From diacritics to the mental lexicon: where is the stress?

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Introduction

When reading out aloud, words must be pronounced correctly not only in terms of their phoneme sequence but also with their stress pattern. If the wrong syllable is stressed the result may sound incorrect or even unfamiliar. How is this stress information stored in the mental representation of the word, and how is it derived and processed when encountering the written word to be read aloud? Are there differences between languages in these processes? In this chapter we consider the study of stress assignment in reading and how it can help us understand reading as well as lexical representations.

Syllables in a word are distinguished by degree of relative prominence, a phonetic-phonological property termed *lexical stress*. Differences may be gradual or multi-level, but usually we can take a simpler approach and assume just a binary distinction: emphasized syllables are stressed, contrasted with unstressed ones. Stressed syllables may alternate with unstressed ones within words or phrases, depending on the phonological properties of each language. Here we will consider the simpler case in which each word contains one stressed syllable that stands out from all the others. The requirement for a single stressed syllable in each word with two or more syllables is a linguistic pattern frequently encountered among European languages. Depending on the language, the location of the stressed syllable may or may not vary: In "fixed stress" languages, the stressed syllable occupies a specific position relative to a word boundary (e.g., first-syllable stress, in Finnish, penultimate-syllable stress, in Polish, or final-syllable stress, in Turkish; Revithiadou, 1999). In contrast, in "free stress" languages the position of the stressed syllable varies among words. Therefore, in free-stress languages stress may contribute to lexical identity, assuming a contrastive (distinctive) role, because a change in stress pattern could result in a different word.

In any stress-assigning language, correct pronunciation of a word entails production of the appropriate relative prominence among the constituent syllables, that is, correct stress assignment. When stress is not entirely predictable but depends on lexical identity, we assume that it is somehow included in the lexical representation associated with the particular word. In other words, lexical stress must be contained in the mental lexicon of speakers of free-stress languages. Even when a "default" stress position is recognized, words bearing stress in nondefault positions must be specified for stress. This specification serves production (Levelt, Roelofs, & Meyer, 1999). It also supports spoken word recognition, because the acoustic correlates of stress constitute salient features that are readily perceived and rapidly bias lexical selection away from stress-mismatching candidates (Reinisch & McQueen, 2010). That is, the phonetic prominence of the stressed syllable is immediately perceived and used to guide the process of spoken word recognition even before the rest of the word is heard.

None of this seems particularly controversial or problematic. However, a particular set of issues arise in the context of *visual* word recognition, where no acoustic prominence exists to guide lexical processing. In reading aloud, word recognition is followed by word production.

Therefore, stress must be assigned at some point in the process. This may be accomplished in the lexicon, based entirely on the aforementioned lexical stress specification. If the mental word lemma contains its own stress pattern then recognizing the word on the basis of its graphemic (letter) string will allow access to the stress pattern along with word identification. Nevertheless, there must be additional or alternative, perhaps sublexical, routes, allowing stress to be assigned in the case of reading aloud pseudowords. Pseudowords are not listed in the mental lexicon but are still pronounced with a stress pattern when read aloud—where does that come from? Moreover, stress is orthographically marked in some languages. In this case, the written stimulus provides visual information relevant for stress assignment, in addition to the segmental information conveyed by the letters. How is this information processed? Is it effective in pseudoword reading? In the case of words, is it integrated with lexical stress specification, does it compete with it, or does one predominate and obviate the other? It is possible that partially matching or otherwise related lexical items might affect stress assignment in reading by biasing certain positions or by triggering mechanisms of analogy.

Although stress assignment is a necessary component of effective word reading, these questions have received little attention in the reading literature, as if "decoding" a grapheme sequence into phonemes caused a word or pseudoword to be magically produced in full, with appropriate prominence attribution among its syllables that need not be systematically investigated. In this chapter I present some work we have carried out in our research group aiming to address some of these questions. Our goal is to understand stress assignment both as a subprocess of reading and as an instance of lexical processing that might reveal information about the structure and contents of the mental lexicon.

Greek stress and the diacritic

Greek is particularly suited to the study of stress assignment in reading because Greek is a free-stress language and because stress is marked in the orthography with a special diacritic. Therefore there is contrastive variation among words and syllables that can be studied and there are visual sources of relevant information that can be manipulated to support such investigation. In particular, every Greek word with two or more syllables carries stress on a single stressed syllable, which stands out phonetically and phonologically.[1] This syllable must be one of the last three syllables of the word (similar to Spanish and Italian), regardless of how many syllables may precede them. Greek has relatively few single-syllable content words (estimated at about 2% or less by token count; Protopapas & Vlahou, 2009). Therefore stress assignment concerns the vast majority of spoken and written content words in typical language processing and use. There are no known segmental or weight constraints on stress assignment in Greek (in contrast to Spanish; Gutiérrez-Palma & Palma-Reyes, 2007, 2008). Stress is therefore considered to be phonologically unpredictable. A relative preponderance of penultimate stress words (about 28%; Protopapas, 2006) offers only weak basis for a structural default, in contrast to the absolute and much higher proportion of "dominant stress"

[1] Actually, this is an oversimplification, but the complications need not concern us in the present discussion. The domain of stress assignment is the *phonological word*, which includes a content word and any clitics that attach metrically to it. There are cases in which a second stressed syllable arises (termed *enclitic stress*) in a phonological word as a result of clitic attachment and metrical constraints sometimes involving inflection. For a thorough discussion of Greek stress see Malikouti-Drachman and Drachman (1989) and Petrounias (2002).

words in other languages (e.g., penultimate stress in Italian; Colombo, 1992; Colombo & Zevin, 2009).

Stress contributes to lexical identity in Greek as attested by the existence of minimal stress pairs, that is, words that are composed of the same phoneme sequence and differ only in stress. Some words appear with two alternative stress patterns distinguishing older from more recent inflectional paradigms now occasionally associated with learned vs. vernacular styles of expression (e.g., άσκοπων /ˈaskopon/-ασκόπων /aˈskopon/ "pointless$_{gen.pl}$"). Frank minimal pairs (i.e., truly different words) include inflectional variants of the same lemma (e.g., ξέχνα /ˈksexna/ "forget$_{2nd.sg.imper}$"-ξεχνά /kseˈxna/ "forget$_{3rd.sg.indic}$"), which therefore express a morphological difference on a single base form, as well as unrelated lexical entries (γέρος /ˈjeros/ "old man"-γερός /jeˈros/ "strong"; μέτρο /ˈmetro/ "meter"-μετρό /meˈtro/ "metro" as well as μετρώ "I count"; συλλαβή /silaˈvi/ "syllable"-συλλάβει /siˈlavi/ "arrest$_{3rd.sg.subjunc.perf}$"). Some of these phonological minimal pairs are also orthographic minimal pairs, that is, they are spelled with the same letter sequence (except for the stress diacritic), whereas others are not; this issue will be taken up in a later section.

The Greek orthography is relatively transparent at the grapheme-phoneme level. Its consistency and predictability have been estimated at 95% for the feedforward (reading) direction (Protopapas & Vlahou, 2009), which concerns us here. Alphabetic strategies for effective reading of words and pseudowords are observed as early as mid-first grade (Porpodas, 1999), with very high performance (98%) on simple single-syllable items, second only to the fully transparent Finnish (Seymour, Aro, & Erskine, 2003). Stress is marked with a diacritic similar to the acute accent on the vowel of the stressed syllable in every word with two or more syllables. Therefore there is a clear, reliable visual stimulus associated with stress position in the Greek orthography.[2] Because the diacritic is obligatory and its omission is a spelling error, it is specifically taught at school as part of regular reading instruction starting in Grade 1. Teachers are supposed to emphasize the correct placement of the stress diacritic and use special drills to sound out syllables and listen for the prominence as a way to increase children's awareness of stress. If Greek readers, beginners and advanced alike, were to fully utilize this diacritic in reading, there would be no stress assignment errors in reading Greek. As detailed below, this is far from being the case. The high error rate in spelling the diacritic that is observed in elementary and even secondary education attests to at least a certain amount of difficulty with stress assignment.

(Mis)stressing pseudowords

Proficient readers know the words they are reading and make no mistakes in pronouncing them. Reading accuracy is very high for readers of Greek as early as the middle elementary grades (Protopapas, Sideridis, Simos, & Mouzaki, 2007), so it is not surprising that stress assignment errors are not observed in expert word reading. Beginning readers may not know many words by sight, but they know in their spoken form most of the words they are asked to read aloud. When they go serially through a letter sequence from left to right and work out the syllables one by one they do not at first pronounce them all together. If they do pronounce each syllable separately, there is no unitary phonological word and no stress assignment.

[2] Although generally very reliable and consistent, orthographic marking of stress is not in fact entirely free from inconsistencies, as pointed out in detail by Petrounias (2002). See Protopapas (2006) for a brief discussion of these issues.

Subsequently, at the point of combining the syllables into a single word to be fluently pronounced, they are necessarily recognizing the word and can thereby assign proper stress to it by recourse to its specification in their mental lexicon. Therefore stress assignment errors are rarely produced in word reading even for beginning readers. For this reason, difficulties with stress assignment have gone largely unnoticed by educators and researchers.

The picture is different with pseudowords, which do not have internal lexical representations and therefore must be stressed by recourse to the printed diacritic. In the context of a study on reading assessment we first noticed substantial proportions of misstressed pseudowords in a sample of 7th-grade (12–13 years old[3]) children from the general population (Protopapas, 2006). The contrast with word reading was striking. Specifically, the stress error rate for words was 1.6% and could be largely accounted for by the existence of similar words with different stress patterns that were familiar to the children (thereby indicating a lexical source of confusion). In comparison, the stress error rate for pseudowords was a whopping 14.1%. This even exceeded the segmental error rate for pseudowords, which was 10.1%, more or less in line with expectations, given the age of the children and the moderate complexity of the stimuli (2–5 syllables long). Most of the children in that sample were otherwise adequate or proficient readers but, as in every unselected sample, children with reading abilities at all levels, including some with reading difficulties, must have been included as well. An analysis of stress assignment accuracy by reading ability showed that more skilled readers made fewer stress assignment errors but the correlation with word reading speed was far from perfect (r = .26) indicating that stress assignment is not simply an index of general reading ability.

The distribution of stress errors across syllables was far from homogeneous. The 10 pseudowords with stress marked by the diacritic on the penultimate syllable were misstressed on average by only 4.2% of the children, whereas the other 10 pseudowords, with stress marked on the antepenultimate or final syllable, were misstressed by 24.4% of the children. Considering only the cases of incorrect stress, assignment on the penultimate was observed 84.6% of the time, compared with 10.5% on the antepenultimate and 4.9% on the final syllable. This preponderance of incorrect stress assignment on the penultimate provided a dramatic illustration that our simplistic ideas about the diacritic providing all necessary information for stress assignment in reading were, well, simplistic. A more apt description of the findings might be that children sometimes ignored the diacritic and placed stress on the penultimate instead. This was puzzling because the diacritic is indeed a reliable source of accurate stress assignment information and readers at any skill level would do fine by attending to it and using this information in pronouncing the visual stimuli. A host of questions were raised by this finding, concerning the conditions under which stress assignment errors are made and the mechanism by which stress is assigned when the appropriate routes fail. It seems that stress assignment is a process that can be conceived separately from segmental decoding in reading and worth studying on its own.

Two ideas emerged prominent from these observations: First, that when reading words stress may be assigned by our knowledge of the words, that is, via the mental lexicon, even when visual (orthographic) information is present. And second, that processing of the diacritic may not be a trivial cognitive task. The former idea was subsequently explored in depth in follow-up studies with adults and with children in a wide range of school ages, as presented in the next section. The latter idea remains relatively unexplored because there are not really any

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[3] In Greece children enter 1st grade in the calendar year in which they reach their 6th birthday. Therefore Grade 1 children are 6–7 years old, Grade 2 are 7–8 years old, and so on.

models of processing diacritics in reading. Even though diacritics serve a variety of purposes in diverse writing systems there is almost no research examining when, how, and even whether, they are processed in the course of visual processing of the written stimuli. These issues are taken up and discussed to some extent in a following section, including some directions for further research.

While on the topic of stress assignment in pseudoword reading, it is informative to consider the performance of children with reading difficulties. Is stress assignment a task of particular difficulty? If yes, then it can be used diagnostically, and it may be studied further in order to understand the nature of the underlying impairments that hinder reading development. There is some discussion in the dyslexia literature suggesting that prosodic aspects of language, including the perception of stress, might be related to reading impairments. Although the theoretical links remain tenuous, there is some evidence in other languages that early sensitivity to prosodic features, including stress contrasts, may be related to subsequent reading performance (e.g., Gutierrez-Palma & Palma Reyes, 2007; see special issue edited by Wade-Woolley &Wood, 2006). Perhaps prosodic sensitivity is another aspect of phonological development and awareness, which is known to be very strongly associated with learning to read. Or prosodic sensitivity may be a specific marker of distinct perceptual or cognitive difficulties that relate to learning to read independently of segmental phonological awareness. To disentangle these issues we first need to establish whether there are in fact any particular difficulties with stress assignment in children with reading problems.

To examine this question, we have explored stress assignment in a group of 29 children with diagnosed dyslexia and a group of 29 control children in secondary education (Anastasiou & Protopapas, submitted). The two groups were matched in age (ranging between 12–17 years) and nonverbal intelligence (Raven's matrices). As expected, children with dyslexia were slower and less accurate than typically developing children in reading words and pseudowords and their spelling was quite poor. They were slower in rapid naming tasks, as expected for reading development in a consistent orthography (Georgiou, Papadopoulos, Fella, & Parrila, 2012; Georgiou, Parrila, & Liao, 2008). Their performance in phonological awareness tests (phoneme deletion and spoonerisms) was also substantially lower than that of the control group, consistent with previous reports in Greek (Protopapas & Skaloumbakas, 2007; Protopapas, Skaloumbakas, & Bali, 2008) and despite the orthographic transparency that supposedly causes phonological awareness to reach ceiling at young ages even for children with reading difficulty. In spite of these difficulties, they were not impaired in passage comprehension or in short-term memory (digit span forward), again in line with expectations from previous studies at similar ages (Protopapas & Skaloumbakas, 2007). So we can be confident that this is a well-selected, if not entirely homogeneous, sample of adolescents with a well-characterized dyslexic profile.

Stress assignment performance was impaired in this dyslexic group, both in reading and in spelling. Some stress assignment errors were noted in word and passage reading (significantly more than by the control group). However, the major differences were observed in pseudoword reading and spelling. Out of 30 pseudowords, typical readers read segmentally accurately on average 27 items and stressed accurately 29 of them. The high proportion of correct stress assignment is consistent with the age of these children and their average or better reading level. In contrast, children with dyslexia read segmentally accurately 23 items on average and stressed correctly only 22, a substantial relative disadvantage indicating difficulties in dealing simultaneously with the demanding task of segmental decoding and the processing of the diacritic. In pseudoword spelling, children with dyslexia were particularly prone to omission of the stress diacritic, even when specifically instructed prior to the spelling

test to be especially careful about it. Children were also tested with a stress marking task, in which they were given a list of familiar words lacking stress diacritics and were asked to note the missing diacritics on the words. This kind of test is used in other relatively transparent languages as a screening for reading difficulties (Paulesu et al., 2001). Typical readers excelled on this task, scoring at ceiling. In contrast, children with dyslexia scored significantly lower and took significantly longer to perform the task.

In all, children with dyslexia presented the expected literacy profile in the reading and spelling tasks, including pronounced difficulties with the orthographic marking of stress, both in receptive and expressive tests. But they were only slightly impaired in a more direct measure of stress sensitivity that did not include orthographic processing. Specifically, they were tested with a set of pseudowords that were composed of 3 identical consonant-vowel syllables, e.g., /ˈlololo/ (a different syllable for each pseudoword). They were first asked to repeat each pseudoword orally, as pronounced by the experimenter. Then they had to indicate with their finger or with a written mark the location of the stressed syllable on a three-dash prompt corresponding to the three syllables (i.e., __ __ __). They were not clearly slower or less accurate in this task than the control group, indicating that their difficulties dealing with stress in reading and spelling were not an issue of phonological sensitivity per se but, rather, an issue of orthographic processing or of interfacing between their metrical awareness and explicit orthographic processing. This result is consistent with recent findings in German and English (Barry, Harbodt, Cantiani, Sabisch, and Zobay, 2012; Mundy & Carroll, 2012, 2013) suggesting that metrical phonological representations are normal in dyslexia but, rather, their explicit processing may be impaired in certain awareness and orthographic tasks.

Sources of stress information

The interplay among alternative potential sources of stress assignment in reading Greek has been explored in a series of studies employing specially designed pseudowords. Use of pseudowords was mandated by the requirement to disentangle lexical from nonlexical sources of information. Because words are presumably stored along with their stress information, it is not possible to examine nonlexical sources in word stress assignment because the lexical specification may swamp alternatives, confounding the manipulations. That is, if a reader stressed a printed word correctly, it is impossible to determine whether the source of stress assignment was knowledge of the word or processing of some aspect of the visual stimulus. Misstressed words are too rare to serve as useful data points. Moreover, when they are misstressed all we can surmise is the failure of every potential stress assignment strategy, without any indication that might help distinguishing among them. It might sound somewhat counterintuitive that lexical stress assignment may be explored using pseudowords, which have no lexical representation. However, pseudowords may be constructed to be very similar to specific words, for example by changing only a single letter of a familiar word. In this way we create pseudoneighbors and take advantage of neighborhood activation via sublexical overlap, even though there is no full match with any word's orthographic representation.

Three potential sources of stress assignment information were considered in the first series of studies. The first is the specific lexical entry, that is, knowledge of how each word is stressed as part of its representation in the mental lexicon. The second is the orthographic mark, that is, the visual information provided by the stress diacritic noted on each properly spelled word. And the third is a general presumed "default", that is, a non-specific property of the language structure or of the entire lexicon, according to which there may be a preferred metrical pattern

in the absence of specific information to the contrary. The notion of a default stress pattern is theoretically attractive in linguistic circles where specification is considered a burden and only necessary in so-called "marked" cases. It is also postulated and to some extent supported with psycholinguistic evidence in certain languages (e.g., Colombo, 1991; Levelt, Roelofs, & Meyer, 1999; Schiller, Fikkert, & Levelt, 2004), although it is contested by alternative notions, either based on statistical properties of the lexicon, such as stress neighborhood (in Italian: Burani & Arduino, 2004; Burani, Paizi, & Sulpizio, in press; Paizi, Zoccolotti, & Burani, 2011; cf. Sulpizio, Arduino, Paizi, & Burani, 2013), or on specific phonological properties of syllables, such as the notion of syllable weight as related to the existence of syllabic codas (in Spanish: Waltermire, 2004).

Two dimensions of manipulation permit investigation of the aforementioned three postulated sources of stress assignment information. The first dimension concerns word resemblance. Starting with an actual familiar word, such as δυνατός (/ðinaˈtos/ "strong"), we may alter a single letter, resulting in, e.g., βυνατός (/vinaˈtos/), or more letters, such as δομελός (/ðomeˈlos/). The former pseudoword is arguably similar to the original, "source," word, and might activate it when seen. In contrast, the latter pseudoword is not similar to the source or to any other word, in which case it would not be expected to strongly activate any lexical entries. This crucial manipulation leads to sets of pseudowords that are matched in overall word-likeness, including syllabic structure, but are distinct in their resemblance to particular words. Of course the intended similarity is verified prior to their use in experiments, by asking samples from the target population to indicate words that come to mind upon viewing each pseudoword. Items are retained for experiments if they fulfill strict resemblance criteria, such as production of the source word by a high proportion of respondents (and production of no items with different stress patterns) for the word-resembling set, and no consistent production of any particular word (source or other) for the word-nonresembling set.

The second dimension of manipulation concerns presentation of the stress diacritic. Items with the diacritic contain orthographic information relevant for stress assignment, whereas items without it do not. Furthermore, the diacritic may be placed on the syllable consistent with the stress pattern of the source word, resulting, for example, in the word-resembling pseudoword βυνατός or the nonresembling one δομελός. Alternatively, the diacritic may be placed on a different syllable, inconsistent with the source word, such as βυνάτος and δομέλος, respectively. Finally, the pseudowords may be presented without a stress diacritic, for example βυνατος and δομελος, providing no visual clue as to their intended stress assignment. This combination of manipulations leads to items combining and contrasting sources of stress assignment information, as follows: Word-resembling items with a source-mismatching diacritic contrast lexical and orthographic information, whereas word-resembling items without a diacritic contain only lexical information and nonresembling items with a diacritic contain only orthographic information. Finally, nonresembling items presented without a diacritic provide no specific stress assignment information, thereby allowing a test for general strategies of preferences: If such items are consistently given a specific stress pattern then this would be evidence for a default. In the absence of a default operation we should expect to see random stress assignment distributed among the three final syllables (the allowed stress domain) equally or perhaps in proportion of the stress distribution in the lexicon.

Pseudowords created in this way were presented to participants to be read aloud. In order to be able to interpret the results in terms of the information sources, specific indices were computed based on the position of stress recorded in the experiment. A *lexical* index was derived by the proportion of readings consistent with the source word relative to the other two

possible stress patterns. A *diacritic* index was likewise derived by the proportion of readings consistent with the displayed diacritic (relevant only for items presented with a diacritic) relative to the other two patterns. Finally, a *default* index was derived by the proportion of penultimate-stress readings relative to antepenultimate- and final-syllable stress assignments. Each index was scaled so that a value of 0.00 would correspond to no effect (that is, to 33% of the readings, consistent with homogeneous assignment across syllable) and a value of 1.00 would correspond to perfect conformance to the corresponding source (that is, 100% consistent with the source word, for the lexical index, 100% consistent with the diacritic, for the diacritic index, or 100% penultimate-syllable stress, for the default index). Negative values indicated stress assignment inconsistent with the respective source.

Similar experiments were conducted in three groups: A group of adults, composed primarily of graduate and advanced undergraduate students (Protopapas, Gerakaki, & Alexandri, 2007), a group of children in Grades 7–9 from the general school population (Protopapas, Gerakaki, & Alexandri, 2006), and groups of children form the general population in Grades 2, 3, and 4 (Protopapas & Gerakaki, 2009). Testing of Grade 1 children was desirable, to discern the first signs of stress assignment processes. Unfortunately, it was practically impossible to achieve that because many children at the end of first grade are still unable to read three-syllable pseudowords fluently—although they can pronounce them correctly on a syllable-by-syllable basis—and therefore it is not possible to determine the stress location in their productions. There were some differences in methods and materials between the experiments, for example different pseudowords were created for the beginning readers, based words familiar to them, to ensure lexical activation in this population. In addition, some versions of the experiments aimed to compare response times and therefore employed computer-delivered presentation of individual stimuli, whereas other versions were based on sheet presentation of the stimulus set. Because of these differences, direct comparisons across groups are made with some reservation, allowing mainly rough qualitative judgments. However, comparisons among relative influences of the different sources of information, based on the within-group differences between stimulus conditions, can be carried out with substantical confidence.

The results of these experiments indicated that beginning readers base their stress assignment predominantly on their word knowledge, as the Grade 2 lexical index for word-resembling pseudowords was around .5 (ranging between .47–.66) whether presented with a diacritic consistent or inconsistent with the source word or without a diacritic. Thus the lexical source of stress assignment information is initially the strongest one, indicating that by the time the children put together the decoded phonemes (or syllables) to pronounce a complete word the diacritic information may be lost or unnecessary. In Grades 3 and 4 the range of lexical index values expanded, reflecting increasing effects of the diacritic. Thus for word-resembling pseudowords presented with a source-consistent diacritic the lexical index progressed from .66 in Grade 2 to .81 in Grade 3 and .90 in Grade 4, whereas for word-resembling pseudowords presented with a source-inconsistent diacritic the corresponding progression was from .47 to .28 and .23, respectively. For word-resembling pseudowords presented without a diacritic there was an increase, from .59 to .67 and .75, indicating the the lexical source was also becoming stronger with grade, but this increase was not as rapid as that of the diacritic. These conclusions were also supported by analysis of the diacritic index, which started small (.16 with word-nonresembling pseudowords) or negative (−.15 with word-resembling source-inconsistent presentation) in Grade 2 and climbed to .59 (and .19, respectively) by Grade 4.

The importance of the lexical source for stress assignment information was confirmed in Grades 7–9, with the lexical index reaching .80 (for high-frequency source words) and .65 (for low-frequency source words) using word-resembling pseudowords presented without a

diacritic. The level of lexically-based stress assignment was thus similar to that attained in Grade 4. The diacritic index reached .74 for word-nonresembling pseudowords, consistent with continuing development beyond the level attained in Grade 4. Finally, in the adult sample, the lexical index was .72–.73 for word-resembling pseudowords presented without a diacritic, and the diacritic index was .75–.77 for word-nonresembling pseudowords, indicating that a plateau had already been reached earlier regarding both sources of information (lexical and orthographic). Word-resembling pseudowords presented with source-consistent diacritic were pronounced with the intended stress almost always, the corresponding lexical index reaching .95, not significantly distinguishable from perfect performance (that is, equal to 1).

While the lexical and orthographic sources of stress assignment information develop rapidly over the course of elementary education, the effects of the presumed default metrical pattern of penultimate stress ranged from a maximum of .44, in word-nonresembling pseudowords presented without a diacritic in Grade 2, down to .37 and .22 in Grades 3 and 4, respectively, and back up to .43 in Grades 7–9 and .42 in adults. Differences in materials may account for the apparent discrepancies and longitudinal wavering of the default index. An alternative interpretation might be that early effects of the default pattern may arise from spoken language biases and are gradually overcome by reading-specific processes, such as learning to process the diacritic. In contrast, later effects may reflect the cumulative reading experience culminating in an efficent orthographic lexicon exerting large-scale statistical effects. This account remains entirely speculative and in need of experimental substantiation with appropriately designed materials and hypotheses. At the moment, all that can be asserted with confidence is that all three hypothesized sources of stress assignment information do in fact exert detectible effects and can therefore be considered active contributing factors in the word reading process in Greek.

A fourth potential source of stress assignment information was considered in subsequent research, namely derivational suffixes. These can be viewed either as morphological units or as mere word-final letter sequences; the distinction among the two bears important theoretical and empirical implications. From a theoretical linguistic point of view, certain morphemes in Greek are thought to constrain stress assignment, either by bearing stress themselves or by restricting stress to a specific preceding syllable (Ralli, 2003; Revithiadou, 1999). Similar claims are made in English regarding stress-affecting (e.g., -ate, -ion, -ic, etc.) versus stress-neutral suffixes (-ness, -less, -ly, etc.) (Chomsky & Halle, 1968; Goldsmith, 1990). Linguistic analysis thus assumes that suffixation involving one of the stress-constraining suffixes results in stress assignment that is perfectly predictable on the basis of the suffix. From a statistical viewpoint no absolute pronouncements are necessary. Instead, a systematic co-occurence of certain metrical patterns with specific word-final letter sequences may cause additional items bearing the same final sequence to receive the same metrical pattern by mechanisms of generalization or analogy, regardless of the diacronic cause of the observed systematicity.

If the formal linguistic analysis is correct then we should expect novel words suffixed with stress-constraining morphemes to receive the fixed stress pattern dictated by the suffix, without exception and without dependence on context or on superficial similarity. On the other hand, if the metrical systematicity expresses synchronically no more than a statistical generalization, then novel items with the same final letter sequence may or may not receive the same stress pattern as existing suffixed words. In this case the word-final letter sequence should no longer be considered as a strictly unitary morpheme. The probability of stress assignment consistent or inconsistent with existing suffixed words may depend on attributes such as superficial similarity (e.g., letter overlap) or, more importantly, on the distribution of

stress over items with the same final letter sequence (Arciuli & Cupples, 2006; Arciuli, Monaghan, & Seva, 2010; Ševa, Monaghan, & Arciuli, 2009).

In our study (Grimani & Protopapas, 2009) we focused on derivational morphemes thought to constrain stress, such as -οσύνη /osini/ and -ότητα /otita/ (both meaning -ness/-ity, e.g., καλοσύνη /kaloˈsini/ "kindness", χρησιμότητα /xrisiˈmotita/ "usefulness"). The former bears penultimate-syllable stress whereas the latter bears antepenultimate-syllable stress. They differ in an important respect, which is relevant from the statistical viewpoint but irrelevant from the theoretical linguistic viewpoint. Specifically, there are no words ending in /otita/ stressed on syllables other than the antepenult. Thus, the -ότητα suffix does not have any stress competitors. However, there are words ending in /osini/ stressed on syllables other than the penult, for example χαρμόσυνη /xarˈmosini/ "joyous." This word is a stress competitor for the -οσύνη suffix. It is not considered affixed itself, so the fact that it ends in the same letter sequence is incidental and, in theory, inconsequential. However, if stress assignment is not morphologically motivated but governed by distributional properties then the two word-final letter sequences will behave differently when applied to novel stems. That is, suffixes without stress competitors might be more effective in constraining stress in novel items than suffixes with stress competitors.

These hypotheses were tested by creating pseudowords composed of pseudostems concatenated to letter sequences matching stress-constraining derivational suffixes. The pseudostems did not resemble any specific words. For example, the pseudoword ρολποσυνη /rolposini/ was created to match the consonant-vowel structure and word-final sequence of the suffixed word λησμοσύνη (/lizmoˈsini/ "forgetfulness") as well as the non-suffixed word χαρμόσυνη which, as mentioned above, incidentally ends with the same letter sequence. The resulting pseudowords were presented to adult participants with or without diacritics, for reading aloud. When present, the diacritic was placed either consistent with the typical stress pattern for this suffix or inconsistent with it. We thus followed the same rationale as with the preceding experiments, except that now we were primarily interested in the relative strength of the diacritic, default, and morphological (suffix or word-end) sources.

The results showed significant effects of the morphological suffixes (or word-final letter sequences) that were strongest in the absence of the diacritic and significantly larger for suffixes without stress competitors than for suffixes with stress competitors. The latter finding indicates that stress-constraining effects of suffixes may not be synchronically formal but, rather, distributional. In other words, they may be analyzed as cumulative lexical rather than morphological effects. The suffix effect was somewhat stronger than the default effect, resulting in a final hierarchy of stress assignment sources of information, from strongest to weakest, as follows: lexical > diacritic > suffix > default. This order of importance suggests that the cognitive processes of stress assignment in reading are affected by a multitude of factors and warrant further research in their own right.

Processing of diacritics

Diacritics are ubiquitous in writing systems but have received very little attention from reading researchers. Diacritics are used in middle-eastern writing systems, such as the Arabic, Hebrew, and Aramaic scripts to denote short vowels and consonant gemination (Bauer, 1996, p. 562) and in southeast Asian scripts to denote post-consonantal or long vowels (Aaron & Joshi, 2006; Karanth, 2006). In these cases, diacritics seem to signify entire phonological segments. Readers make use of information obtained from diacritics: for example, diacritics

used to denote vowels in written Hebrew are used by readers in reading aloud (though not consistently in silent reading, restricted to low-frequency words) and in ordered word recall (both for deaf and hearing participants) (Miller, 2004). In many European languages diacritics are used to modify the phonetic value of letters. For example, different high front vowels are denoted with accent diacritics on the letter e in French; vowel fronting is denoted with umlaut in German; vowel length is denoted with accents in Hungarian, Czech, and Slovak (Comrie, 1996; Csépe, 2006); and consonant palatalization is denoted by the háček in several Slavic and Baltic languages (Comrie, 1996). In these cases, diacritics do not signify phonological segments by themselves but contribute to the overall visual shape of the letter they are combined with to determine the corresponding segmental value. Although letters with diacritics are often treated as separate letters for lexicographic purposes, they may be treated as variants of the same letter perceptually (Ayçiçeği & Harris, 2002).

Diacritics are also used for suprasegmental functions. In some tone language adaptations of the Roman alphabet, diacritics placed above or below the vowels denote phonemic tones, as in Vietnamese (Đình-Hoà, 1996) and the pīnyīn romanization system for Mandarin Chinese (Mair, 1996). In some European languages with lexical stress, including Greek, Spanish, and Italian, the acute accent mark is used to signify stress assignment at least in certain cases (e.g., when irregular or unpredictable). In these cases diacritics do not contribute to the segmental characterization of the phonological word but operate on a suprasegmental tier. There is some evidence, in Italian, that the diacritic is computed separately from letter identity and provides a processing advantage for lexical access (Cubelli & Beschin, 2005).

In the aforementioned cases the function of the diacritic lies on a continuum from fully segmental through feature modification to prosodic. Further along this continuum, beyond word-level suprasegmentals, one finds punctuation marks. These are often similar in shape and size to diacritics but they are placed between words instead of on the letters and they serve purely prosodic functions such as signifying a phrasal boundary or breath group. These orthographic symbols are used in many languages to mark phrase-level boundaries (e.g., commas and periods in European languages) or to indicate phrasal intonation (e.g., question marks). They cannot be considered diacritics in that they are not added to characters (letters) in the script. However, they resemble diacritics both in shape and in suprasegmental domain of function. Like diacritics, these symbols have not attracted very much attention from reading researchers even though they presumably contribute important information to facilitate fluent reading (Hirotani, Frazier, & Rayner, 2006; Pynte & Kennedy, 2007; Steinhauer & Friederici, 2001; Steinhauer, 2003).

In Greek, there are two diacritics relevant to single-word pronunciation, one signifying stress and another (diaeresis) that is used to break apart digraphs.[4] In the study of Greek spelling both diacritics have been found to depart from the common pattern of spelling errors (Protopapas, Fakou, Drakopoulou, Skaloumbakas, & Mouzaki, 2013). Specifically, they are both frequently omitted by children with dyslexia as well as by typically developing children. Moreover, their omission is disproportionate to the overall spelling error rate, as the stress diacritic is rarely used by some children with reading difficulties and by younger typically developing children, while the diaeresis diacritic is omitted frequently by advanced readers, despite the resulting spelling error with clear phonological consequences. In fact omission of

[4] For example, the digraph αι is pronounced /e/, as in παιδάκια /peðaca/ “kids”. The two letters are split by diaeresis (¨) placed atop the ι, so that αϊ is pronounced /ai/, as in παϊδάκια /paiðaca/ “chops”.

the diaeresis is the only phonological spelling error observed with any appreciable frequency in the spellings of children past the elementary grades. Further scrutiny is thus warranted to shed light on the particular difficulties posed by the diacritics in orthographic processing, with potential consequences for a deeper understanding of reading.

Difficulties in spelling the stress diacritic are said to be currently pervasive among beginner as well as advanced readers. The diacritic is often left out of electronic communication, for simple convenience, as users apparently won't be bothered with the extra keystroke. In this context it may be relevant that despite the ubiquity of electronic communication devices and keyboards hardly anyone in Greece is trained to type. However, this practice wouldn't be so widespread if it seriously hampered communication. The fact that it is so widespread suggests that perhaps the diacritic is not so important after all for efficient writing and reading Greek. Consistent with this interpretation, a corpus-based assessment of orthographic stress minimal pairs, that is, words that are graphemically identical (i.e. are written with the same letter sequence) and can be distinguished only by stress pattern (i.e., the diacritic), led to an estimate of the rate of lexical confusion well below 1% in isolated words (Protopapas, 2006). That is, if stress diacritics were entirely removed from Greek texts less than 1% of words would be read incorrectly as a result of misstressing. Moreover, this estimate fails to take into account any disambiguating effects of context, which are likely to be substantial. Although individual words differing only in stress make up between 3–5% of corpus tokens, and the cumulative frequency of the minimum-frequency members of stress pairs barely approaches 1%, it may be expected that the vast majority of ambiguities will be resolved by sentential context and they will be hardly noticed. Therefore only a vanishingly small proportion of stress diacritics are actually necessary for disambiguation when dealing with modern Greek texts. Considered in this light, the tendency of many contemporary users of the language to omit the diacritics seems not entirely unjustified.

This reasoning can be more fully developed in the context of the competition model (Bates, Wulfeck, & MacWhinney, 1991), in which cue validity is weighed against cue cost in determining the effect of any given cue in language processing. Cue validity refers to the information value of a form whereas cue cost refers to the amount and type of processing associated with it. In reading Greek, the validity of the diacritic for stress assignment is low from an information point of view. Even though the diacritic is reliably associated with stress position, processing of the diacritic is usually unnecessary for the identification of the appropriate lexical item. Because the lexical representation presumably includes stress assignment information, processing the diacritic poses a needless burden: By the time the segmental specification of the word is available for pronunciation or further processing, the stress pattern is also available through lexical activation and the diacritic may be ignored without loss. Better to focus one's resources on efficient lexical selection on the basis of the letter sequence alone.

What about cue cost? One might argue that there is no difficulty associated with decoding the diacritic, because it is a simple visual stimulus and is consistently paired with a letter corresponding (alone or in combination) to the vowel of the stressed syllable. However, there are two reasons why this initial approach may be overly simplistic. First, the result of decoding the diacritic is not found at the segmental level but at the metrical level, which lies atop syllables which lie atop segments. That is, stress assignment concerns the outcome of a syllabification operation applied on the decoded letter sequence, and is not commensurate with the letters themselves or with their immediate decoding product. It may not be so simple to construct a metrical frame on the basis of the decoded segments and then somehow mark as stressed the syllable that includes, in its graphemic specification, the letter on which the stress

diacritic was marked. This operation would require retention of the diacritic location across a sequence of decoding operations, namely from letters to graphemes to phonemes to syllables. Any overload or slip of attention in any of the intervening levels will cause the stress information to be lost or misplaced. Therefore decoding of the diacritic may in fact pose nontrivial demands on the reading system, which might be best directed elsewhere. This situation is very different from spoken word recognition, in which a stressed syllable is simply indicated in the signal (being louder and longer than unstressed syllables) and can be mapped directly onto the corresponding lexical phonological entry without the need for any intervening mapping or complicated processing.

The second reason for which decoding of the diacritic may be difficult has to do with learning through experience, that is, the history of reinforcement or, rather, the lack of it. If decoding the diacritic is not entirely transparent and effortless for beginning readers, and if lexical access can be successfully carried out without decoding the diacritic, then stress assignment may largely proceed on the basis of the lexical specification. Therefore, children will practice not decoding the diacritic and will thereby fail to attain expertise in the requisite processing. Repeated successful reading while ignoring the diacritic will cause processing of the diacritic to remain increasingly difficult, compared to segmental decoding, due to relative lack of practice. It will also cause the diacritic to diminish in information value because of the success achieved in its absence. Processing the diacritic will be increasingly inefficient, in a vicious circle of successfully ignoring it. In this line of thought it is almost surprising that the diacritic is processed at all and that proficient readers seem to be affected by it as much as by lexical activation.

Some evidence relevant to this concern is provided by timed measures of word reading in different diacritic conditions. As discussed above, children in Grades 2–4 read aloud words with the diacritic present versus absent and, when present, consistent with the word stress or inconsistent with it (Protopapas & Gerakaki, 2009). In addition to a significant grade effect of about 100 ms between Grades 2 and 4, there was a significant diacritic effect, arising from the contrast between the two conditions in which it was present. Specifically, reading the word (and pronouncing it with the correct stress) was 70–90 ms faster when the diacritic was consistent with the word stress than when it was inconsistent with it. Absence of the diacritic did not hamper reading times, as the approximately 20-ms mean difference between the conditions with consistent and without diacritic did not approach significance. Although this difference might have come out significant in a substantially larger sample, it seems clear that the effect of removing the diacritic is weak at best whereas the effect of misplacing it is substantial. This suggests that the diacritic need not be processed to recognize and pronounce the word correctly, consistent with the preceding discussion. Still, the diacritic does become part of the orthographic image of the words, so that its misplacement can affect orthographic processing.

The idea that the diacritic is not decoded as an individual component but, rather, forms part of a fully specified orthographic representation is consistent with evidence from the rates of reading development in the same sample of children. We hypothesized that if processing the diacritic was a form and a part of learning to decode written stimuli, then the index of diacritic influence in stress assignment would follow the development of segmental decoding, as provided by pseudoword reading tasks. In contrast, if processing the diacritic was a form and a part of orthographic processing leading to sight-word reading, then the diacritic index would be more strongly correlated with assessments of word reading efficiency, as provided by word reading tasks. As it turns out, the diacritic index was much more strongly correlated with word fluency than with pseudoword fluency (r = .63 vs. .49, respectively; and partial

coefficients, controlling for grade, .56 versus .39, respectively). Thus the inhibitory, rather than facilitatory, effects of the diacritic on reading times are preferably interpreted as reflecting the development of word reading efficiency and sight-word reading. Again, this conclusion is consistent with the cue validity/cost analysis indicating that decoding of the diacritic would be inefficient and therefore not a preferred processing option.

The aforementioned experiments should not be construed as suggesting that diacritics are entirely ignored or completely useless. Although lexical sources of stress assignment seem to predominate, especially in less experienced readers, it remains the case that proficient readers do eventually reach a stage in which the diacritic is fully processed when present, evidenced in largely or entirely accurate reading of pseudowords. For adult expert readers effective processing of the diacritic is evidenced even in the face of lexical competition from word resemblance. It must also be taken into account that orthographic stress minimal pairs exist, in which the disambiguating role of the diacritic has not yet been investigated. The story of processing the stress diacritic is certainly more complex than a move from an original preconception that it is always effective toward an (equally unsupported) experimental conclusion that it is always ineffective and mostly ignored. What is most interesting about the diacritic is that it seems to require a developmental and computational approach on its own, related to but not identical with the development and cognitive processes of visual word recognition as typically conceived at the grapheme-phoneme level alone.

Stress priming

The aforementioned studies establish a clear role for the diacritic in orthographic processing as well as a leading role in lexical activation for stress assignment in written word recognition and production. However, stress assignment may not be necessary in the absence of production. That is, if lexical activation is successfully achieved without recourse to stress, then we don't have any direct evidence that stress patterns are activated at all unless the words need to be pronounced. The fact that lexical entries specify stress and that this specification can be activated on the basis of the visual stimuli (written words) does not necessarily mean that metrical patterns are involved in visual word recognition in the absence of production requirements. This issue was addressed in a series of stress priming experiments, aiming to uncover whether and under what conditions stress patterns are activated from visual stimuli.

Assuming that stress patterns are activated by incoming stimuli, then it is conceivable that stress match between successive stimuli may facilitate processing of the later stimulus (i.e., priming), whereas stress mismatch might cause processing delays instead. Stress priming in some form or other has been obtained in a number of European languages. Specifically, in Italian (Colombo & Zevin, 2009) stress priming has been obtained in speech production with written words and pseudowords using the "pathway" method, in which short blocks of same-stress primes precede a target. All stimuli were read out aloud and stress assignment was recorded. The main finding was that words were assigned default ("dominant") stress incorrectly more often after pseudowords than after words, but only when the pseudoword primes had been assigned the dominant pattern. In other words there was an effect of stress pattern which was consistent with the construction of sublexical metrical frames and a weak effect of the default pattern. However, this stress effect was observed in the context of a speech production requirement, so it does not provide clear evidence for the activation of stress patterns by processing the visual word and pseudoword stimuli. It is plausible (indeed,

likely, given the pseudoword primes) that the priming effect was based on the output (production) stage.

In Spanish (Gutiérrez-Palma & Palma-Reyes, 2008) stress priming was obtained in visual lexical decision by a visual prime that was the same word as the target, orthographically matched or mismatched in stress specification (that is, correct versus incorrect placement of the Spanish stress diacritic). A priming effect was obtained only for long interstimulus times, suggesting that the incorrect orthographic representation of stress hampers word recognition at late stages of processing. This stress priming effect also cannot provide evidence for the activation of stress patterns by orthographic processing because it involved actual words and was detected only at relatively long delays between prime and target. Therefore it can be plausibly (indeed, preferentially) interpreted as stemming from lexical rather than orthographic processing. That is, the representation of the words in the mental lexicon mediated to produce the match or mismatch leading to the observed priming. Thus the finding concerns a lexical—rather than abstract metrical—mismatch. This and the aforementioned finding in Italian do not necessarily indicate the operation of a metrical level of processing and certainly do not imply the activation of stress information in visual word recognition.

Additional experiments have been conducted in Spanish, English, and Dutch using the cross-modal "fragment" method (Cooper, Cutler, & Wales, 2002; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001; van Donselaar, Koster, & Cutler, 2005). In this method the primes are auditory pairs of syllables not forming a word, such as /ˈprinθi/, followed by visual word targets with matching (príncipe /ˈprinθipe/) or mismatching (principio /prinˈθipio/) beginning (Spanish examples from Soto-Faraco et al.). The auditory fragment primes facilitated lexical decision on the matching targets, consistent with lexical activation based on the fragments. These findings highlight the role of stress patterns in the recognition of spoken words, consistent with more recent findings in Dutch showing rapid selection of matching lexical candidates as soon as a stressed syllable is detected (Reinisch, Jesse, & McQueen, 2009). However, these results still do not establish the existence of separate metrical patterns and their activation from visual (written) stimuli. All of these findings are more parsimoniously explained as indicative of lexical activation: the fragments activate matching lexical candidates but not mismatching ones. For example, the auditory stimulus /ˈprinθi/ activates the word "príncipe" but not "principio," thereby facilitating subsequent processing of the former but not the latter, given the corresponding orthographic stimuli. Again, priming occurs as a result of lexical—rather than abstract metrical—mismatch. Thus the involvement of stress *per se* in the reading process remains largely unexplored.

In our experiments (designed in collaboration with Nicolás Gutiérrez-Palma; Panagaki & Protopapas, unpublished data) we have addressed this issue by reasoning that, if metrical frames are activated as a result of visual word processing, then stress priming effects should be obtained across stimuli that are not segmentally identical and are only matched (versus mismatched) in stress. If the stress pattern originates in lexical activation then priming should only be observable with words. If, however, processing of the diacritic suffices to activate a stress pattern then stress priming should also be evident with pseudowords. Furthermore, this method allows us to address the theoretical issue of stress specification: If all stress patterns are stored in the mental lexicon then priming should be observed equally across stress positions, that is, for any stressed syllable. If, on the other hand, stress is underspecified, such that only lexical entries with nondefault stress contain stress information, then priming should not be observed for words with penultimate-syllable stress, because as the default it would not be specified in the lexicon and therefore there would be no mismatch (cf. Lahiri & Marslen-Wilson, 1991; Wheeldon & Waksler, 2004).

To examine these questions we created twenty groups of 3-syllable words, selected from a corpus-based list (Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, 2012). Each group included three morphologically unrelated words with penultimate-syllable stress and three with antepenultimate-syllable stress. All six words had the same initial syllable, consonant-vowel structure, and number of letters. The two stress subgroups in each group were matched in printed frequency, bigram frequency, orthographic and phonological neighborhood, the number of higher-frequency phonological neighbors, and cohort size (taking stress into account). An equal number of pseudoword groups were created, with the same initial syllables, by exchanging syllables and vowels among the words in each group. Thus the resulting pseudowords were fully matched to the words in all of the aforementioned orthographic and phonological characteristics. A preliminary lexical decision experiment confirmed that the selected items were indeed recognized as words and pseudowords by reasonably proficient readers (children in Grades 11 and 12). An example group of stimuli included the 3 penultimate-syllable stress words χαμένε /xaˈmɛnɛ/, χαλίκι /xaˈlici/, χαρίσω /xaˈriso/, the 3 antepenultimate-syllable stress words χάζεμα /ˈxazɛma/, χάλασα /ˈxalasa/, χάραζε /ˈxarazɛ/, and the corresponding pseudowords χαμάζε /xaˈmazɛ/, χαλάνο /xaˈlano/, χασάρα /xaˈsara/, χάραλη /ˈxarali/, χάμασω /ˈxamaso/, and χάριμι /ˈxarimi/.

A series of priming experiments were conducted using these stimuli, testing activation of stress patterns under different conditions. Both words and pseudowords were included in every experiment, along with the necessary filler items, but the experimental trials never crossed words with pseudowords, to analyze them separately. Participants performed lexical decision on targets, following presentation of primes that were not responded to. A visual-visual intramodal experiment tested whether stress patterns are activated by visual word recognition and visual nonword decoding. Two visual-auditory cross-modal experiments tested whether stress patterns activated by visual stimuli are compatible with stress representations arising from spoken word recognition, so that they might match or mismatch them. In one of these experiments, visual primes and auditory targets had a near-simultaneous onset (short stimulus onset asynchrony or SOA) whereas in the other the auditory target was delayed about 300 ms after the appearance of the visual prime (long SOA). Finally, an auditory-visual cross-modal priming experiment, with the visual target appearing at the offset of the auditory prime, provided the converse test. This was set up as a fallback situation, because it is clear that stress is processed acoustically and contributes to lexical access. Therefore, there is no question as to whether an auditory prime will activate a stress pattern or not. The question is only whether this stress pattern can exist outside the specific lexical items that are activated and whether it can interact with subsequent activation arising from the processing of visual stimuli.

The results were clear-cut: there was no stress priming whatsoever in any of these experiments, either for words or for pseudowords. With 60 participants per experiment and 60 targets per lexicality condition (words and pseudowords) we can be fairly confident that the magnitude of any stress priming effect is statistically indistinguishable from zero within a few milliseconds. Therefore it seems that metrical frames are not activated independently of specific lexical representations and specifically they do not seem involved in the visual processing of (printed) words and pseudowords. Although it is generally considered risky to interpret null effects, there is a certain confidence that arises from repeated testing across multiple relevant conditions and from the careful matching and selection of the stimuli. Thus we may interpret previous effects of stress and stress-related priming as not addressing stress patterns in general but, rather, the role of stress patterns in specific situations where stress processing is necessary (as in production) or unavoidable (in the perception of spoken words).

Considering our experiments together with all previous studies, the situation remains that at the moment we have no evidence for the activation, or even the existence, of abstract metrical frames in perception that can operate within or in relation to the mental lexicon independently of their involvement in the processing of particular words.

Implications and future directions

Stress remains underexplored in word processing, including spoken and written word recognition, and its representation and role in the mental lexicon is generally assumed but poorly understood. Especially from the viewpoint of reading there is very little work related to stress. Cognitive models of word recognition, in particular, have generally ignored stress, perhaps in part because they have originated in the English-language studies where the convenience of single-syllable words does not completely invalidate the reported findings. In most European languages, however, single-syllable words are not the norm. In Greek, in particular, single-syllable content words are extremely few and atypical (Protopapas & Vlahou, 2009), so any attempt to model psycholinguistic processes based on them would be laughable. The same can probably be said about other languages. Fortunately, there is some recent activity to rectify the situation, including computational models of multisyllabic word recognition with stress assignment procedures in Italian (Pagliuca & Monaghan, 2010), English (Perry, Ziegler, & Zorzi, 2010), as well as preliminary work in Greek (Outos & Protopapas, 2009). This trend will hopefully pick up additional steam as computational advances make it possible for both connectionist and dual-route systems to address the complexities of multisyllabic stimuli and associated stress contrasts.

The stress diacritic is also particularly underexplored, even though it is not an isolated Greek peculiarity but similar to signs and functions found in several languages. The Greek studies suggest that its processing is delayed and may be overly demanding for the beginning reader, but it is probably eventually incorporated in the orthographic lexicon with reading practice. However, the extent to which this situation is related to its relatively low informational value is unknown. There are no studies in Greek that directly examine the role of the diacritic in the disambiguation of stress minimal pairs, in which its informational value would presumably be high, or in the processing of words within sentential context, in which it might be less useful. Cross-linguistic work on diacritics will be necessary to examine the course of development in processing signs of high versus low informational value. The validity of the competition model as an explanatory tool for the differential attention apparently paid to different aspects of the written stimuli can be examined experimentally across languages, ages, and situations.

Finally, the issue of metrical frames as it relates to studies in phonology and the structure of the mental lexicon calls for further study. We need to understand the nature and role of stress patterns in the specification of lexical entries, in the processing of spoken and written stimuli in word recognition, and in the planning of articulatory and written output in word production. Our expectation that metrical frames would be activated by written words and could be matched or mismatched across words to produce priming effects has met with null findings. If comparable findings can be obtained in other languages that are generally similar in phonological structure, including stress, such as Italian and Spanish, this would go a long way towards limiting the theoretical role ascribed to metrical frames. This is an important matter that requires further psycholinguistic attention from multiple viewpoints, related fields and complementary research methods.

In conclusion, in this chapter I have presented our recent work on stress assignment in reading Greek, focusing on the written diacritic and the presumed lexical specification of stress. Our experiments have led to some preliminary conclusions that underscore the importance of stress assignment and indicate avenues of interesting follow-up research. The present volume suggests that interest in stress may be on the rise, and will hopefully stir further discussion and investigation. We are looking forward to further exciting work in the coming years.

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