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FREQUENCY EFFECTS WITHIN A COMPLEX ADAPTIVE SYSTEM APPROACH TO PHONOLOGY

EFEITOS DE FREQUÊNCIA EM FONOLOGIA NA PERSPECTIVA DE SISTEMAS ADAPTATIVOS COMPLEXOS

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ABSTRACT: Este artigo apresenta uma abordagem de Sistemas Adaptativos Complexos para a fonologia com foco em feitos de frequência. É apresentada a proposta de Modelo de Exemplares que é compatível com a abordagem dos Sistemas Adaptativos Complexos e permite incorporar informações detalhadas às representações fonológicas as quais incluem efeitos de frequência lexical. É sugerido que efeitos de frequência oferecem evidências importantes sobre o desenvolvimento dos sistemas fonológicos. Desafios impostos para trabalhos futuros são discutidos.
KEYWORDS: Sistemas Adaptativos Complexos; Teoria de Exemplares; Frequência Lexical; Desenvolvimento.

RESUMO: This paper presents a Complex Adaptive System approach to phonology with a focus on frequency effects. An Exemplar Model that is compatible with a Complex Adaptive System approach, and which incorporates detailed information on phonological representations, including frequency effects, is presented. It is suggested that frequency effects may provide important evidence for the development of sound changes. Challenges for future research are also discussed.
PALAVRAS-CHAVE: Complex Adaptive Systems; Exemplar Theory; Lexical Frequency; Development.

INTRODUCTION

This paper presents a Complex Adaptive System (henceforth CAS) approach to phonology with focus on frequency effects (Bybee 2010; Ellis 2011; Oliveira 2014; Cristófaro Silva & Leite 2015; Cristófaro Silva 2016). Phonological processes, as

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traditionally described, state generalizations but do not explain their primary source, which raises the following question: WHY do synchronic phonological generalizations emerge and HOW do they develop? It is suggested that an Exemplar Model, which is compatible with CAS approaches, provides the representational model where detailed information is represented, which includes frequency effects (Johnson 1997; Pierrehumbert 2001; Bybee 2001, 2013; Foulkes & Docherty 2006). The first section presents the Complex Adaptive Systems appraoch. The second section considers phonological representations within an Exemplar Model perspective. The role of frequency is addressed in the third section which is followed by conclusions and references.

1. COMPLEX ADAPTIVE SYSTEMS

One of the bedrock assumptions of linguistics up to the twentieth century was that representations are simple, i.e., redundant information is not present in linguistic representations. However, this assumption has been recently challenged by Usage-based Models, Exemplar Models or Construction Grammar. These recent approaches suggest that what has traditionally been assumed to be redundant and inferable by processes, rules or constraints are in fact part of the core property of grammar which promotes the continuous and changing states that are observed in every language.

As posited by Oliveira (2014: 11) "there is no need for any language to change, but they all do". He concludes that languages change because they ought to change. Based on a CAS approach to language he argues that variation and change follow from the intrinsic nature of language and therefore should be modeled as part of it. Within a CAS perspective language is understood as emergent (Bybee & Hopper 2001) and complex (Beckner et ali 2009). Emergence and complexity predict that any language will work as a dynamic system which is subject to permanent changing states.

As pointed out by Massip-Bonet & Bastardas-Boada (2013: 5) "it is difficult to define complexity precisely, since it can be found everywhere.". Complexity follows from interactions that operate at all levels of any system. Thus, it is difficult to separate components or elements within a system since they reflect interactions rather than discrete elements. In order to understand language as a complex adaptive system one has to assume a new approach to the study of grammar. Instead of simply to look for elements within the system and describe how they interact amongst themselves one

should look for pathways or trajectories that promote the ever-changing system of a language. Within this perspective, one can understand grammatical complexity as the interweaving of communicative actions which reflect changing states.

A CAS approach to language suggests that languages have "a great deal of variation and gradience" (Bybee 2010: 2). It is variation, together with the continuous pathways of change, that create gradience. Gradience operates at all levels of grammar. Of course, some categories are closer to one another than others, but all categories are interconnected. The interweaving of categories is what composes the system. Categories which are closer to each other reflect the interwoven relationship of trajectories in the system. This can be illustrated, for example, by aspirated and unaspirated stops. The likelihood of aspirated and unaspirated stops interacting in an ongoing sound change is much higher than stops and laterals to do so. This is because aspirated and unaspirated stops share articulatory properties which tie them closer together within the system than laterals. Of course, there is also an interaction between stops and laterals as they are consonants and as such may, for example, begin or end a syllable. They can also co-occur with a vowel and other consonants in patterns like a syllable or a morpheme, etc. The interaction between aspirated and unaspirated stops operates at the neuromotor level of the system, whereas the interaction between a stop and a lateral operates at another level which can be, for example, pattern formation (syllables or morphemes).

The system works as a whole where all parts are interconnected. Thus, rather than describing static and discrete patterns in a language, a CAS approach will evaluate tendencies in language change. Tendencies are not deterministic, but they rather reflect ongoing pathways in a changing system. The CAS perspective is designed to search for tendencies that evolve over time, rather than a final product. Within this view synchronic and diachronic patterns are related throughout time.

A CAS approach to language assumes that domain-general cognitive processes, which operate in several areas of human cognition other than language, contribute to the organization of linguistic knowledge. This is not to deny that there might be processes that are exclusive to languages, however this is an empirical matter. If one assumes that domain-general processes promote linguistic knowledge then it would be possible to, eventually, encounter evidence to falsify this approach. However, if one assumes that there are processes exclusive to promoting linguistic knowledge it is not possible to identify how domain-general processes contribute to the emergence and

development of grammatical knowledge (Bybee 2010). Therefore, to posit that domain-general cognitive processes contribute to the organization of linguistic knowledge is an interesting line of investigation and compatible with a CAS approach to language and applies to all areas of language (Christiansen & Macdonald 2009; Dabrowska & Lieven 2005).

Amongst domain-general cognitive processes there are, for example, categorization, chunking, rich memory storage, analogy and cross-modal association (Bybee 2010). Other domain-general cognitive processes such as shared attention, imitation, sequential learning and fragmentation contribute to linguistic knowledge (Massip-Bonet & Bastardas-Boaba 2013). Categorization is all embracing, contributing both to the emergence of linguistic categories and the promotion of their change.

As mentioned by Berkenfield (2001: 303), Exemplar Models of storage within a Usage-based approach to language allows for complexity to be modeled. Furthermore, an Exemplar Model allows for gradual changes in representations where frequency effects play an important role. The next section will discuss phonological representations within an Exemplar Model.

2. PHONOLOGICAL REPRESENTATIONS WITHIN AN EXEMPLAR MODEL

In this section I suggest that production and perception should be taken into account in order to understand phonological representations. Although phonology deals mostly with alternations and most alternations take (or took) place in sound change, one notices that variability has traditionally been excluded in formal models. Phonology has been somewhat deprived of variability, it having often been neglected and discarded.

In fact, the development of the phonetics and phonology disciplines was primarily based on production. Articulatory parameters accounted for how sounds are produced (phonetics) and to some extent how phonological categories are related to one another (phonetic similarity). It is by the principle of phonetic (dis)similarity that allophones are usually grouped together and natural classes are defined. In spite of phonetic (di) similarity having been a controversial issue in the development of sound changes, and also in defining phonological categories, it has been a central concept in phonological theories (Janda 1999).

Although, articulatory properties were crucial for proposing phonological entities (phonemes), they were later discarded as part of phonological representations. Phonetic detail, present in the articulation of sounds, was not present in phonological representations since it reflected gradient categories (Keating 1985). Thus, phonemes (or features) would fit the system as discrete and abstract entities. Phonemes are not pronounceable! This is because, if phonological representations are seen as abstract they have no empirical correlate in production (phonetics).

As noted by Port (2007), phonetic and phonological categories were inspired in the linear and discrete symbolic representation from alphabetic systems. Of course, phonetic symbols are as good as any writing system and serve an excellent purpose for describing how sound systems are organized. However, one's intuition about discrete sound units is strongly biased by the literacy education that s/he has received. As noted by Morais et ali (1979: 330) "the ability to deal explicitly with the phonetic units of speech is not acquired spontaneously". The authors tested the ability of literate and illiterate adults, with similar backgrounds, to either delete or add a sound at the beginning of a non-word. They found that illiterate adults could not perform the task whereas individuals who could read and write could. They concluded that awareness of speech, as a sequence of individual sounds, is not achieved spontaneously as part of cognitive development, but rather demands some specific training which involves acquiring writing within an alphabetical system.

Port (2007: 165) suggests that, "As children learn to speak, they store phrases and "words" as rich and complex high-dimensional patterns, learning eventually to categorize them into lexical and phonological categories". To assume that words are the unit in sound changes is a central claim of Lexical Diffusion (Wang 1969). Lexical Diffusion assumes that sound changes are lexically gradual and phonetically abrupt, a view which is at odds with the the neogrammarians who claimed that sound changes are phonetically gradual and lexically abrupt. A Usage-based approach to phonology conciliates these views by claiming that sound changes are both phonetically and lexically gradual (Bybee 2001). Words or constructions are seen as the unit of representation and this is in accordance with Exemplar Models (Bybee 2001: 7).

> Lexical organization provides generalizations and segmentation at various degrees of abstraction and generality. Units such as morpheme, segment, or syllable are emergent in the sense that they arise from the relations of identity and similarity that organize representations.

Recent developments suggest that constructions, i.e., pairs of form-meaning, are the core elements of grammatical knowledge (Goldberg 1995, 2006; Bybee 2012). Constructions amalgamate form-meaning and may consist of one or more words. Thus, a construction (*drive someone x*) - where (*x*) can be *crazy*, *mad*, *insane*, *bananas*, etc. - has its own meaning. On the other hand, *drive, someone, crazy*, *mad*, *insane*, *bananas* can also be understood as independent constructions. As the construction (*drive someone x*) aggregates several elements the construction (*mad*) also aggregates several elements. The challenge of phonology is to identify these elements and explain how they work together in a construction. Most certainly, current research indicates that representations are extremely detailed and that experimental results may offer theoretical insights into the understanding of grammatical knowledge, as noted by Pierrehumbert (2016:48).

> Experimental studies of speech perception and speech production, as well as sociolinguistic field studies and analysis of archival recordings, have provided unequivocal evidence that mental representations of phonological forms are extremely detailed. They include word-specific phonetic characteristics that have arisen from contextual factors, as well as traces of individual voices or types of voices. These effects cannot be captured in strongly abstractionist models, in which phonological information should be completely separable from indexical information and other sorts of contextual information.

It is a fact that the development of the phonetics and phonology disciplines was primarily based on production and that the notion of discrete sounds has a close relationship with alphabetic systems. In fact, not only articulatory parameters were at the center in defining phonological categories, but also perception was not taken into account in phonology until relatively recently. The perception of phonological categories was formerly studied by psychologists, who also considered frequency effects in defining phonological categories (Johnson & Mullenix 1997; Pisoni & Remez 2005). As phonology dealt with abstract knowledge as part of speakers' competence, there was no reason to consider frequency effects which were part of performance. To my knowledge, an Exemplar Model proposal was the first attempt in phonology to embrace perception and production and also to address frequency effects in phonological representations. The next section focuses on frequency effects in phonology with emphasis on an Exemplar Model approach.

3. ON THE ROLE OF FREQUENCY

This section addresses the role of frequency effects in shaping phonological representations. Within a CAS approach, frequency effects should play an important role in shaping linguistic representations. This is because CAS operates through time. Thus, more frequently used grammatical patterns will have more prompt access in language use and processing than rare ones. Furthermore, use strengthens representations so that more frequently used categories are remembered more promptly than less frequently used ones due to the effect of recency. This section first considers the relevance of studying frequency effects in general and then discusses some case studies. Two types of frequency may be studied: token frequency and type frequency. Token frequency is a numerical index that reflects the number of times a unit, usually a word or construction, occurs in a corpus. Type frequency, on the other hand, is a numerical index that refers to the dictionary frequency of a particular pattern.

The study of frequency effects in language dates back to the 17th century in works by William Bathe or Jan Amos (Popescu 2009: v). However, it was after Zipf's influential work that frequency effects became a theoretical issue in linguistic research, as well as in several other disciplines (Zipf 1929, 1949 apud Bybee & Hooper 2001). Obviously, frequency is not a property of the word itself, but is rather dependent on the source where the word occurs, i.e. the corpus which was used to measure frequency. Thus, frequency expresses relative values that may change from corpus to corpus. Although frequency may vary from time to time, it reflects the development of a language and synchronic corpora may reflect a language period. It is likely that a corpus which reflects a 10, or 20-year span, is more homogenous than a corpus that covers several decades. This is because all languages change and changes in frequency effects are expected at least to some words since new words enter a language and others fall into decline. Thus, methodological procedures are crucial in the examination of frequency.

Different aspects of frequency can be studied in languages, but the most common one is the counting of specific words (see, for example, Francis & Kucera 1982). In fact, defining the unit of investigation in a corpus is a theoretical matter and it is likely that, once again, as in the case of phonemes, our alphabetic system has played an important role. Considering that in writing, each word is separated by a

blank space, making it relatively straightforward to determine words as units. However, this methodological procedure poses problems, as for example, the fact that some affixes cannot be directly distinguished from prepositions or postpositions, although they may share some characteristics in some languages as, for example, in Malay (Popescu 2009).

A question one has to ask is WHY frequency effects are relevant, and if so, how they can be measured. In order to consider these questions, one needs to be guided by some theoretical assumptions on grammatical knowledge. Of course, if one's theoretical principles discard empirical information then frequency effects are not worth investigating. This would be the case in generative models of grammatical knowledge.

However, from the 80's some proposals on Usage-based Grammar emerged (Bybee 1985; Langacker 1987; Barlow & Kemmer 2000). In phonology, there was the seminal work by Joan Bybee (Bybee 2001) and, regarding frequency effects in grammatical knowledge, Hopper & Bybee (2001) who revealed an innovative line of research. Obviously, around the same time one could observe a great technological development which contributed to the new empirical lines of investigation in linguistics. Not only had computers much greater memory and processors to handle big data, but also there were improvements in statistical models and experimental designs. Praat provided free tools to investigate acoustic parameters in speech (Boersma 2001). It is around the same time, during the late 80's that Laboratory Phonology emerged. The first Laboratory Phonology meeting was held at the University of Ohio, in 1987 (Kingston & Beckman 1990). Laboratory Phonology started, in fact, as a meeting of scholars from different theoretical backgrounds who had the aim of understanding the nature of human speech sounds and sound systems. Ultimately, these researchers wanted to understand the relationship between the cognitive and physical aspects of human speech and understand the nature of phonological representations (Cohn et ali 2012). As an empirical enterprise, Laboratory Phonology came to highlight frequency effects as a key issue to be investigated.

As mentioned above, one should ask WHY frequency effects are relevant in the study of speech. Bybee (1976, 2001) and Phillips' (1984, 2001) work suggested that "changes resulting from articulatory reduction affect high-frequency words first, while changes resulting from an analysis based on other forms of the language affect low-

frequency forms first" (Bybee 2001: 83). These works were inspired by the lexical diffusion model (Wang 1969). However, they suggested that sound changes were not implemented just lexically, in a gradual fashion, but were also phonetically gradual. In their view, online reduction would contribute to the reshaping of stored representations in high frequency words or constructions. The reduction in magnitude of gestural configurations, as well as gestural overlapping, could produce an acoustic effect where phonetic detail was observed (Browman & Goldstein 1992). Exemplar Models offered the representational perspective that accommodates this view (Johnson 1997; Bybee 2001; Pierrehumbert 2001; Foulkes & Docherty 2006).

Evidence that articulatory reduction tends to affect more frequently used words comes, for example, from schwa reduction in English (Bybee (Hooper) 1976). Whereas commonly used words such as *memory* or *evening* tend not to present a schwa, words such as *mammary* and *artillery* tend to keep the schwa (Bybee 2001; Pierrehumbert 2001). Another example where more frequent words are affected first is the loss of final [t] or [d] after a consonant in English as in *just* or *and* (Bybee 2000). In both cases, the reductive processes may lead to segmental loss and high frequency words tend to be affected first.

The reductive process, which leads to schwa-deletion or t/d-deletion, can be accounted for by language use. As words are used more frequently they have a greater opportunity to be affected by reductive processes. As sound change occurs in real time, online, those more frequently used words will change at a faster rate than less frequently used words. The reshaping of phonological representations takes place as a consequence of online processes.

An example of a BP sound change that affects high frequency words first was presented in Cristófaro Silva & Oliveira-Guimarães (2009). They studied cases where a (sibilant+affricate) sequence is reduced to a sibilant in BP as in 'triste' *sad*: tri[ʃtʃ]e > tri[ʃ]e. The reduction, in this case, is motivated by the similar acoustic and articulatory properties of the adjacent consonants as gestural overlap: alveopalatal sibilant and affricate. They found a tendency for more frequently used words to have the (sibilant+affricate) reduced to a (sibilant) rather than less frequently used words.

Obviously, not all sound changes occur as gestural reorganization. Bybee (1976, 2001) and Phillips' (1984, 2001) suggested that sound changes, resulting from an analysis based on other forms of the language, such as analogy or phonological generalizations, affect low-frequency forms first. In this case, one would expect that

low frequency words will be affected at higher rates, whereas in phonetically motivated sound changes high frequency words will be affected at higher rates. This is the case, for example, in English, where less frequently used verbs such as *weep* or *creep* have a tendency to regularize, as *weeped*/*wept*, *creeped*/*crept*, rather than high frequently used verbs such as *keep*/*kept*, *sleep*/*slept* which resist analogical leveling (Bybee 2001: 12).

Tomáz (2006) studied cases in BP where plural forms of a noun are subject to methaphony. In these cases, the plural is formed by adding the suffix –s as well as by changing the quality of the stressed vowel from closed to open: [o]vo > [ɔ]vos *eggs*. She found that frequently used nouns, such as *egg,* preserved metaphony, whereas those used less frequently, as for example c[o]ro *choir*, were regularized to have the same vowel quality: *choir* c[o]ro when in the plural tends to preserve the vowel as in the singular - as c[o]ros - rather than the irregular expected c[ɔ]ros *choirs*. Tomáz's (2006) results are in compliance with the claim that in sound changes with no phonetic motivation, less frequently used words are affected first, thus at higher rates, than more frequently used ones.

Therefore, in phonetically motivated sound changes, more frequently used words will change first, and at higher rates, and low frequency words will lag behind until or when the sound change is completed. On the other hand, in sound changes with grammatical motivation, less frequently used words will change first, and at higher rates, and low frequency words will lag behind.

Of course, the frequency effects discussed above have to be understood as reflecting a tendency in languages rather than being deterministic. It is also possible that phonetically motivated sound changes will interact with sound changes that result from an analysis based on grammatical generalizations. If this is the case, the prediction is that frequency effects may be blurred when sound changes that are phonetically motivated converge with sound changes which have a grammatical source.

Cristófaro Silva et ali (2013) considered cases where in the Past Perfect (PP) the diphthong [ãw] is reduced to [u] as in *to stay(PP)* ficar[ãw] > ficar[u] but, on the other hand, in the Past Imperfect (PI) the diphthong [ãw] is reduced to [a] as in *they stay(PI)* ficav[ãw] > ficav[a]. Of course, the reduction from a nasal diphthong to a single oral vowel is accounted for as a phonetically motivated reductive process which is widespread in BP in the unstressed position and affects other nasal diphthongs, as for

example, the Present form of the verb (*they)want* quer[ẽi]>quer[i] or in the noun *man* hom[ẽi] > hom[i] homem. As expected in a phonetically motivated sound change, more frequently used verbs should be affected first, and they are: Past Perfect (84.78%) and Past Imperfect (61.29%). However, these results were statistically significant for the Past Perfect, but not for the Past Imperfect. The lack of significance for the Past Imperfect was certainly due to the fact that 38.71% of infrequent verbs were affected in this case. A closer examination of the data showed that for the Past Imperfect, nasal diphthong reduction to a single oral vowel promotes analogical levelling where all verb endings are regularized to –ava. On the other hand, analogical levelling does not occur in the Past Perfect where verbal forms present several endings after nasal diphthong reduction. The authors suggest that it is the convergence of a phonetically motivated reductive process (nasal diphthong reduction) with analogical levelling (verbal forms regularization) that leads to blurred frequency effects in the Past Imperfect in their case study, which is reflected by the lack of statistical significance.

The frequency effects discussed above are assumed to reflect lexical diffusion or construction diffusion patterns which may be understood as pathways that evolve in time through trajectories, as predicted by CAS. A consequence of this assumption is that sound change cannot be undone (Bybee 1994, 2000). This is because CAS evolves towards future states. Previous states of course affect future ones, but no return to a previous state takes place. As Massip-Bonet (2013: 42) observes:

> Irreversibility is not a universal property (Prigogine & Stengers 1997: 33). However, the world as a whole seems to belong to these intrinsically random complex systems for which irreversibility is significant, and this is the category of systems that break with temporal symmetries. This is the category to which living phenomena belong, including human existence.

Thus, phonological systems will change continuously through time, without undoing sound changes and this is of course the case (Cole & Hualde 1998; Janda 1999; Bybee 2001). Frequency effects cannot be understood as deterministic and definite properties. They actually express tendencies in the development and evolution of languages and there are unresolved methodological issues as to what sort of corpora should be considered when measuring frequency (spoken or written), the equivalence between synchronic and diachronic corpora and how to deal with corpora that covered a long period of time.

Of course, the frequency effects suggested above can be challenged and falsified. This would be the case if one finds no frequency effects at all in a sound change, or if a

phonetically motivated sound change, which affects low frequency words first is attested, or if there are cases where high frequency words are affected first in sound changes resulting from grammatical patterns.

Tamminga (2014) considered frequency effects by investigating *like* in English when occurring as an adjective, conjunction, discourse marker, or preposition in order to investigate /ay/-raising in Philadelphia. She considered cases where *like* was followed by voiced and voiceless segments, her data span stretching from 1900 to 1980. She argues that no frequency effect was overtly observed in the development of /ay/-raising and thus claims that her results challenge Exemplar Model assumptions on frequency effects.

Hay et ali (2015) also presented a diachronic study which investigates changes in vowels in New Zealand English (NZE) over a 130-year period. According to these researchers, in NZE *bat* often sounds to speakers from elsewhere like *bet*, *bet* sounds like *bit* and NZE *bit* sounds like *but*. Their work showed that low frequency words were affected at higher rates rather than high frequency ones. They suggest that the vowel changes they considered are phonetically motivated and thus claimed their results challenge the view that, in phonetically motivated sound changes, high frequency words are affected first.

Tamminga (2014) and Hay et ali. (2015) appear to provide some evidence against word frequency effects as proposed by Bybee (1976, 2001) and Phillips' (1984, 2001) within an Exemplar Model approach. Tamminga (2014) did not find any frequency effects and Hay et ali. (2015) suggest that low frequency words are affected first in a phonetically motivated sound change. Of course, further evidence for the controversy of frequency effects, posited by Tamminga (2014) and Hay et ali. (2015), is still needed. Some methodological refinements are also needed, especially for dealing with sound changes reported over a long time span. Since some sound changes are completed rapidly, and others take longer to be concluded, there might be a need for specific modeling in order to account for the generational development of sound changes. It could be the case that throughout time some sound changes converge so that frequency effects are blurred between phonetically motivated sound changes and grammatical ones (Cristófaro Silva et ali 2013). Within a CAS approach to language, frequency effect is one of the parameters which interacts in the implementation of sound changes and it might be the case that frequency has to interact with other parameters. Further investigations will clarify these issues.

CONCLUSION

This paper aimed to present a CAS approach to phonology with a focus on frequency effects. It has been shown that phonological processes, as traditionally described, state generalizations but do not explain their primary source: WHY do synchronic phonological generalizations emerge and HOW do they develop? I suggested that synchronic phonological generalizations emerge because languages are dynamic systems that ought to change (Oliveira 2014). Sound changes, which reflect synchronic phonological generalizations, develop through frequency effects. Thus, a phonological system is always changing towards future states, as predicted by CASs.

The following question was also posited in this paper: WHY are frequency effects relevant in linguistics and how can they be measured? Frequency effects are relevant in linguistics because they offer important guidelines to the understanding of how grammatical knowledge – and particularly sound changes – develop. Several works presented in this paper provide insightful understanding of frequency effects in the development of phonological systems. Methodological challenges as, for example, how to model corpora effects over a long time span have to be dealt with so that a more comprehensive understanding of frequency effects can be reached. I hope to have provided evidence that the results presented in this paper, not only provide a better account for empirical data, but they also offer a more comprehensive understanding of the development of phonological phenomena than that provided by traditional phonological theories.

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