25 Informative Differences: An Argument for a Comparative Approach to Written, Spoken, and Signed Language Research

Ariel M. Cohen-Goldberg
Tufts University, United States

Despite the existence of many similarities in the cognitive architectures that support written, spoken, and signed processing, psycholinguistic research in each domain has proceeded largely independently of the others. I argue that a comparative approach that examines the similarities and differences of performance across these domains can be an extremely useful tool for distinguishing competing theories within a domain. As case studies, two theoretical questions about language production are considered. The first concerns whether the orthographic representations that support spelling contain information about syllable structure. While it is difficult to answer this question in hearing individuals, important progress has been made by comparing the spelling errors of deaf and hearing individuals. I review studies that find that in both populations, spelling errors are syllabically constrained, indicating that syllabic structure can develop on the basis of experience with orthography alone. The second topic focuses on the question of whether certain phenomena observed in speech result from learned grammatical computations or rather are the by-products of the processes involved in speech production. Here, I review a number of studies that have found very similar phenomena in written production. I argue that since the patterns in written production are extremely unlikely to have been learned and grammaticalized, this suggests that grammatical accounts are not necessary to account for these specific phenomena in either domain. This chapter thus provides a sketch of how a comparison of production behavior across modalities can be used to constrain theories of language processing.

Malgré l'existence de nombreuses similitudes entre les architectures cognitives qui assurent le traitement du langage écrit, parlé, ou signé, les recherches psycholinguistiques ont abondamment procédé de façon indépendante dans chacun des domaines. Je défends l'idée qu'une approche comparative qui examine les similarités et les différences de performances au travers des différents domaines peut être extrêmement utile pour différencier les théories concurrentes au sein d'un domaine. Deux questions théoriques au sujet de la production du langage seront considérées en tant que cas d'étude. La première concerne le fait de savoir si les représentations orthographiques qui sous-tendent l'orthographe contiennent des informations sur la structure syllabique. Alors qu'il est difficile de répondre à cette question en écoutant les individus, d'importants progrès ont été faits en comparant les erreurs d'orthographe commise par les sourds et par les entendants ; Je passe ne revue des études qui constatent que dans les deux populations, les erreurs d'orthographe sont contraintes sur le plan syllabique, mettant en évidence que le développement de structure syllabique peut s'opérer sur la seule base de l'orthographe. Le second thème porte sur la question de savoir si certains phénomènes observés dans le langage oral résultent de calculs ou sont plutôt des sous-produits des processus mis en œuvre dans la production langagière. Là je passe en revue un certain nombre d'études qui ont constaté des phénomènes tout à fait semblables dans la production d'écrit. Je défends l'idée que, puisqu'il est extrêmement improbable que les modèles de production écrite aient été appris et grammaticalisés, cela suggère que les calculs grammaticaux ne sont pas nécessaires pour ce type spécifique de phénomène, et cela dans chacun des domaines. Cet article fournit ainsi une esquisse de la manière dont la comparaison entre des comportements de production verbale recourant à différentes modalités peut être utilisée pour restreindre les théories de la production langagière.

1. Introduction

One of the most basic yet powerful techniques in psychology is the comparative approach. In this approach, performance across theoretically relevant groups or domains is contrasted: humans and animals, adults and infants, typically developing children and children with genetic abnormalities, speakers of different languages, performance in comprehension vs. production, and so on. Patterns of similarity and dissimilarity across these comparisons

provide critical information about—first and foremost—the similarity and dissimilarity of the relevant neural and cognitive systems but also the genetic, maturational, and environmental (e.g., linguistic) factors that are necessary and sufficient for the development of these cognitive systems.

The comparative approach has been especially useful in research on written language processing, particularly to understand how the properties of a language's orthographic system influence how reading and writing are achieved. Numerous studies, for example, have contrasted performance across production tasks (e.g., Bonin, Méot, Lagarrigue, & Roux, 2014), shallow and opaque orthographies (e.g., Cuetos & Labos, 2001; Toraldo, Cattani, Zonca, Saletta, & Luzzatti, 2006), alphabetic, syllabary, and logographic systems (e.g., Okano, Grainger, & Holcomb, 2013; Weekes, Yin, Su & Chen, 2006), and languages with concatenative and non-concatenative morphologies (e.g., Velan & Frost, 2011). Comparisons between written comprehension and production have also been informative, for example in shedding light on whether reading and writing rely on a common orthographic lexicon (e.g., Holmes & Carruthers, 1998) and positional representation scheme (Fischer-Baum, McCloskey, & Rapp, 2010; Fischer-Baum, Charny, & McCloskey, 2011).

Many similarities and differences exist between written, spoken, and signed language which should provide enormously fertile ground for advancing our theories of processing through the comparative approach. Unfortunately, though theories in these areas have converged on a generally similar processing architecture (e.g., the major stages of processing: semantic processing → lexical processing → segmental planning → motor planning → execution) and computational paradigm (interactive spreading activation), research within these domains generally proceeds exclusive of input from the others (though see Chen & Mirman, 2012 and Caselli & Cohen-Goldberg, 2014, for examples of recent attempts to bridge these domains). For example, in Levelt's (1989) seminal work on spoken language, *Speaking*, only one out of the 566 pages mentions research from written language. When interaction does occur between these domains, it tends to be from spoken production to written and signed production, rather than in the reverse direction.

The present paper is a call for an ongoing, mutually-informing, integrated approach to written, spoken, and signed production research. I argue that while there are numerous topics that are unique to each domain (e.g., phoneme-grapheme conversion is unique to written language processing), important theoretical advances can be made by exploiting the similarities and differences between written, spoken, and signed language in a comparative fashion. The paper is organized into two sections. The first section focuses on how the comparative method may be used to advance research on written

production. In particular, I examine the issue of how one may disentangle orthographic and phonological information when investigating the nature of the writing system. As a case study, I review how researchers have compared the spelling performance of hearing and deaf individuals to probe the nature of orthographic representations, free from the influence of phonology.

In the second section, I describe how research on written language may constrain theories of spoken production. I first review two phenomena in spoken production where there is debate not only as to which theory best accounts for the data but which general approach is most perspicacious (specifically, grammatical or non-grammatical explanations). I then describe some findings from written production research that I believe constrain the choice of theories in spoken production, in this case in favor of non-grammatical mechanisms.

2. The Comparative Approach in Written Production Research

One of the fascinating aspects of written language is its close relationship to spoken language. In languages with alphabetic and syllabary orthographies the basic graphemic units correspond to phonological units, making written words simultaneously representations of lexical items and sounds. The close relationship that exists between orthography and phonology, however, often makes it difficult to determine which properties of the written language system are unique to the written modality and which may have their origin in the spoken modality. This question is critical not only for determining the architecture of the reading and spelling systems but also for understanding the nature of orthographic representations and how they develop.

Some aspects of written language are clearly unique to orthography. For example, the ways that written words are articulated are entirely different from the way spoken words are articulated (e.g., the writing of letter shapes or the typing of keys vs. the constriction of the vocal tract). As another example, some facts about spelling are unrelated to the language's phonology. In English, for instance, consonants may not be doubled word-initially (the non-word /farp/ could be spelled FIPE but not FFIPE) and words may not end in J (the non-word /bIdz/ could be spelled BIDGE but not BIJ) but there are no phonological correlates of these facts.

Unfortunately, however, many of the computations involved in written production and comprehension could in theory be in some way influenced by or wholly derived from phonology. Perhaps the earliest of such debates concerned the role that phonology plays in the cognitive architecture of writ-

ten word production. The debate has centered on whether individuals may directly access a word's spelling on the basis of its meaning (and vice versa in comprehension) or whether access between print and meaning is obligatorily mediated by phonology. Specifically, the debate concerns whether individuals may directly access a word's orthographic form on the basis of its meaning or whether spellers must first access the word's entry in the phonological lexicon and then either convert the phoneme string into a string of graphemes using sub-lexical conversion processes or access an orthographic lexical entry before writing the word. On the former view, written language processing may occur independently of the phonological system while on latter view, written language is parasitic upon existing spoken language access mechanisms (see Shelton & Weinrich [1997] and Rapp, Benzing, & Caramazza [1997] for reviews and evidence in favor of direct access).

Another area where the close relationship between orthography and phonology has been particularly problematic is in the domain of spelling. Here, an important theoretical goal is to uncover the content of orthographic representations, determining how letters and their positions are represented. An interesting and important empirical finding is that spelling errors made by neurologically intact and brain-damaged individuals are frequently constrained, with some errors being far likelier than others. Non-phonologically plausible errors—errors that are not possible spellings of a word's phonological form—frequently preserve the consonant/vowel status of the target letter (e.g., MASK → MALK rather than MAIK; Caramazza & Miceli, 1990; Buchwald & Rapp, 2006) and rarely result in illegal sequences of letters (e.g., MASK → MALK rather than MAPK). The relatively constrained nature of these errors suggests that structural knowledge of some sort—statistical or linguistic—influences the spelling process. The fact that phonological information may become activated during the spelling process makes it difficult to determine the origin of this knowledge, however. While MAPK may be an unlikely error for MASK because PK is an illegal sequence of word-final letters, it is also possible that it is unlikely because no English word ends with the sounds /pk/. Spelling errors could thus be the result of orthotactic constraints, phonotactic constraints, or both. The correlation between orthography and phonology makes it difficult to determine the origin of this influence and thus, makes it difficult to make inferences about the structure of orthographic representations.

While it may be difficult or impossible to remove the influence of phonology on spelling tasks in hearing individuals, deaf individuals represent a population that has by and large learned to read and write in the absence of a phonological system. By testing deaf individuals who demonstrate mini-

mal spoken language abilities, one may gain an insight into what the written language system may look like when it develops on the basis of orthographic information alone. Using the comparative approach in this way, written language researchers have been able to investigate whether the constraints described above are necessarily derived from phonology or can develop independently, from orthography.

To this end, some studies have used syllable counting (Sterne & Goswami, 2000) and illusory conjunction tasks (Olson & Nickerson, 2001) to infer whether knowledge of syllable structure may develop in the absence of phonological input. Other studies have investigated whether deaf readers have knowledge of orthographic legality by testing memory performance for legal and illegal letter strings (e.g., Aaron, Keetay, Boyd, Palmatier, & Wacks, 1998; Gibson, Shurcliff, & Yonas, 1970). These and other studies have found that deaf individuals have knowledge about syllable structure and letter sequences, suggesting that syllable structure is not necessarily derived from phonology. Consistent with these findings, Hanson, Shankweiler, and Fischer (1983) reported that 96% of the spelling errors made by deaf participants were orthographically legal, mirroring the performance of hearing individuals (see also Padden, 1993).

One especially elegant study illustrates the particular power of the comparative approach to disentangle orthographic knowledge from phonological knowledge. Olson and Caramazza (2004) examined the spelling errors made by reading-level matched deaf and hearing participants. The majority of the spelling errors made by the deaf participants were phonologically implausible while the majority of the spelling errors made by hearing participants were phonologically plausible (e.g., SUBSTITUTE → SUBITUSE vs. SUBSTATUTE). This basic analysis in and of itself demonstrates the relative influence of phonology in the spelling of these different populations. Fascinatingly, despite their dissimilarity with respect to the overall influence of phonology, the two groups' spelling errors were very similar when phonology was controlled. When only the phonologically *im*plausible errors were analyzed, it was found that the two groups nearly always made orthographically legal errors (Deaf: 92%, Hearing: 93%). In further analyses, Olson and Caramazza argue that this extremely low rate of illegal errors was not due to chance, did not correlate with the deaf participants' level of hearing, and was not plausibly the result of letter bigram frequency. They conclude that the spelling errors were thus constrained by syllable structure. Since these patterns were observed in the deaf participants, they further concluded that syllable structure can develop on the basis of experience with orthography alone. Olson and Caramazza were careful to state that their results do not rule out

the possibility that phonological information influences the development of orthographic syllable structure in hearing individuals, just that "syllabic structure can be relatively independent of the peripheral systems devoted to speech." (Olson & Caramazza, 2004:412). Thus used, the comparative method can allow us to discover the nature of orthographic representations despite the intimate relationship between orthographic and phonological processing in most readers.

3. The Comparative Approach in Spoken Production Research

In this section, I examine how the comparative method can use data from written production to inform theories of spoken production. First, it is useful to explore the differences between the articulation of written and spoken language and how they relate to the learning of grammatical patterns.

3.1 Grammar and the Differences in Articulatory Transmission Between Written and Spoken Production

As framed by contemporary linguistics and psycholinguistics, a grammar is an unconscious set of rules or principles that determine which structures are well-formed within a particular linguistic domain. The notion of a grammar has typically been invoked in reference to spoken and signed language, although some researchers have argued that it may have explanatory value in written language as well (e.g., Eden & Halle, 1961; Myers, 1996, 2011; Goldberg & Cohen-Goldberg, in prep). While many theories of spoken and signed grammar have argued that some grammatical components are innately specified ('Universal Grammar', Chomsky, 1965; Prince & Smolensky, 1994/2004), all theories assume that the bulk of an individual's grammatical knowledge is learned on the basis of *experience* with a language. This fact places a lower bound on the sort of information that can be encoded in a grammar. Fundamentally, for a pattern to be grammaticalized it must be detectable in the linguistic signal. It is here that differences between spoken and written language begin to manifest.

In spoken language, sub-phonemic phonetic properties such as vowel-to-vowel coarticulation (Beddor, Harnsberger, & Lindemann, 2002; Manuel, 1999), voice onset time (e.g., Cho & Ladefoged, 1999), and vowel nasalization (Clumeck, 1976; Henderson, 1984; Rochet and Rochet, 1991) have all been shown to vary across languages. For example, Cho and Ladefoged (1999) report that in their sample of 18 languages, velar stops range in aspiration

from 20 ms to 160 ms. There thus appear to be language-specific settings for aspiration. Though these values span what might be considered to be different phonetic categories (e.g., unaspirated to highly aspirated stops), significant variation was found within categories as well. For example, among the languages classified as containing aspirated velar stops, aspiration varied by as much as 20 ms (26%). These findings indicate that very subtle facts about articulation 1) manifest in the auditory signal, 2) are detectable by listeners, and 3) are learnable as grammatical rules (see, e.g., Morley, 2013). The fact that phonetic properties such as these are learnable is due at least in part to the fact that speech is continuous, allowing subtle changes in articulatory parameters to have a direct physical impact on the acoustic signal. A longer delay between the release of a stop constriction and the onset of vocal fold vibration leads to a longer period of high-frequency noise in the acoustic signal, giving longer aspiration.

Written language presents a very different picture from spoken language. Apart from cursive and calligraphic writing which in many respects mirror the continuous articulation found in spoken language, much of the graphic form of writing is divorced from the details of its articulation. Consider, for example, block uppercase writing, which is the typical script used in psycholinguistic experiments. Many aspects of how block letters are written—the amount of time it takes to write a letter, the amount of time that elapses between letters or strokes—simply do not have a necessary effect on the graphic form of the letter. For example, one may write a relatively small and a relatively large letter W in the same span of time; conversely, one may spend a short or long amount of time writing letters of the exact same size. The same thing is true for the amount of time that elapses between strokes. The discrete nature of block writing further implies that each letter is executed independently of the letters that surround it, minimizing if not eliminating coarticulatory influences. Together, these facts entail that many of the gradient properties of written articulation will not manifest in the graphic output. This is taken to the extreme in the most common form of written communication today—printed text—which reveals absolutely no information about the process that produced it (e.g., the amount of time elapsed between keystrokes is not in any way revealed by printed text).

The difference in the way articulatory details are transmitted between the spoken and written modalities has significant consequences for the likelihood that gradient details may become grammaticalized in spoken and written language. Gradient articulatory details are frequently observable in the acoustic signal, making it plausible that these facts could be learned by speakers and internalized in a grammar. By contrast, the fact that many details of the writing

process are not evident in the graphic form of written language makes it highly unlikely that readers could encode and grammaticalize these details.[1] Crucially for the present purposes, this entails that the gradient patterns we observe in written production do *not* arise from learned, grammatical computations.

3.2 Patterns in Spoken Production

The fact that written and spoken language differ in the inherent ability to grammaticalize facts about articulation can serve as a useful point of comparison when attempting to determine whether we need to appeal to a grammatical account of some pattern in production. In this section, I describe two phonetic patterns that have been described in spoken production as well as the various accounts that have been proposed to explain them.

The first case is the phenomenon of *pre-boundary lengthening*. According to prosodic accounts of phonology, utterances are parsed into hierarchical constituents such as prosodic words and intonational phrases that govern the prosodic properties of the utterance (e.g., Nespor & Vogel, 1986; Selkirk, 1984). Numerous studies have shown that phonemes tend to be pronounced with longer durations before prosodic boundaries than in other environments (e.g., Oller, 1973; Lehiste, 1973; Klatt, 1975, 1976; Lehiste, Olive & Streeter, 1976; Cooper & Paccia-Cooper, 1980; Wightman, Shattuck-Hufnagel, Ostendorf & Price, 1992; Ladd & Campbell, 1991; Fougeron & Keating, 1997; Byrd & Saltzman, 1998). Pre-boundary lengthening has also been shown in some cases to correlate with the level of the constituent—longer durations are observed at the end of higher-level prosodic constituents (e.g., Wightman et al., 1992). Lengthening has been observed in many languages (even languages with phonemic length and tone, where lengthening could interfere with the perception of these features; Duanmu, 1996; Hockey & Fagyal, 2008) leading some researchers to suggest that it may be a universal property of spoken language (Hayes, 1995; Vassière, 1983).

The second phenomenon is the fact that suffixed words in English tend to have longer durations than monomorphemic words, a fact that will be referred to here as *multimorphemic lengthening*. A number of studies have compared the pronunciation of homophones that differ only in their morphological structure and have found that segments in multimorphemic words tend to be longer than their monomorphemic counterparts: plural *–s* is longer than non-morphemic /s/ (*lap̲s̲* > *lap̲s̲e*; Walsh & Parker, 1983; Schwarzlose & Bradlow, 2001; Song, Demuth, Evans & Shattuck-Hufnagel, 2013; see also Song, Demuth, Shattuck-Hufnagel & Ménard, 2013); past tense *–ed* is longer than non-morphemic /d/ (*ban̲n̲ed̲* > *ban̲d̲*; Losiewicz, 1995); vowels in suffixed

words are longer than vowels in monomorphemic words (*passed* > *past*; Frazier, 1995), and the same thing is true for VC rhymes more generally (*missed* > *mist*; Sugahara & Turk, 2009).

A variety of theories have been proposed to account for both of these phenomena. In the case of pre-boundary lengthening, both grammatical and non-grammatical theories have been proposed; in the case of multimorphemic lengthening, only grammatical theories have been advanced. These proposals will now be briefly reviewed.

3.3 Theoretical Accounts

3.3.1 Accounts of Pre-Boundary Lengthening

A number of theories have proposed that pre-boundary lengthening is the direct result of a grammatical rule. Duanmu (1996) proposes that while all languages undergo pre-boundary lengthening, English contains a rule that causes *additional* lengthening to occur in order to satisfy a grammatical constraint requiring all feet to be binary. Selkirk (1984, 1990) argues that the temporal properties of an utterance are derived from a phonological structure constructed by the grammar. According to her proposal, pre-boundary lengthening is the phonetic realization of abstract timing units ('virtual pauses') that are assigned by rule to prosodic boundaries. Finally, Vassière (2008) proposes that final lengthening has been grammaticalized as a way to signal constituent structure to listeners. Indeed, many studies have found that listeners can use segmental lengthening as a cue to parsing (e.g., O'Malley, Kloker and Dara-Abrams, 1973; Macdonald, 1976; Lehiste, Olive and Streeter, 1976; Streeter, 1978).

While all of these theories assume that listeners lengthen segments before boundaries as a result of a learned grammatical computation, a handful of theories have proposed that lengthening instead has its origins in the psycholinguistic processes responsible for planning and ordering speech. Cooper and Paccia-Cooper (1980:199, as cited in Cutler, 1990), state "The lengthening effect could be attributable to execution . . . [and] represents a general relaxation response . . . The internal clock, in effect, runs more slowly at the ends of major constituents, presumably due to processing fatigue." Watson and Gibson (2004) propose that lengthening before prosodic boundaries results from the increased cognitive load that occurs when speakers plan upcoming syntactic constituents. These accounts differ from the grammatical theories in that they propose that lengthening arises epiphenomenally from other aspects of processing. Lengthening is thus proposed to be neither learned nor the specific result of a computation, it is simply a side effect of the way that the mechanisms that produce language function.

3.3.2 Accounts of Multimorphemic Lengthening

Similar to pre-boundary lengthening, a variety of grammatical proposals have been advanced to account for the lengthening observed in multimorphemic words. Walsh and Parker (1983) propose that speakers have a grammatical rule that lengthens suffix phonemes. Specifically, they propose a rule that adds the feature [+long] to the phonological specification of the plural morpheme prior to articulation. Frazier (1995), working within the phonological framework of Optimality Theory, proposes a paradigmatic explanation for why vowels in suffixed words are longer than their counterparts in monomorphemic words. She proposes that grammars compute the length of a word's root (e.g., *pass*) and then factor this information into the computations that determine the length of the suffixed word (e.g., *passed*). Thus, Frazier proposes that the phonological grammar of English is organized in such a way as to maintain the durational properties of a root as much as possible in its suffixed forms.

Finally, Sugahara and Turk (2009) propose multimorphemic lengthening is simply a special case of pre-boundary lengthening. Working within the framework of Prosodic Phonology, they propose a two-part explanation: English speakers assign prosodic structure to multimorphemic words and the boundaries of these constituents trigger pre-boundary lengthening. In particular, they propose that in words containing inflectional and highly productive derivational suffixes ("Level-2" morphology), both the entire word and the stem are parsed into prosodic words. For example, the phonological representation of the word *missed* with its fully elaborated prosodic structure would be: $/((miss)_{PWD} -ed)_{PWD}/$. Pre-boundary lengthening would then apply to the segments immediately preceding the prosodic word boundaries, lengthening them relative to monomorphemic words, which are proposed to have only the whole-word prosodic structure (e.g., *mist* $/(mist)_{PWD}/$).

Finally, as with pre-boundary lengthening, there has been some suggestion that multimorphemic lengthening may occur in order to facilitate comprehension. Frazier (1995) reports experimental data indicating that listeners can use differences in vowel duration to guide their decisions about the morphological structure of homophonic words. She concludes that vowel duration is "actively used by speakers to avoid ambiguity" (Frazier, 1995:9). According to this account, a grammatical rule for multimorphemic lengthening may exist to differentiate mono- and multimorphemic words for listeners.

3.3.3 Summary

To summarize, pre-boundary and multimorphemic lengthening have primarily been proposed to be the result of grammatical processes. These ac-

counts propose that phoneme lengthening before boundaries and in multimorphemic words are teleological rather than epiphenomenal outcomes: speakers learn a computation or set of computations that specifically calculate word duration and these computations are organized in such a manner that segments before prosodic boundaries and in multimorphemic words are given longer durations than segments in other environments. These theories contrast with a handful of accounts that propose that lengthening is simply the by-product of the way that the processes responsible for the timing and planning of sequences function. Currently, there does not appear to be any evidence or theory-internal data that suggest which theory (or even class of theory, grammatical or non) best accounts for the data. It is here, I propose, that data from written production could be useful.

3.4 Data from Written Production

Beginning with the issue of pre-boundary lengthening, a very similar result has been reported in typewriting. Sternberg, Monsell, Knoll, and Wright (1978) examined inter-key intervals ('IKIs'; the amount of time that elapses between successive keystrokes) in the production of random 5-letter sequences. They found that IKIs increased across positions, peaking just before the end of the sequence. Converging evidence comes from similar investigations of pressure in handwriting. Using a pressure-sensitive plate, Kao (1983) had participants trace 5 different simple figures (e.g., a circle, a single line, and two lines joined at 3 different angles) 10 times each using a ball-point pen. He found that both the pressure and the standard deviation in the pressure increased across the ten tracings, peaking uniformly on trial 9. Although Kao (1983) speculated that the effect may be limited to cases where the same motor task is performed repeatedly, Kao, Mak, and Lam (1986) observed it within a single trial, finding increasing pressure and variability in pressure from the beginning to the end of a single sequence of strokes (see also Figure 23.2 of Portier, van Galen, & Meulenbroek, 1990). This progression was also found across different types of stimuli (linear vs. cursive strokes) and tasks (e.g., tracing, copying, etc.). Finally, Wann and Nimmo-Smith (1991) found the same result in the writing real words. Together, these results suggest that the progressive increase in pressure is a general property of written serial production.

Although these experiments examined specific letter and stroke sequences rather than abstract prosodic structure, their results can be aligned with pre-boundary lengthening in that both relate to how production varies near the end of a constituent. We see that duration, pressure, and variability in pressure peak just before the end of a sequence, similar to how phoneme duration peaks just before the end of a prosodic constituent.[2]

Turning now to the issue of multimorphemic lengthening, a recent study by Kandel and colleagues (Kandel, Spinelli, Tremblay, Guerassimovitch, and Álvarez, 2012) analyzed handwriting data to investigate the way that mono- and multimorphemic words are produced in written production. In their study, Kandel and colleagues compared French suffixed words (e.g., *boulette*, containing the diminutive suffix *-ette*) to monomorphemic words containing the same final sequence of letters (e.g., *omelette*, which does not contain the diminutive suffix). The English analog would be the words *teacher* and *father*, which do and do not contain the agentive suffix *-er*, respectively. Kandel and colleagues found that inter-letter intervals ('ILIs', the amount of time between the end of one letter and the beginning of the next) were longer for the two letters preceding the morpheme boundary in suffixed words (e.g., between U and L and L and E in *boulette*) than the corresponding letters in monomorphemic words. They also found that the stroke duration of the same letters (how long participants spent writing the letters) was longer in multimorphemic words than the monomorphemic words. Similar results with longer IKIs have been found in the typing of English compounds and pseudocompounds (Libben & Weber, 2014; Spalding, Gagné, Nisbet, & Park, 2014). In sum, this pattern directly replicates the pattern reported in the spoken production of English suffixed words.

3.5 Implications

Stepping back, we see that very similar phenomena have been observed in both spoken and written production. In spoken production, phonemes are lengthened near the ends of prosodic constituents; in written production, typing durations and pen pressure peak near the ends of words. In spoken production, phonemes are lengthened in multimorphemic words relative to monomorphemic words; in written production, letter durations and inter-letter intervals are similarly lengthened in multimorphemic words.

How then should we interpret these results? What does it mean for the same results to be observed in both spoken and written production? The crucial observation is that grammatical accounts, while plausible for spoken language, are not plausible for written language. Given that the temporal properties of typing are in no way evident in printed text, it is simply impossible for typing durations to be learned and subsequently encoded as a grammatical rule. While pressure, pressure variability, duration, and ILI could all in principle manifest in handwriting, the fact that these are likely to be extremely subtle effects, coupled with the fact that most readers have very little exposure to handwriting suggests that a learned, grammatical account of these effects is highly unlikely.

We can thus conclude that the phenomena observed in written production are neither learned nor produced for the benefit of readers—they arise epiphenomenally from the functioning of non-grammatical processes. This raises the possibility that the same thing is true for spoken language. If grammatical processes are not responsible for these patterns what is? The most likely account appears to be the one suggested by Cooper and Paccia-Cooper and Watson and Gibson: these effects arise from the processes that plan and sequence linguistic units for production. A similar proposal was made by Kandel et al. (2012) in their investigation of written production. Kandel and colleagues argue that the increased stroke durations and ILIs observed in suffixed words result from the way that multimorphemic words are planned in written production. They argue that their data provide evidence that the written production system plans the production of the suffix *while* the stem is being written. In particular, they argue that the suffix morpheme is activated during the articulation of the stem, which either 1) causes information to cascade from central to peripheral processes or 2) places additional load on the peripheral processes due to limited resources shared with central processes. In both cases, this additional information/load is proposed to slow the motoric execution of the stem letters (see Orliaguet & Boë, 1993 for a similar load-based account).

It turns out that a planning/cascading account is plausible for spoken production as well. Psycholinguistic research has demonstrated that information cascades during spoken production (e.g., Dell, 1986; Rapp & Goldrick, 2000; Peterson & Savoy, 1998) and that upcoming units may be planned during the articulation of other elements (e.g., Meyer, 1990, 1991; Roelofs, 1996; Jacobs & Dell, 2014). It is thus plausible that the incremental processing of a stem and suffix in an interactive system (e.g., cascading activation, yoked resources) results in temporal disfluencies in suffixed words relative to form-matched monomorphemic words in both spoken and written production.

It is important to note that the comparison with written production does not rule out the possibility that these lengthening effects have been grammaticalized in spoken production, it simply makes the case that this position is not *necessary*. It could be the case that these effects initially arose epiphenomenally from planning processes and then were subsequently learned as a grammatical rule by listeners. In this way, lengthening would be caused by non-grammatical mechanisms in written production and by both non-grammatical and grammatical mechanisms in spoken production.

4. Discussion

This chapter reviewed two examples of the comparative approach where com-

paring production across domains can reveal facts about processing that are difficult to determine when working within just a single domain. In the first example, data from deaf and hearing spellers were compared to determine the nature of orthographic representations. In the second example, data from written and spoken production were used to make inferences about the origins of two phonetic phenomena. In both cases, the argument was the same: if similar performance is observed in two domains that differ in the presence/absence of a particular property, this implies that that property is not necessary to obtain that performance. In the first example, the fact that deaf and hearing spellers make similarly constrained spelling errors despite the fact that the former were never exposed to phonological information implies that the operative constraints are not necessarily phonological in origin. In the second case, the fact that similar lengthening phenomena are observed in written and spoken production despite the fact that grammaticalization is unlikely in the former suggests that the phenomena are not necessarily the result of grammatical computations. The comparative approach is particularly useful in cases where the property of interest is not amenable to experimental manipulation. Rather than attempting to artificially control the property, the comparative approach makes use of natural patterns of similarity and dissimilarity to reveal what conditions are sufficient to give rise to a particular effect.

The reviewed research and the novel analysis presented in this chapter provide a sketch of how a comparative approach can allow research in different domains to both inform and mutually constrain each other. Similar comparisons can and should be made among all three modalities: written, spoken, and signed production. Where a pattern has been attributed to a property that is unique to a domain, finding a similar pattern in another domain provides evidence against that property as the sole underlying cause.

5. Acknowledgments

Notes

1.   Note that macro-level properties of written language are clearly observable in the graphic signal. For example, Arabic numerals often differ in form by geographic region (7 vs. 7̄, 0 vs. Ø), indicating that writers must be able to encode and reproduce these features.
2.   It is important to note that the effects are not identical across modalities—while pre-boundary lengthening is typically only observed immediately before a

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