, N. A., & Halle, M. (1968). *The Sound Pattern of English*. Cambridge, Mass.: The MIT Press.
  33. Chomsky, N. A., Ronat, M., & Viertel, J. (1979). *Language and Responsibility: Based on Conversations with Mitsou Ronat*.
  34. Condon, W. S., & Sander, L. W. (1974). Synchrony demonstrated between movements of neonate and adult speech. *Child Development*, 45(2), 456–462. <https://doi.org/10.2307/1127968>
  35. Cziko, G. (1984). Some problems with empirically-based models of communicative competence. *Applied Linguistics*, 5(1), 23–38. <https://doi.org/10.1093/applin/5.1.23>
  36. Cziko, G. A. (1981). Psychometric and edumetric approaches to language testing: implications and applications. *Applied Linguistics*, 2(1), 27–44. <https://doi.org/10.1093/applin/2.1.27>
  37. Dallos, P., Santos-Sacchi, J., & Flock, A. (1982). Intracellular-recordings from cochlear outer hair-cells. *Science*, 218(4572), 582–584. <https://doi.org/10.1126/science.7123260>
  38. Davis, B. L., & MacNeilage, F. F. (1995). The articulatory basis of babbling. *Journal of Speech and Hearing Research*, 38(6), 1199–1211.
  39. Deussing, L. (2008). *Unlocked: A review of "The Diving Bell and the Butterfly."* The ASHA Leader, 13, 18. <https://doi.org/10.1044/leader.FTR3.13062008.18>
  40. Di Ieva, A., Grizzi, F., Jelinek, H., Pellionisz, A. J., & Losa, G. A. (2014). Fractals in the neurosciences, part I: General principles and basic neurosciences. *Neuroscientist*, 20(4), 403–417. <https://doi.org/10.1177/1073858413513927>
  41. Diaz-Galaz, S., Padilla, P., & Bajio, M. T. (2015). The role of advance preparation in simultaneous interpreting: A comparison of professional interpreters and interpreting students. *Interpreting*, 17(1), 1–25. <https://doi.org/10.1075/intp.17.1.01dia>
  42. Dodd, B. (1979). Lip reading in infants: Attention to speech presented in- and out-of-synchrony. *Cognitive Psychology*, 11(4), 478–484. [https://doi.org/10.1016/0010-0285\(79\)90021-5](https://doi.org/10.1016/0010-0285(79)90021-5)
  43. Dórea, J. (2015). Exposure to mercury and aluminum in early life: developmental vulnerability as a modifying factor in neurologic and immunologic effects. *International Journal of Environmental Research and Public Health*, 12(2), 1295–1313. <https://doi.org/10.3390/ijerph120201295>
  44. Ejiri, K. (1998). Relationship between rhythmic behavior and canonical babbling in infant vocal development. *Phonetica*, 55(4), 226–237. <https://doi.org/10.1159/00028434>
  45. Esposito, S., Prada, E., Mastrolia, M. V., Tarantino, G., Codecà, C., & Rigante, D. (2014). Autoimmune/inflammatory syndrome induced by adjuvants (ASIA): clues and pitfalls in the pediatric background. *Immunologic Research*, 60(2–3), 366–375. <https://doi.org/10.1007/s12026-014-8586-0>
  46. Farrell, M. P. (2011). Bilingual competence and students' achievement in Physics and Mathematics. *International Journal of Bilingual Education and Bilingualism*, 14(3), 335–345. <https://doi.org/10.1080/13670050.2010.516817>
  47. Ferguson, B., & Waxman, S. R. (2016). *Who has the [bee]?* Six-month-olds link novel communicative signals to meaning. *Cognition*, 146, 185–189. <https://doi.org/10.1016/j.cognition.2015.09.020>
  48. Fisher, D. L., Defres, S., & Solomon, T. (2015). Measles-induced encephalitis. *QJM*, 108(3), 177–182. <https://doi.org/10.1093/qjmed/hcu113>
  49. Fox-Boyer, A., Salgert, K., & Clausen, M. (2016). Assessment of childhood speech sound disorders of unclear origin [Diagnostik von kindlichen Aussprachestörungen unklarer Genese]. *Sprache • Stimme • Gehör*, 40(02), 61–67. <https://doi.org/10.1055/s-0042-100715>
  50. Galantucci, B., Fowler, C. A., & Turvey, M. T. (2006). The motor theory of speech perception reviewed. *Psychonomic Bulletin & Review*, 13(3), 361–377. <https://doi.org/10.3758/BF03193857>
  51. Giacompo, S., Galuppo, M., Calabrò, R. S., D'Alco, G., Marra, A., Sessa, E., ... Mazzon, E. (2014). Heavy metals and neurodegenerative diseases: an observational study. *Biological Trace Element Research*, 161(2), 151–160. <https://doi.org/10.1007/s12011-014-0094-5>
  52. Gray, H. (1918). *Anatomy of the Human Body*. (W. H. Lewis, Ed.) (20th ed.). New York and Philadelphia: Lea and Febiger. Retrieved from <http://www.bartleby.com/107/>
  53. Green, J. R., Moore, C. A., Ruark, J. L., Rodda, P. R., Morvée, W. T., & VanWitzenburg, M. J. (1997). Development of chewing in children from 12 to 48 months: longitudinal study of EMG patterns. *Journal of Neurophysiology*, 77(5), 2704–2716.
  54. Haan, J. (2013). Locked-in. In *Progress in Brain Research* (Vol. 206, pp. 19–34). Elsevier. Retrieved from <http://linkinghub.elsevier.com/retrieve/pii/B9780444633644000181>
  55. Haley, B. E. (2005). Mercury toxicity: Genetic susceptibility and synergistic effects. *Medical Veritas*, 2, 535–542. <https://doi.org/10.1588/medver.2005.02.0006>
  56. Har-Even, R., Aichenbaum, S., Rabej, J. M., Livne, A., & Bistrizer, T. (2011). Measles-Vaccinated Israeli Boy With Subacute Sclerosing Panencephalitis. *Pediatric Neurology*, 44(6), 467–470. <https://doi.org/10.1016/j.pediatrneurol.2011.01.011>
  57. Harley, B., Hart, D., & Lapkin, S. (2008). The effects of early bilingual schooling on first language skills. *Applied Psycholinguistics*, 7(04), 295. <https://doi.org/10.1017/S0142716400007700>
  58. Harris, Z. S. (1969). *Structural Linguistics* (Eighth Impression edition). Chicago: Chicago: Phoenix, 1969.
  59. History of special relativity. (2017, November 15). In Wikipedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=History\\_of\\_special\\_relativity&oldid=810394886](https://en.wikipedia.org/w/index.php?title=History_of_special_relativity&oldid=810394886)
  60. Hybenova, M., Hrda, P., Prochazkova, J., Stejskal, V., & Sterzl, I. (2010). The role of environmental factors in autoimmune thyroiditis. *Neuroendocrinology Letters*, 31(3), 283–289.
  61. InternationalPhoneticAlphabet.org. (2016). IPA Chart with Sounds. Retrieved December 6, 2017, from <http://www.internationalphoneticalphabet.org/ipa-sounds/ipa-chart-with-sounds/>
  62. Jean-François Champollion. (2017, May 5). In Wikipedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Jean-Fran%CC%80ois\\_Champollion&oldid=778883038](https://en.wikipedia.org/w/index.php?title=Jean-Fran%CC%80ois_Champollion&oldid=778883038)
  63. Jonz, J. (1987). Textual cohesion and second-language comprehension. *Language Learning*, 37(3), 409–438. <https://doi.org/10.1111/j.1467-1770.1987.tb00578.x>
  64. Jonz, J. (1989). Textual sequence and second-language comprehension. *Language Learning*, 39(2), 207–249. <https://doi.org/10.1111/j.1467-1770.1989.tb00422.x>
  65. Jonz, J. (1990). Another turn in the conversation: what does cloze measure? *TESOL Quarterly*, 24(1), 61. <https://doi.org/10.2307/3586852>
  66. Kaye, K. L., & Bower, T. G. R. (1994). Learning and intermodal transfer of information in newborns. *Psychological Science*, 5(5), 286–288. <https://doi.org/10.1111/j.1467-9280.1994.tb00627.x>
  67. Kennedy, D., Senef, S., Davidson, R. M., Oller, J. W., Haley, B. E., & Masters, R. D. (2016). Environmental toxicants and infant mortality in America. *Peertechz Journal of Biological Research and Development*, 1(1), 36–61.
  68. Kunnan, A. J. (1994). Review of Language and Bilingualism: More Tests by John W. Oller, Jr, Steve Chesarek, and Robert Scott. *Language*, 70(1), 216–216. <https://doi.org/10.2307/416781>
  69. Laureys, S., Pellas, F., Van Eeckhout, P., Ghorbel, S., Schnakers, C., Perrin, F., ... Goldman, S. (2005). The locked-in syndrome: what is it like to be conscious but paralyzed and voiceless? In S. Laureys (Ed.), *Boundaries of Consciousness: Neurobiology and Neuropathology* (Vol. 150, pp. 495–511). Amsterdam: Elsevier Science Bv.
  70. Lee, A. S.-Y., & Gibbon, F. E. (2015). Non-speech oral motor treatment for children with developmental speech sound disorders. In *The Cochrane Collaboration* (Ed.), *Cochrane Database of Systematic Reviews*. Chichester, UK: John Wiley & Sons, Ltd. <https://doi.org/10.1002/14651858.CD009383.pub2>
  71. Lee, C.-C., Jhang, Y., Chen, L., Relyea, G., & Oller, D. K. (2017). Subtlety of ambient-language effects in babbling: a study of English- and Chinese-learning infants at 8, 10, and 12 months. *Language Learning and Development*, 13(1), 100–126. <https://doi.org/10.1080/15475441.2016.1180983>
  72. Leydesdorff, L., Johnson, M. W., & Ivanova, I. A. (2014). The communication of expectations and individual understanding: Redundancy as reduction of uncertainty, and the processing of meaning. *Kybernetes*, 43(9/10), 1362–1371. <https://doi.org/10.1108/K-07-2014-0151>
  73. Liberman, A. M., Cooper, F. S., Shankweiler, D. P., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Review*, 74(6), 431–461. <https://doi.org/10.1037/h0020279>
  74. Liberman, A. M., & Mattingly, I. G. (1985). The motor theory of speech perception reviewed. *Cognition*, 21(1), 1–36. [https://doi.org/10.1016/0010-0277\(85\)90021-6](https://doi.org/10.1016/0010-0277(85)90021-6)
  75. Lohmander, A., Holm, K., Eriksson, S., & Lieberman, M. (2017). Observation method identifies that a lack of canonical babbling can indicate future speech and language problems. *Acta Paediatrica*, 106(6), 935–943. <https://doi.org/10.1111/apa.13816>
  76. Ludlow, M., McQuaid, S., Milner, D., de Swart, R. L., & Duprex, W. P. (2015). Pathological consequences of systemic measles virus infection: Measles virus pathology. *The Journal of Pathology*, 235(2), 253–265. <https://doi.org/10.1002/path.4457>
  77. Luñán, L., Pérez, M., Salazar, E., Álvarez, N., Gimeno, M., Pinczowski, P., ... Chapullé, J. L. G. (2013). Autoimmune/autoinflammatory syndrome induced by adjuvants (ASIA syndrome) in commercial sheep. *Immunologic Research*, 56(2–3), 317–324. <https://doi.org/10.1007/s12026-013-8404-0>
  78. Max Planck. (2017, May 17). In Wikipedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Max\\_Planck&oldid=780895662](https://en.wikipedia.org/w/index.php?title=Max_Planck&oldid=780895662)
  79. Max Planck Society. (2016, September 2). In Wikipedia, the free encyclopedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Max\\_Planck\\_Society&oldid=737408740](https://en.wikipedia.org/w/index.php?title=Max_Planck_Society&oldid=737408740)
  80. Max Planck Society. (2017). Max Planck Science Gallery | Berlin | WhereTraveler. Retrieved September 30, 2016, from <http://www.wheretraveler.com/berlin/max-planck-science-gallery>
  81. McGurk, H., & Macdonald, J. (1976). Hearing lips and seeing voices. *Nature*, 264(5588), 746–748. <https://doi.org/10.1038/264746a0>
  82. Moore, C. A., & Ruark, J. L. (1996). Does speech emerge from earlier appearing oral motor behaviors? *Journal of Speech and Hearing Research*, 39(5), 1034–1047.
  83. Motor theory of speech perception. (2016, June 20). In Wikipedia, the free encyclopedia. Retrieved from [https://en.wikipedia.org/w/index.php?title=Motor\\_theory\\_of\\_speech\\_perception&oldid=726208302](https://en.wikipedia.org/w/index.php?title=Motor_theory_of_speech_perception&oldid=726208302)
  84. Mutter, J., Naumann, J., Schneider, R., Walach, H., & Haley, B. (2005). Mercury and autism: accelerating evidence? *Neuro Endocrinology Letters*, 26(5), 439–446.
  85. Nardone, R., Golaszewski, S., Trinka, E., Tezzon, F., & Zuccoli, G. (2011). Acute disseminated encephalomyelitis preceding measles exanthema. *Journal of Child Neurology*, 26(12), 1590–1592. <https://doi.org/10.1177/0883073811413130>
  86. Nazzi, T., Bertoni, J., & Mehler, J. (1998). Language discrimination by newborns: Toward an understanding of the role of rhythm. *Journal of Experimental Psychology: Human Perception and Performance*, 24(3), 756–766. <https://doi.org/10.1037/0096-1523.24.3.756>
  87. Nirenberg, M., Leder, P., Bernfield, M., Brimacombe, R., Trupin, J., Rottman, F., & O'Neal, C. (1965). RNA codewords and protein synthesis. VII. On the general nature of the RNA code. *Proceedings of the National Academy of Sciences of the United States of*

- America, 53(5), 1161–1168.
88. Nirenberg, M. W. (2004). Historical review: Deciphering the genetic code – a personal account. *Trends in Biochemical Sciences*, 29(1), 46–54. <https://doi.org/10.1016/j.tibs.2003.11.009>
  89. Nirenberg, M. W., & Matthaei, J. H. (1961). The dependence of cell-free protein synthesis in *E. coli* upon naturally occurring or synthetic polyribonucleotides. *Proceedings of the National Academy of Sciences of the United States of America*, 47(10), 1588–1602.
  90. Oller, D. K. (1980). The emergence of the sounds of speech in infancy. In G. H. Yeni-Komshian, J. F. Kavanagh, & C. A. Ferguson (Eds.), *Child phonology* (pp. 93–112). New York: Academic Press.
  91. Oller, D. K., Buder, E. H., Ramsdell, H. L., Warlaumont, A. S., Chorna, L., & Bakeman, R. (2013). Functional flexibility of infant vocalization and the emergence of language. *Proceedings of the National Academy of Sciences*, 110(16), 6318–6323. <https://doi.org/10.1073/pnas.1300337110>
  92. Oller, J. W. (1970). Transformational theory and pragmatics. *Modern Language Journal*, 54, 504–507.
  93. Oller, J. W. (1972). On the relation between syntax, semantics and pragmatics. *Linguistics: An International Review*, 83, 43–54.
  94. Oller, J. W. (1975). Pragmatic mappings. *Lingua*, 35(3–4), 333–344. [https://doi.org/10.1016/0024-3841\(75\)90063-7](https://doi.org/10.1016/0024-3841(75)90063-7)
  95. Oller, J. W. (2005). Common ground between form and content: the pragmatic solution to the bootstrapping problem. *The Modern Language Journal*, 89(1), 92–114. <https://doi.org/10.1111/j.0026-7902.2005.00267.x>
  96. Oller, J. W. (2010). The antithesis of entropy: biosemiotic communication from genetics to human language with special emphasis on the immune systems. *Entropy*, 12(4), 631–705. <https://doi.org/10.3390/e12040631>
  97. Oller, J. W. (2013). Pragmatic information. In *Biological Information* (pp. 64–86). World Scientific. Retrieved from [http://www.worldscientific.com/doi/abs/10.1142/9789814508728\\_0003](http://www.worldscientific.com/doi/abs/10.1142/9789814508728_0003)
  98. Oller, J. W. (2014a). Biosemiotic entropy: Concluding the series. *Entropy*, 16(7), 4060–4087. <https://doi.org/10.3390/e16074060>
  99. Oller, J. W. (2014b). Milestones in language development. In P. J. Brooks & V. Kempe (Eds.), *Encyclopedia of Language Development* (pp. 377–382). Thousand Oaks, CA: Sage Publications, Inc. Retrieved from <http://www.sagepub.com/refbooks/Book239623>
  100. Oller, J. W. (2018). *Human Anatomy and Physiology for Speech-Language Pathologists and Audiologists* (1st ed.). Austin, Texas: Sentia.
  101. Oller, J. W., Chesarek, S., & Scott, R. (1991). *Language and Bilingualism: More Tests of Tests*. Lewisburg: Bucknell University Press; Associated University Presses.
  102. Oller, J. W., Sales, B. D., & Harrington, R. V. (1969). A basic circularity in traditional and current linguistic theory. *Lingua*, 22, 317–328. [https://doi.org/10.1016/0024-3841\(69\)90076-X](https://doi.org/10.1016/0024-3841(69)90076-X)
  103. Oller, S. D. (2005). Meaning matters: A clinician's/student's guide to general sign theory and its applicability in clinical settings. *Journal of Communication Disorders*, 38(5), 359–373. <https://doi.org/10.1016/j.jcomdis.2005.03.002>
  104. Paradis, J. (2003). French-English bilingual children with SLI: How do they compare with their monolingual peers? *Journal of Speech, Language, and Hearing Research*, 46(1), 113–127. [https://doi.org/10.1044/1092-4388\(2003\)009](https://doi.org/10.1044/1092-4388(2003)009)
  105. Paul, L. M., Simons, G. F., & Fennig, C. D. (Eds.). (2016). *Ethnologue: Languages of the World* (19th ed.). Dallas TX: SIL International. Retrieved from <http://www.ethnologue.com>
  106. Peirce, C. S. (1877). The fixation of belief. In J. W. Oller (Ed.), *Language and Experience: Classic Pragmatism* (pp. 217–222). University Press of America.
  107. Peirce, C. S. (1878). The pragmatic maxim. In J. W. Oller (Ed.), *Language and Experience: Classic Pragmatism* (pp. 99–106). University Press of America.
  108. Peirce, C. S. (1897). The logic of relatives. *The Monist*. Retrieved from <http://archive.org/details/jstor-27897407>
  109. Peirce, C. S. (1982). The logic notebook. In M. Fisch, C. J. W. Kloesel, E. C. Moore, D. D. Roberts, L. A. Ziegler, & N. P. Atkinson (Eds.), *Writings of Charles S. Peirce: A Chronological Edition* (Vol. 1). Indianapolis, Indiana: Indiana University Press.
  110. Pellionisz, A. J. (2012). The decade of fractogens: from discovery to utility - proofs of concept open genome-based clinical applications. *International Journal of Systemics, Cybernetics and Informatics*, 17–28.
  111. Perricone, C., Colafrancesco, S., Mazor, R. D., Soriano, A., Agmon-Levin, N., & Shoenfeld, Y. (2013). Autoimmune/inflammatory syndrome induced by adjuvants (ASIA) 2013: Unveiling the pathogenic, clinical and diagnostic aspects. *Journal of Autoimmunity*, 47, 1–16. <https://doi.org/10.1016/j.jaut.2013.10.004>
  112. Phenylalanine. (2017, May 9). In Wikipedia. Retrieved from <https://en.wikipedia.org/w/index.php?title=Phenylalanine&oldid=779490766>
  113. Pinker, S., & Morey, A. (2014). *The Language Instinct: How the Mind Creates Language* (Unabridged edition). Brilliance Audio.
  114. Provasi, J., Anderson, D. I., & Barbu-Roth, M. (2014). Rhythm perception, production, and synchronization during the perinatal period. *Frontiers in Psychology*, 5. <https://doi.org/10.3389/fpsyg.2014.01048>
  115. Raoul, V., Canam, C., Onyeoziri, G., Overboe, J., & Paterson, C. (2001). Narrating the unspeakable: Interdisciplinary readings of Jean-Dominique Bauby's *The "Diving-Bell and the Butterfly"*. *Literature and Medicine*, 20(2), 183–208. <https://doi.org/10.1353/lm.2001.0023>
  116. Redondo-Dominguez, I. (2009). *El Signo Como Medio: Claves del Pensamiento de C. S. Peirce para una Teoría Constitutiva de la Comunicación*. Navarra, Pamplona, Spain.
  117. Redondo-Dominguez, I. (2017). An "onion without a peel:" transparency and embodiment in the light of Peirce's semiotic, 421.
  118. Reichling, A. (1961). Principles and methods of syntax: cryptanalytic formalism. *Lingua*, 10, 1–17.
  119. Ruark, J. L., & Moore, C. A. (1997). Coordination of lip muscle activity by 2-year-old children during speech and nonspeech tasks. *Journal of Speech, Language, and Hearing Research: JSLHR*, 40(6), 1373–1385.
  120. Sai, F. Z. (2005). The role of the mother's voice in developing mother's face preference: Evidence for intermodal perception at birth. *Infant and Child Development*, 14(1), 29–50. <https://doi.org/10.1002/icd.376>
  121. Santos-Sacchi, J. (2003). New tunes from Corti's organ: the outer hair cell boogie rules. *Current Opinion in Neurobiology*, 13(4), 459–468. [https://doi.org/10.1016/S0959-4388\(03\)00100-4](https://doi.org/10.1016/S0959-4388(03)00100-4)
  122. Saussure, F. de. (1959). *Course in General Linguistics* edited by Charles Bally and Albert Sechehaye translated from the French by Wade Baskin. (C. Bally & A. Sechehaye, Eds., W. Baskin, Trans.) (First Am edition edition). Philosophical Library.
  123. Seikel, J. A., Drumright, D. G., & King, D. W. (2016). *Anatomy & Physiology for Speech, Language, and Hearing* (5th ed.). Independence, KY: Cengage.
  124. Seki, F., Yamada, K., Nakatsu, Y., Okamura, K., Yanagi, Y., Nakayama, T., ... Takeda, M. (2011). The si strain of measles virus derived from a patient with subacute sclerosing panencephalitis possesses typical genome alterations and unique amino acid changes that modulate receptor specificity and reduce membrane fusion activity. *Journal of Virology*, 85(22), 11871–11882. <https://doi.org/10.1128/JVI.05067-11>
  125. Shaw, C. A. (in press). *Dynamics of Neurological Diseases*. Wiley-Blackwell.
  126. Shaw, C. A., Li, D., & Tomljenovic, L. (2014). Are there negative CNS impacts of aluminum adjuvants used in vaccines and immunotherapy? *Immunotherapy*, 6(10), 1055–1071. <https://doi.org/10.2217/imt.14.81>
  127. Shaw, C. A., Seneff, S., Kette, S. D., Tomljenovic, L., Oller, J. W., & Davidson, R. M. (2014). Aluminum-induced entropy in biological systems: implications for neurological disease. *Journal of Toxicology*, 2014, 491316. <https://doi.org/10.1155/2014/491316>
  128. Shoenfeld, Y., & Agmon-Levin, N. (2011). ASIA – "Autoimmune/Inflammatory Syndrome Induced by Adjuvants." *Journal of Autoimmunity*, 36(1), 4–8. <https://doi.org/10.1016/j.jaut.2010.07.003>
  129. Sigrist, R., Rauter, G., Riener, R., & Wolf, P. (2013). Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review. *Psychonomic Bulletin & Review*, 20(1), 21–53. <https://doi.org/10.3758/s13423-012-0333-8>
  130. Sips, G. J., Chesik, D., Glazenburg, L., Wilschut, J., De Keyser, J., & Wilczak, N. (2007). Involvement of morbilliviruses in the pathogenesis of demyelinating disease. *Reviews in Medical Virology*, 17(4), 223–244. <https://doi.org/10.1002/rmv.526>
  131. Sperry, R. W. (1964). The great cerebral commissure. *Scientific American*, 210(1), 42–52.
  132. Sperry, R. W. (1976). Changing concepts of consciousness and free will. *Perspectives in Biology and Medicine*, 20(1), 9–19.
  133. Sperry, R. W. (1979). Consciousness, freewill and personal identity. In D. A. Oakley & H. C. Plotkin (Eds.), *Brain, Behaviour and Evolution* (pp. 219–228). Methuen and Company.
  134. Sperry, R. W. (1981, December 8). Some effects of disconnecting the cerebral hemispheres. Retrieved July 9, 2015, from [http://www.nobelprize.org/nobel\\_prizes/medicine/laureates/1981/sperry-lecture\\_en.html](http://www.nobelprize.org/nobel_prizes/medicine/laureates/1981/sperry-lecture_en.html)
  135. Spitzer, M. (2001). Learning in the womb: Hearing, touching, smelling. *Nervenheilkunde*, 20(2), 123–124.
  136. Tarski, A. (1949). The semantic conception of truth. In H. Feigl & W. Sellars (Eds.), *Readings in Philosophical Analysis* (p. 341–374.). New York, NY: Appleton.
  137. Tarski, A. (1956). The concept of truth in formalized languages. In J. J. Woodger (Ed.), *Logic, Semantics, and Metamathematics* (pp. 152–278). Oxford, UK: Oxford University Press.
  138. Uhlenbeck, E. M. (1967). Some further remarks on transformational grammar. *Lingua*, 17, 263–316.
  139. Victoria Arlen | Dancing with the Stars. (2017). Retrieved December 6, 2017, from <https://abc.go.com/shows/dancing-with-the-stars/cast/victoria-arlen>
  140. Walton, G. E., & Bower, T. G. R. (1993). Amodal representation of speech in infants. 16, 233–243. *Infant Behavior and Development*, 16, 233–243.