MECHANISMS OF STRESS ASSIGNMENT IN GREEK AND ENGLISH SKILLED READING

Antonios Kyparissiadis

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ABSTRACT

Assignment of lexical stress to the appropriate syllable is an integral part of reading polysyllabic words. The attention of reading research and computational modelling of reading has recently shifted from the monosyllabic to the polysyllabic domain, hence making more apparent the need to understand the stress assignment process. The great amount of cross-linguistic variability regarding the type and the amount of information that each language provides to its readers about stress position indicates that the stress assignment mechanism is not a uniform process among different languages. Research on the stress assignment mechanism investigates how diverse sources of information on stress position in each language interact with and shape the process of assigning stress to polysyllabic words. The main focus of this thesis was to enhance theoretical knowledge regarding stress assignment by collecting and analysing data in two languages with quite distinct linguistic characteristics regarding stress, namely, Greek and English.

The sources of information on stress position can be generally summarised in lexical contributions by access to the stored position of stress for each word in the mental representations, the explicit indication of stress position by orthographic stress marks, and language-dependent statistical regularities between orthography and/or phonology and stress position. In Greek, stress position is explicitly and consistently marked orthographically by means of a diacritic over the vowel of the stressed syllable but only in lower and not uppercase words. Hence, it provides an ideal platform for investigations with naturalistic manipulations of the availability of this information through manipulation of case. A default metrical bias to stress a specific syllable, the prefinal, has also been observed. With the utilisation of reading aloud and lexical decision experiments, it was investigated: 1) how the different sources of information interact with each other; 2) how the shift in reading strategies has an impact on this mechanism; and 3)

within the framework of a computationally implemented theory of reading, what levels of representation stress is encoded at.

Experiments with Greek skilled readers in reading aloud showed that the stress assignment mechanism is directly dependent upon shifts of processing strategies in reading with lexical processing encouraging the extraction of stress position information directly from the lexicon. The default bias was also found to be active and dominant in the absence of other sources but also of relatively limited contributions when the other sources are present. Effects of case type of presentation were also disentangled from any potential effects from the availability of the diacritics. Case type was found to have an independent role in reading regardless whether this coincides with the presence of stress marks (in lowercase) or not (in uppercase). Experiments with skilled readers in visual word recognition showed evidence that stress is a multifaceted feature encoded in several levels of representation in the reading system, including as an independent unit processed at the letter level, stored in the phonological representations, and embedded in the orthographic representations of known words.

Additionally, statistical analyses of the statistical characteristics of Greek orthography, which eventually led to the development of a new psycholinguistic database (Kyparissiadis, van Heuven, Pitchford & Ledgeway, 2017), showed that, in similarity with other languages such as English, the orthographic patterns in the endings of Greek words can be associated with specific stress positions. It remains to be investigated whether such regularities have a behavioural dimension and inform the stress mechanism as an additional source of information on stress assignment. This has been shown in other languages that present similar regularities. Furthermore, it was shown that the default metrical bias, which has universally been accounted as the result of a statistical preponderance of stress on a specific syllable, does not present a uniform statistical dominance in Greek. The process of adding part-of-speech information to the database

elucidated that not all grammatical categories are predominantly stressed on the default position. In contrast to other languages, in which readers have been shown to be sensitive to the shift of statistical regularities within different subsets of the language's battery, a lexical decision experiment in Greek showed uniform conformance of readers to the default bias even in a subset or words that does not present this statistical dominance. This raises questions regarding the origins of the default bias and warrants further investigations.

In English, in conjunction to lexical retrieval, stress assignment is argued to be heavily affected by associations between orthography and the stressed syllable. Investigations on the default metrical bias in English have given rise to inconsistent results. Direct comparison of the contributions of the default mechanism against lexical activations in stress assignment showed no evidence for a default pattern being active in English reading in the presence of lexical information. However, the shifting of stressing strategies induced by a subsequent implicit priming experiment suggests that stress assignment through lexical access can be still affected by sublexical processes. Computational simulations with a leading computational model of reading showed a heavier reliance of the model on lexical contributions rather than orthographic information when these two sources where contrasted against each other. However, the model showed sub-optimal performance when simulating the behavioural results of the first experiment in English reported above. The reasons behind this inefficiency of a model that is able to simulate a wide range of behavioural patterns are considered and discussed. Finally, results of simulations from a preliminary word recognition model in Greek are presented and future directions for these modelling investigations are discussed.

Overall, the results of this body of research indicate the stress assignment mechanism is multi-facetted and language-dependent. This has implications for universal models of written word recognition and reading aloud that future research will need to address.

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List of journal publications and conference presentations arising from the work undertaken for this thesis.

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Lexical or *word stress* is a supra-segmental feature that functions at the syllabic level and determines the pronunciation of one or more syllables in a written word. This is realised by changes in duration, intensity and frequency of the sound related with the stressed syllable. The result is an accentuated degree of emphasis given on this syllable (or syllables) in oral speech. To correctly read a polysyllabic word, in conjunction to phonological assembly, stress also needs to be assigned to the appropriate syllable. Languages with variant stress do not have a fixed stress position so flawless reading of polysyllabic words requires the additional task of extracting information determining the stressed syllable by the reader. However, the availability of orthographic information on the syllabic position that receives stress varies across languages. At one extreme, English readers cannot differentiate the stress position between homographs such as *permit* (noun, as in "I have a parking permit") and *permit* (verb, as in "I permit you to park") unless they hear the word spoken aloud or see it written in context. In contrast, Greek readers can determine the position of stress in lowercase words directly from orthography as diacritics explicitly mark the stress position. For example, the position of the diacritic denotes that in the word *τάξη* stress falls on the first syllable, whereas in the word *ψιλή* it falls on the second syllable. Although reading research dates back to the early 20th century (e.g. Huey, 1908/1968), until recent decades stress assignment has received little to no attention as a reading process. Questions of critical importance relate to how stress is represented, what sources of information on stress position are utilised by the reader to correctly assign it to the appropriate syllable, and how available stress information facilitates word recognition.

It has been argued that a long-term aim of reading research should be the development of a set of universal properties of reading that reflects the common cognitive mechanisms involved in reading irrespective of the largely diverse writing systems (Frost, 2012). A universal model would need to accurately describe the fundamental and invariant phenomena of the reading process (Frost, 2012) in any orthography. The linguistic differences among languages with respect to stress that are reported above add to the complexity of developing such a model. In this thesis, the reading behaviour of speakers in a language with unique characteristics in marking lexical stress, Greek, is investigated and compared with documented evidence in other languages. Additionally, the reading behaviour of English speakers in regard to stress assignment is investigated, tapped against results of computational simulations, and used to draw comparisons between the sources of stress assignment in the two languages. In order to assess the universality of the processes involved in stress assignment, one needs first to address the question of whether different writing systems encourage different reading strategies to their speakers through which stress information might be encoded. The following section describes how languages differ in terms of their orthographic systems.

1.2 Diversity in orthographic systems

There are approximately 400 different writing systems currently used around the world (Coulmas, 1989). With the starting point being identified on pre-historic cave drawings and paintings from the Palaeolithic period that are regarded as pictorial representations of the world, writing systems have evolved throughout time to the contemporary logographic (e.g. Chinese), syllabic (e.g. Japanese Kana) and alphabetic (e.g. English) orthographies of modern times. While logographic scripts comprise different units to represent each word, and syllabic scripts comprise different symbols to represent each unique syllabic unit of the language, arguably the last milestone in the evolution of orthographies has been the introduction of the alphabet. Alphabetic scripts adhere to the principle that each phoneme (i.e. unique sound of a language) is represented by one or more letter(s) or grapheme(s) (i.e. letter clusters).

The complexity of each language's orthographic system has been typically assessed according to two criteria (Goswami 2010; Seymour, Aro, & Erskin, 2003); the first is syllabic structure and is determined by the types of syllables typically occurring in a language. For example, languages such as Greek, Italian and Spanish mostly comprise simple syllabic units with the open consonant-vowel (CV) or CCV structure (Greek: *νε-ρό*, *πέ-τρα*; Italian: *no-ve*, *pa-sta*; Spanish: *na-da*, *gu-sto*) while languages such as English and German typically comprise more complex units with larger consonant clusters (English: *brought*; German: *Schlecht*). The second criterion is orthographic transparency which relates to the extent that each letter or grapheme of a language consistently maps to a specific sound (feedforward direction) and that each sound is consistently represented by a specific letter or grapheme (feedback direction). For example, Greek is a language that is regarded as highly transparent in the feedforward direction because once a finite set of grapheme-to-phoneme conversion rules is acquired, a proportion higher than 95% of Greek words can be read correctly (Protopapas & Vlahou, 2009). In contrast, Greek is less transparent in the feedback direction as certain vowel sounds are represented by more than one letter or grapheme (e.g. *ι, υ, η, ει, οι*: /i/). Deep orthographies, such as English, do not present a high level of grapho-phonemic consistency

and are considered to be non-transparent. For example, the letter ‘o’ is contained in both words *hold* and *home* yet corresponds to different vowel phonemes. Orthographic transparency is better regarded as a continuum rather than an all-or-none property and languages are preferably compared pairwise as one being more (or less) transparent than the other. Seymour et al. (2003) have devised a two-dimensional classification table of thirteen European languages based on the two criteria described above (Table 1.1).

Table 1. 1 Classification of 13 European languages relative to the dimensions of syllabic complexity (simple, complex) and orthographic transparency (shallow/transparent to deep). Adapted from Seymour et al. (2003).

		Orthographic transparency				
		Shallow (transparent)				**Deep**
Syllabic structure	**Simple**	Finish	Greek Italian Spanish	Portuguese	French	
	Complex		German Norwegian Icelandic	Dutch Swedish	Danish	English

1.3 Stress in different orthographies

In conjunction to the grapho-phonemic conversion on the segmental level, flawless reading also requires suprasegmental information to be applied as part of the complete phonological specification. The most prominent suprasegmental feature is prosody and it has been suggested that readers apply intonation patterns even during silent reading (Rayner & Pollatsek, 1989). At the lexical level, stress is the most salient feature and it needs to be correctly assigned in single-word reading otherwise the output is erroneous. This is not an issue for the reader in languages with a fixed stress position such as Finnish in which stress always falls on the first syllable of the word (Hirst & di Cristo, 1998). On the other hand, languages with variant stress position largely vary in the amount and the type of information their orthographies provide to indicate the stressed syllable. At one extreme, Greek is a language that consistently marks stress position in lowercase writing with the use of a diacritic over the nucleus vowel of the stressed syllable. At the other extreme, languages such as English do not explicitly mark stress position orthographically hence the reader needs to rely on alternative sources of information about stress position in order to correctly assign it. For readers of such languages, one option is to retrieve stress position directly from the phonological lexicon following successful lexical access, under the assumption that stress position is always specified in the lexical representations.

Furthermore, additional sources of stress information have been identified to operate in several languages. One such source is the statistical preponderence of words in a given language that are stressed on a specific position. This leads to a metrical pattern and a default bias towards this position that has been shown to be utilised by readers when assigning stress in such languages (e.g. a default bias towards the prefinal syllable in Italian, Colombo, 1992; Greek, Protopapas, Gerakaki & Alexandri, 2007). In English, the default position depends on grammatical category with disyllabic verbs being typically stressed on the final syllable and disyllabic nouns receiving stress on the prefinal syllable (CELEX Database: Baayen, Piepenbrock, & van Rijn, 1993). Typically stressed words under this criterion have been

shown to present a processing advantage over atypically stressed words (Arciuli & Cupples, 2006). Additionally, while orthographies such as English do not explicitly indicate stress position by the use of diacritics, they present statistical orthographic regularities in the initial or final letter sequences of the words that are associated with specific stress patterns (Monaghan, Arciuli, & Seva, 2016). Behavioural experiments have shown that skilled readers are sensitive to these regularities and utilise them as a source of information regarding stress position (Arciuli & Cupples, 2006). Finally, indication of stress position by means of diacritics does also not constitute an all-or-none property for several languages. For example, in Italian, 2% of polysyllabic words are stressed on the final syllable and are the only ones that are marked with a stress diacritic on this position (Cubelli & Beschin, 2005). Similarly, in Spanish, certain words receive stress diacritic in different positions. However, the remaining words have fully predictable stress position based on grammatical rules, unlike Italian in which stress can fall on either the prefinal or the antepenultimate (the third from the end) when the final syllable is not marked with a diacritic.

Interestingly, languages such as Spanish and Italian, that mark stress position in specific occasions, retain the diacrtics in both lower and uppercase, whereas Greek, that consistently marks stress position in lowercase, does not retain the diacritics in uppercase. An examination of the above-described properties of different languages with respect to variant sources of stress information shows that their classification with regards to grapho-phonemic transparency does not necessarily overlap with their level of transparency regarding the orthographic information they provide on stress position. Table 1.2 illustrates this by considering four languages that are classified by Seymour et al. (2003) as being at the same level of transpareny (see Table 1.1) yet present different transparency levels when considering stress, and English, which is classified as a deep orthography yet presents stress properties similar to a shallow orthography, i.e. German. Thus, encoding of stress varies across orthographies and consequently might pose difficulties for universal accounts of reading.

Table 1. 2 Properties of five indicative languages regarding orthographic transparency, stress predictability, and marking of diacritics.

Language	**Orthographic transparency**	**Stress diacritics (in lowercase)**	**Stress predictability**	**Diacritics in uppercase**
Greek	Shallow	Yes	Yes	No
Spanish	Shallow	Partially	Yes	Yes
Italian	Shallow	Partially	No	Yes
German	Shallow	No	No	-
English	Deep	No	No	-

1.3.1 Greek orthography and stress in Modern Greek

Greek alphabet consists of 24 letters (17 consonants, 7 vowels), 25 phonemes (20 consonants, 5 vowels) at the phonological level (Triantafyllidis, 1941) and 32 phones (27 consonants, 5 vowels) at the phonetic level (Protopapas & Vlahou, 2009). Consonants are always pronounced and vowel letters are always mapped to the same vowel phonemes. Exceptions do occur but they are typically predictable by conditional rules employing a sequential strategy based on the subsequent letters (Aidinis & Nunes, 2001). Vowel cluster correspondings to single vowel sounds are also consistent and unambiguous according to rules (e.g. *οι*, *ει*: /i/; *οί*, *εί*: /'i/; but *οϊ*: /o-i/, *εϊ*: /e-i/; *όι*: /'o-i/, *έι*: /'e-i/). Greek has a simple vowel system with five distinct sounds and no difference in vowel lengths in pronunciation. For example, the vowel epsilon (*ε)* will always map to the phoneme /e/ regardless of its position in the word. However, when followed by the letter iota (*ι*) they will both form a grapheme pronounced as /i/ on the condition that epsilon is not stressed and iota does not carry the umlaut symbol (*εϊ*). In the context of Greek Grammar, this symbol is termed dieresis in which case the two vowels are pronounced separately (from the Greek *διαίρεσις* that means 'separation'). All consonants are pronounced except for double consonants (e.g. *αλλά*: /a-'la/) and certain consonant clusters, that consistently map to one consonant phoneme (e.g. μπ: /b/). The only major opacity in the spelling-to-sound direction is the letter iota (*ι*) when preceded by a consonant and followed by another vowel (the CiV pattern). In this case, it cannot be extracted from any rule whether iota is fully realised (/i/) as the nucleus vowel of a separate syllable or a palatal consonant in the same syllable (e.g. *διάθεση*: /δi-'a-θe-si/ vs. *διάβασμα*: /'δja-va-zma/). Less frequently, the same ambiguity can arise with other vowels (e.g. *υ)* or vowel clusters (e.g. *ει*) that typically correspond to this sound (/i/). However, Protopapas and Vlahou (2009) estimated that this irregularity does not allow the consistency of grapheme-to-phoneme mapping to fall below 95%.

In contrast, the sound-to-spelling direction in Greek is less straight-forward due to different mappings of letters to their corresponding sounds. It has already been mentioned that the

sound /i/ can correspond to five different letters or graphemes. Such phenomena are remnants of historical changes in the spoken language from Ancient to Modern Greek (Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). Similarly, the sound /o/ can correspond to the letters omicron (*ο*) and omega (*ω*) and the sound /e/ to either epsilon (*ε*) or the grapheme (*αι*). Additional reasons of such complications are that Greek is a highly inflected language (Nikolopoulos & Goulandris, 2000) and incorporates etymology as well (Porpodas, 2006). For example, with regards to the /i/ sound, the letter eta (*η*) at the end of the word indicates that it is a nominal (i.e. noun or adjective) whereas the *ει* grapheme indicates that the word is a verb. Hence, correct spelling requires knowledge of Greek inflectional rules and the spelling of root morphemes. For all these reasons, Greek has been characterised as a historic-morphophonemic orthography (Chiliounaki & Bryant, 2003) rather than a purely phonetic one.

As mentioned earlier, in Greek lowercase polysyllabic words, the stressed syllable needs to be marked by means of a diacritic over its nucleus vowel. Omission of the diacritic in such cases constitutes a spelling mistake. Only three monosyllabic words take stress (*πού, πώς, ή*) so that they are distinguished from the corresponding unstressed -but otherwise identical- words that bear a different meaning. Polysyllabic stress minimal pairs (i.e. orthographically identical words that only differ in stress position) can also be found in Greek. For example, words such as γέροϛ (/'ʝe-ros/ m. old) and γερόϛ (/ʝe-'ros / m. strong, healthy) can only be distinguished when seen in isolation from the position of the diacritic. However, this is not possible in uppercase because the diacritcs are not marked (*ΓΕΡΟΣ*). Consequently, Greek lowercase permits a transparent decoding route on the segmental as well as suprasegmental level. This means that case might influence the reading process in Greek to a greater extent than other orthographies.

In Greek, stress can only fall on any of the three final syllables of the word. According to Petrounias (2002), the stress domain is the phonological word which comprises each content

word with its adjacent function words such as pronouns, articles etc. For example, the word *παιδιά* (m. 'kids') is accompanied by an article and a possessive pronoun (*τα παιδιά μας* m. 'our kids') forming the phonological word /ta-pe-'ðja-mas/ that also needs to conform to the rule governing stress to fall on the three final syllables. This results in the marking of an additional stress, the enclitic stress, when its original position in the word is the antepenultimate syllable but falls on the fourth from the end in the phonological word after the addition of a pronoun (e.g. *ο άνθρωπος*: /o-'an-θro-pos/ m. 'the man' vs. *ο άνθρωπός μου*: /o-'an-θro-'pos-mu/ m. 'my man'). The presence of a second diacritic in this limited number of cases guarantees that stress will necessarily be assigned on one of the final three syllables of the phonological word. It follows then that this feature of Greek language can only arise when reading words in context whereas it cannot occur in single word reading.

In brief, it has been highlighted that in both the segmental and supra-segmental level, there is large variation in the amount of information that each language's orthography conveys to its readers. The following section is a review of the different theories about the way in which reading in different languages is dependent upon the amount and the type of information that is provided by each orthography.

1.4 Effects of orthographic transparency in reading

1.4.1 The Orthograpchic Depth Hypothesis

The differences in orthographic transparency that can be observed across languages have raised the question of whether they also encourage different reading strategies. The Orthographic Depth Hypothesis (ODH, Katz & Frost, 1992) suggests they do. According to the ODH, the task of pronouncing a word in any orthography may require both phonological computations on the basis of grapheme-to-phoneme correspondences as well as lexical access. Due to their high level of letter-to-sound consistency, transparent languages are expected to encourage reading strategies that mainly rely on sublexical computations of mapping graphemes to their corresponding sounds. These should be adequate to generate a phonological code that might or might not require a minimal amount of lexical shaping so that the word is recognised or accurately read. In contrast, the low level of regularity and consistency that deep languages present means heavier reliance on lexical shaping is a necessary part of the reading process.

Importantly, the ODH does not make any assumptions or claims on the architecture of the reading system that has been proposed by different modelling frameworks. For example, dual-route approaches (e.g. Dual Route Cascaded Model, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) propose both a sublexical, serial, GPC conversion pathway as well as a direct-access, orthographic, lexical pathway. In the context of this framework, heavy lexical shaping in deep orthographies occurs through fast, visual access to the orthographic lexicon so that the word's phonology is subsequently retrieved from the phonological lexicon, a process which interacts and informs the sublexical route at all stages of processing (due to the cascade-type architecture). In contrast, strong phonological accounts of reading (e.g. Berent & Perfetti, 1995; Lukatela & Turvey, 1994) posit that pre-lexical phonological computations are always a mandatory and major part of the reading process. But, in deep languages, the initial output of this process will be an impoverished skeletal structure that will be more difficult to

associate with representations in the phonological lexicon. Hence, this kind of output will require heavier top-down shaping of lexical knowledge in order to result in the correct pronunciation.

There are several ways to evaluate the validity of the ODH, one of which is to compare performances in naming and word recognition across languages that differ in orthographic depth. Evidence in favour of the ODH comes from a study by Frost, Katz, and Bentin (1987) who manipulated the frequency and lexicality of words presented in a reading aloud and a lexical decision task that were performed by speakers of either Serbo-Croatian, English, or Hebrew. The way these languages are ordered reflects their position in the transparency continuum from shallow to deep. The extent that these two lexical factors affect reading has been interpreted as indicative of the extent that phonology is lexically mediated (Frost, 2008). In word naming, the deeper the language, the larger the effect these variables had in performance. This was interpreted as evidence that deeper languages encourage heavier reliance on lexical processing. Additionally, Frost and colleagues observed a gradual shift in the difference in response times between word naming and lexical decision, the latter being a task that does not necessitate the activation of phonological code (Grainger & Jacobs, 1996) but necessarily relates to orthographic lexical representations. The difference in reading times between the two tasks was largest in Serbo-Croatian (the most shallow orthography investigated), hence supporting the assumption that naming was performed mainly sublexically, but there was no difference between the two tasks in Hebrew (the most deep orthography investigated), suggesting that, in the latter language, the phonology of the words was heavily lexically mediated in both naming and written word recognition.

An alternative way to test the ODH is by semantic priming which should be expected to yield effects under the assumption that reading involves lexical processing. Katz and Feldman (1983) compared performance in naming and lexical decision and found that semantic priming had an effect on both tasks in English (a deep orthography) but only in lexical

decision in Serbo-Croatian (a shallow orthography). Interpreted in the same theoretical framework presented in the previous paragraph, results were taken as evidence in favour of the ODH. The same pattern of results was replicated by Tabossi and Laghi (1992) when comparing English to another shallow orthography, Italian. Frost et al. (1987) also utilised the semantic priming paradigm in the cross-linguistic comparison across Serbo-Croatian, English and Hebrew. Results replicated the gradual shift observed in the comparison of reading performance between lexical decision and reading aloud; semantic priming had a larger effect on naming latencies in Hebrew than English, and no effect in Serbo-Croatian.

Results from brain imaging research have also provided evidence for the biological plausibility of the ODH. Paulesu, McCrory, Fazio, Menoncello, Brunswick et al. (2000) compared the positron emission topography (PET) scans of Italian and English participants when reading words and nonwords in their native languages. They found that Italian readers showed higher activation in the left superior temporal regions which are associated with phoneme processing, whereas English readers showed higher activations in left posterior inferior temporal gyrus and anterior inferior frontal gyrus which are areas associated with lexical retrieval. Again, these results are in line with the ODH because according to this theory, Italian, as a transparent orthography, is expected to encourage sublexical processing whereas English is expected to encourage retrieval of representations on the whole-word level from the orthographic and phonological lexicons.

From the perspective of a strong phonological theory, the ODH can be scrutinised on the basis of its predictions in relation to the phonological code that is initially generated prior to accessing the phonological representations. According to the ODH, in shallow orthographies this code is likely to be accurate and fully specified whereas in deep orthographies it is expected to be underspecified and impoverished due to inconsistencies and irregularities in the print-to-sound conversion process. Evidence in favour of this prediction comes from two studies in Hebrew (a deep orthography) that compared performance with phonologically

ambiguous or unambiguous items in lexical decision and word naming (Bentin, Bargai, & Katz, 1984; Bentin & Frost, 1987). The researchers only observed differences in performance between the two groups of stimuli in naming but not lexical decision. This suggests that in lexical decision, a task that does not necessitate access to phonology, readers of a deep orthography recognised words after generating an underspecified phonological code. This was consistent regardless of whether each stimulus allowed full phonological specification or not.

1.4.2 A universal hypothesis

Despite the abundance of data reported above that are consistent with the predictions of the ODH, there is a substantial body of evidence suggesting that orthographic transparency is not the only dimension differentiating reading strategies employed by native speakers of different languages. More precisely, there is evidence suggesting that the different strategies described above only pertain to low-frequency words and nonwords, whereas high-frequency words are universally processed through direct lexical access. In a study by Seidenberg (1985), native speakers of English (an alphabetic script) and Chinese (a logographic script) were not affected, in terms of reading times, when naming high-frequency words regardless of whether they were phonologically regular or not. In contrast, they observed an advantage for phonologically regular over irregular stimuli of low frequency in both languages.

Additional evidence in favour of a fast, visual-orthographic channel is provided by experiments performed by Besner and Hildebrandt (1987) in Japanese. There are three written scripts that are used in this language, one logographic, and two syllabic (Kana, Katakana, and Hiragana respectively). The researchers compared reading performance between naming words that were either presented in their normal script, which was orthographically familiar for the reader, or transcribed in an alternative script that was orthographically unfamiliar. This is possible because a word that normally appears in, say, Hiragana can also be printed in the

other scripts (e.g. Katakana). This resulted in orthogonal manipulations of words written in all scripts that were orthographically familiar or unfamiliar but otherwise phonologically identical, and their phonology could always be generated by means of spelling-to-sound conversion. Orthographically unfamiliar items yielded longer response latencies, which also supports the operation of the visual-orthographic route. Consequently, the predictions of this hypothesis are quite clear-cut. Even in shallow orthographies, the visual form of high-frequency words can generate a match in the mental lexicon before sublexical computations are complete. But for low-frequency words, the level of visual familiarity will not be sufficient for the word-level channel to generate a match before sublexical processing is accomplished (Seidenberg, 1985). Thus, word frequency is another dimension that determines the extent to which lexical processes influence the naming of written words.

Furthermore, there are accounts suggesting that a visual-orthographic channel at the whole-word level operates always, in any language, under normal reading conditions. Baluch and Besner (1991) have attributed the differential naming patterns across orthographies that are explained in the ODH framework simply as the result of strategic effects from the presence of nonwords in the experimental materials of these studies. This is because nonwords necessitate sublexical processing to be read correctly so this, in turn, might have shifted the reading strategies of participants. Baluch and Besner (1991) found equal facilitation arising by semantic priming in phonologically transparent and opaque Persian words when nonwords were not present in the experimental materials. But when nonwords were included, semantic facilitation was only observed for opaque words. Similar conclusions were drawn by Pagliuca, Arduino, Barca, and Burani (2008) who conducted a study in Italian, a transparent language, and acquired clear lexicality effects in naming that were interpreted as evidence that the lexical route is the main one used by skilled readers even in a transparent language such as Italian. Importantly, they observed the lexicality effect in the comparison between either high-frequency words or low-frequency words and nonwords when presenting them in both mixed and pure blocks (i.e. including both words and nonwords or not). However, it is

not clear why the researchers did not directly compare performance between low- and high-frequency words since the frequency effect is also used as evidence for the operation of lexical processing (Frost, 2008).

Finally, an additional factor that has been claimed to modulate the reading strategies regardless of the orthography is word length (in letters). Length effects are associated with sublexical processing because of the seriality of its nature which is expected to yield a disadvantage for longer stimuli. This would not be expected in parallel processing, usually associated with the lexical route, since in this case input from all letters is processed simultaneously hence the number of letters is not expected to have an effect on processing time (Zoccolotti, Luca, Pace, Judica, Orlandi et al., 1999). Spinelli, De Luca, Di Filippo, Mancini, Martelli et al. (2005) observed no length effect in skilled Italian reading aloud of words of up to five letters which was interpreted as indicative of parallel (lexical) processing. In contrast, they reported length effects for words comprising between five and eight letters, suggestive of sequential decoding (GPC conversions) of longer words.

1.4.3 Psycholinguistic Grain Size Theory

Aiming to address the issues raised by such studies towards the fundamental theoretical principles of the ODH, Ziegler and Goswami (2005; 2006) proposed an alternative approach that was formulated into the Psycholinguistic Grain Size Theory (PGST). According to this theory, instead of focusing on the amount of lexical and sublexical contributions to reading in different orthographies, attention is shifted towards the size of units on which GPC mappings are performed. According to the PGST, phonological computation underlies reading in any orthography, but orthographic transparency affects the units of the grapho-phonemic conversions. Transparent languages, that present a high level of consistency between letters and their corresponding sounds, encourage GPC conversions to be performed on the lowest grain size, the letter level. In contrast, opaque languages, that present a low level of GPC

consistency on the letter level, encourage print-to-sound mapping on larger grain sizes. Indicatively, Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty (1995) computed the level of GPC consistency in English to be 51% on the letter level but 77% when considering rhyme units.

There is a wealth of empirical evidence in favour of the PGST (Goswami, Gombert, & de Barrera, 1998; Goswami, Porpodas, & Wheelwright, 1997; Goswami, Ziegler, Dalton, & Schneider, 2001; Goswami, Ziegler, Dalton, & Schneider, 2003; Wimmer & Goswami, 1994). In a series of studies, Goswami and colleagues carried out cross-linguistic experiments with developing readers of languages varying in orthographic depth. It has been shown that German children (a shallow orthography) perform better with nonwords, that necessitate GP conversions, than English children (a deep orthography) who seem to rely more heavily on whole-word recognition (Wimmer & Goswami, 1994). This has also been confirmed in a cross-cultural study involving Grade-1 children who were native speakers of one of 14 European languages (Seymour et al., 2003). It was shown that their word and nonword accuracy performance could be explained as a function of orthographic depth and that readers of deep orthographies were far from having mastered the mechanism of converting written words to their spoken equivalents (phonological recoding) by this this stage (indicatively, the accuracy with simple nonwords was German: 98%, Dutch: 91%, Danish: 87%, English: 74% - compare to Table 1).

Additionally, it has been shown that English but not German children show switching costs when asked to read mixed blocks of nonwords that can either be decoded solely based on GPCs or larger units such as rhymes (Goswami et al., 2003). This suggests that German children do not rely on grain sizes larger than the minimal grapheme-to-phoneme units and always employ this strategy whereas English children switch between small- and large-unit processing depending on the decoding needs of each stimulus. This is also supported by the findngs of Goswami et al. (2001) who observed a naming pseudohomophone (e.g. *faik*)

advantage over baseline nonwords only in English but not German children. Again, this was interpreted as evidence that German children perform phonological recoding on the GPC level, whereas English children rely more heavily on whole-word phonology. Finally, facilitation effects of orthographic and/or phonological rhyme similarity were only observed with English but not Greek (a shallow orthography) children (Goswami et al., 1997), or their effect sizes were gradual, following the hierarchical order on the transparency continuum for English, French and Spanish-speaking participants (Goswami et al., 1998).

Importantly, Ziegler, Perry, Jacobs and Braun (2001) investigated whether such differences in reading strategies during reading acquisition have an impact on adult reading. Researchers compared performance between German (a shallow orthography) and English (a deep orthography) adult skilled readers when reading orthographically identical words (cognates) in their native languages. They confirmed that the level of transparency affects the preferred grain size of units that GPC mappings are attempted because, in reading aloud, German participants exhibited stronger length effects whereas English participants exhibited stronger body-rhyme effects; items with a high number of body neighbours -e.g. *hat* has a large body-N (*sat, fat, cat,* etc.)- only showed an advantage in English reading, hence reflecting sublexical processing of larger-than-grapheme units. This is in accordance with what the PGST would predict and also shows that different reading strategies at early developmental stages leave footprints in reading maturity. Results of this study are more pertinent for the purposes of the current thesis that does not focus on the developmental aspect of reading acquisition but is rather concerned with the reading plateau reached by skilled readers.

However, the study by Ziegler et al. (2001) involving mature readers has recently been subjected to additional scrutiny. Schmalz, Robidoux, Castles, Coltheart and Marinus (2017) further examined the stimuli used by Ziegler and colleagues and showed that the body-N manipulation was significantly stronger for English (high body-N: 12.6, low: 3.3) than German (high: 8.9, low: 3.8) stimuli. They also pointed that body-N significantly correlated (*r*

= .44) with orthographic N (Coltheart, Davelaar, Jonasson, & Besner, 1977), a measurement indicating the number of real words that can emerge from a given word if any single letter is changed. This variable is known to affect reading (see Andrews, 1997, for a review) yet was proven to be confounding in this study with body-N, making it difficult to disentangle effects between the two. Replication of the analysis with more rigorous statistical methods (multiple regression and Bayes factors) did not yield the body-N by language interaction. Additionally, when reaction times on the same experimental items were retrieved from the English Lexicon Project, a body-N effect did not emerge for English thus making the results incompatible with the original study. In general, the authors argue that, in the absence of cross-linguistic differences, behavioural reading patterns attributed to the PGST could as well be explained within the ODH framework so failure to replicate the body-N by language interaction in the new analyses as well as in a large-scale analysis they conducted with nine new experiments is evidence against the PGST.

Finally, it is also worth mentioning other studies that provide evidence of reliance on larger than GPC grain sizes in transparent languages. In German, Schmalz, Marinus, Robidoux, Palethorpe, Castles and Coltheart (2014) report that the prior point of reference for sublexical correspondences is the GPC level, in line with the PGST, but larger units (orthographic bodies) and context-sensitive conversions are also at play. Similarly, Carreiras, Alvarez and Devega (1993) have shown that syllables constitute independent sublexical representational units for visual word recognition in Spanish which is also a transparent language.

1.4.4 Extensions to the supra-segmental domain

While the debate about the effect of orthographic depth on reading has largely focused on segmental phonology, it has been shown that it can be extended to the supra-segmental domain which involves features such as lexical stress (e.g. Colombo, 1992; Monsell, Doyle,

& Haggard, 1989). Since stress position is part of the phonological specification in polysyllabic words, it can also be computed sublexically or directly retrieved from the phonological lexicon. This, in turn, depends on the level of transparency for each orthographic script regarding information on stress position that can be extracted by the reader. Greek language, in particular, offers both possibilities to determine stress position, i.e. either compute it sublexically by decoding the orthographic diacritics or directly retrieve it from the whole-word phonological representations, but only for lower case words. In contrast, in uppercase Greek, the diacritics are not marked so the reader does not have the option of directly extracting stress position from orthography. Hence, for lower case words, where diacritics are present, phonology on the supra-segmental level can behave in a similar manner and replicate the interaction between frequency and regularity discussed earlier, in which irregular pronunciations or, in this case, stress positions only seem to hinder reading when phonology is derived sublexically (with low-frequency words and nonwords) but not when it is directly retrieved (with high-frequency words). On the level of segmental phonology, this effect has been successfully simulated in English using the DRC model (Coltheart et al., 2001) which is a typical example of the dual-route architecture. It should be noted, however, that English does not mark stress position with diacritics. Rather, orthographic information on stress position can be extracted from statistical regularities of orthographic affixes. In that case, computations of stress position based on such patterns only occurred in low- but not high-frequency words. Alternatively, for upper case words, that lack diacritics, Greek behaves in a similar manner to English and Italian in which stress position is not overtly predictable from orthography. Interestingly, the frequency by regularity interaction in the stress domain has been replicated in such languages. In this case, sublexical computations for stress assignment with less familiar stimuli are performed on the basis of implicit statistical knowledge of the language's regularities by the reader (e.g. Colombo, 1992; Monsell et al., 1989). Consequently, this interaction could be replicated in Greek language in either, both, or none of the case types of presentation, with each outcome having different implications about how stress is encoded and should be implemented in computational models of reading. The

next section provides a brief overview of the main approaches in modelling reading behavior that are currently undertaken in reading research.

1.5 Different approaches in modelling reading

1.5.1 Dual-route reading

Computational models that adopt the dual-route architecture in reading assume two distinct processing routes for the task of converting print to sound, a lexical route and a non-lexical route. A typical example of such models is the DRC model (Coltheart et al., 2001) that can simulate reading aloud and lexical decision tasks and will be considered here. This model comprises representations on three levels, namely the feature level, the letter level and, as dictated by the localist approach, the word level. Word-level representations have both an orthographic form and a phonological form. The model works in a cascade-like fashion; as soon as there is activation on any level of representation, it flows between adjacent components without the need to pass a given threshold. Connections between neighbouring levels are of excitatory and inhibitory nature (increased and reduced activation respectively). Lateral inhibition allows units of the same level to interact as well by suppressing activation of competing units.

The lexical route is largely based on the Interactive Activation (IA) model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) which was a purely orthographic model developed to simulate solely visual word recognition and did not involve phonology. The DRC model is also interactive as activation flows between adjacent levels in both directions. In the lexical route, an input word initially activates the feature level, subsequently the letter level and then the orthographic entry of the word. This in turn activates the phonological entry from which the constituent phonemes are assembled. These processes always operate in parallel, across all positions of the feature and letter units. It is widely termed the *orthographic* pathway of the model because it relies on the recognition of the orthographic form of the word prior to generating its phonology. Its lexical nature lies on the prerequisite that whole-word candidate units need to prevail before their phonology is subsequently retrieved. This means that this route is not adequate to read nonwords correctly given that

they are not present as whole-word units in the lexicon. However, the model will still produce a phonological output for nonwords by analogy (Coltheart, 2005). For example, the nonword SARE will activate the phonology of similarly spelled words such as CARE and SANE.

The non-lexical route operates in a serial manner, from left to right, and converts letters to their corresponding phonemes based on a set of a hand-written rules. Hence, it reaches phonology directly, without the mediation of the orthographic lexicon. However, the two routes operate simultaneously (although the non-lexical route is set to commence with a small lag, on the tenth cycle, whereas the lexical route straight from the first cycle) and converge at the phoneme level with the information fed from the feature and letter levels. Figure 1.1 illustrates the connections between the different levels of representation. The general principles of interactive activations and both excitatory and inhibitory connections are only violated in (a) the single-direction activations from the feature to the letter level, (b) the lack of inhibitory connections between the orthographic and phonological lexicons in the lexical pathway, and (c) the one-direction, solely excitatory connections of the non-lexical module.

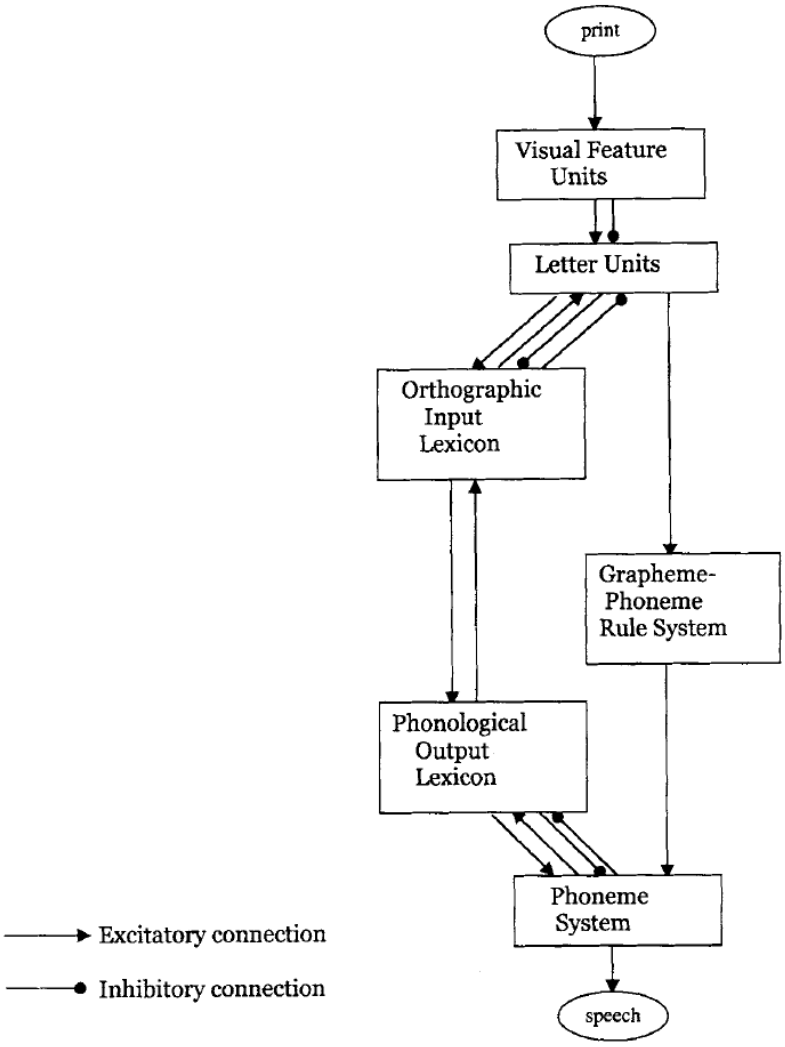


Figure 1. 1 Current architecture of the DRC model (taken from Coltheart et al. 2001)

1.5.2 Parallel-distributed models

Parallel distributed models (Harm & Seidenberg, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989) belong to the connectionist family of models that aim to capture properties of the brain lying from the single neuron level up to aggregated behaviour of neural networks. A major difference of such models in comparison to dual-route ones is that they use distributed rather than localist representations which means that words are not represented at the whole-word level as independent units. An equally important distinction is that such models are not 'hand-wired' in the sense that the weights of the connections among units are not manually set by the experimenter. Rather, they result from an automatic training procedure typically involving the technique of back-propagation. This is a supervised learning procedure that adjusts the weights between the connections of the units by comparing the output of the model at each training stage to the correct output and aiming to gradually reduce this discrepancy to the lowest possible level. The outcome of these two characteristics of such an approach is that the resulting model also includes 'hidden' units that connect the units of whichever levels of representation have been initially set by the modeller (e.g. orthography, phonology, etc.). These units are considered 'hidden' because once the training phase is performed the resulting weights in the connections mediated by the hidden layer as well as the network's functional architecture are difficult to establish. Figure 1.2 illustrates the architecture of triangle models (Harm & Seidenberg, 2004; Plaut et al., 1996; Seidenberg & McClelland, 1989) that involve the levels of orthography, phonology, and semantics as well as layers of hidden units interconnecting these levels of representation. It should be noted that a common criticism of connectionist approaches is that it is difficult to establish *how* they are solving a particular problem in comparison to 'hand-wiring' the parameters of a model (Coltheart et al., 2001). On the other hand, such models are more appropriate for investigating developmental aspects of cognitive mechanisms because each reading stage can be simulated by different stages of the algorithm's learning process.

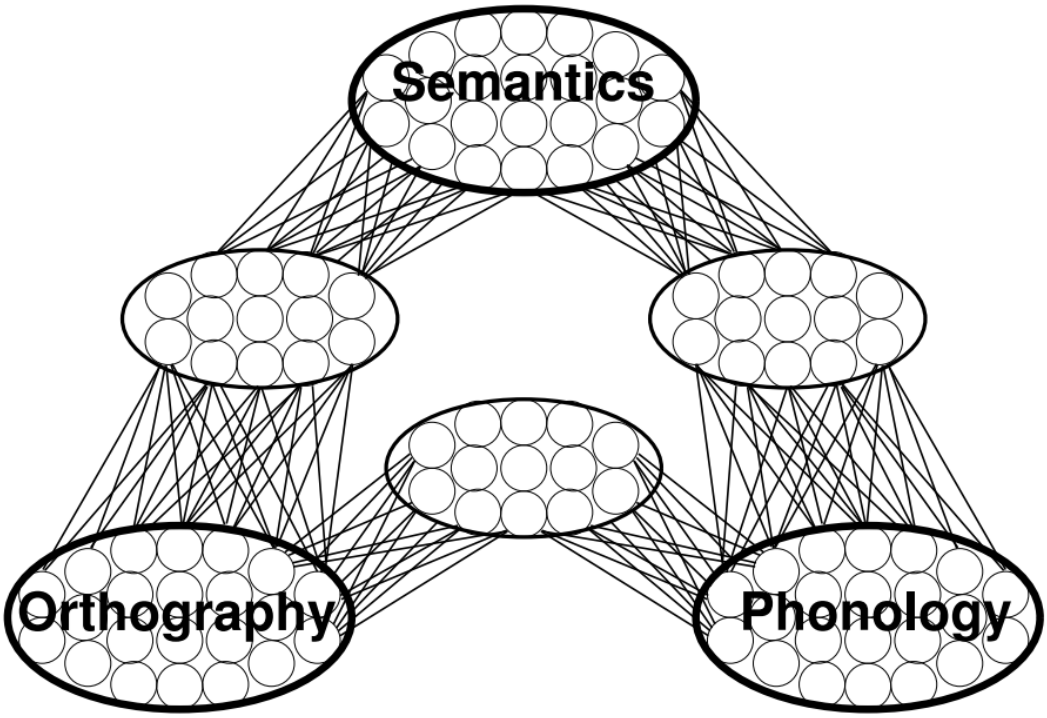


Figure 1. 2 A connectionist network based on the “triangle” framework that relates orthographic, phonological, and semantic information (taken from Plaut, 2005).

1.5.3. A converging approach

A more recent development in computational models of reading is the Connectionist Dual-Route (CDP) approach (Perry, Ziegler, & Zorzi, 2007; Perry, Ziegler, & Zorzi, 2010; Zorzi, Houghton, & Butterworth, 1998) that combines elements of the two modelling approaches discussed earlier. The CDP+ model of reading aloud (Perry et al., 2007) includes a lexical route that has localist (word-level) representations and closely resembles the DRC approach, inherited from the IA model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). In contrast, the sublexical route does not adopt the DRC approach of manual GPC rules but rather uses a training algorithm to develop the print-to-sound mappings. The only deviation from the typical connectionist models is that this associative network is not developed with back-propagation but rather a simpler delta rule learning procedure. Hence, this is not a trained network with hidden units but rather a simpler two-layer associative network (TLA) that only includes connections between orthographic and phonetic units. The architecture of this model is illustrated in Figure 1.3. Once letters are encoded at their absolute spatial positions, the input is fed to the lexical route and to a graphemic buffer that operates in the sublexical route and parses the input into the onset, vowel, and coda positions. Importantly, the implemented versions of all modelling approaches discussed in this section can only accommodate monosyllabic input hence syllabification is not an issue before the input is fed to the graphemic buffer. Subsequently, the TLA network converts the word's graphemes to their corresponding sounds, and, finally, processed information from the two routes converges in the phonological output buffer that includes phoneme nodes and assembles the output phonology of the target word.

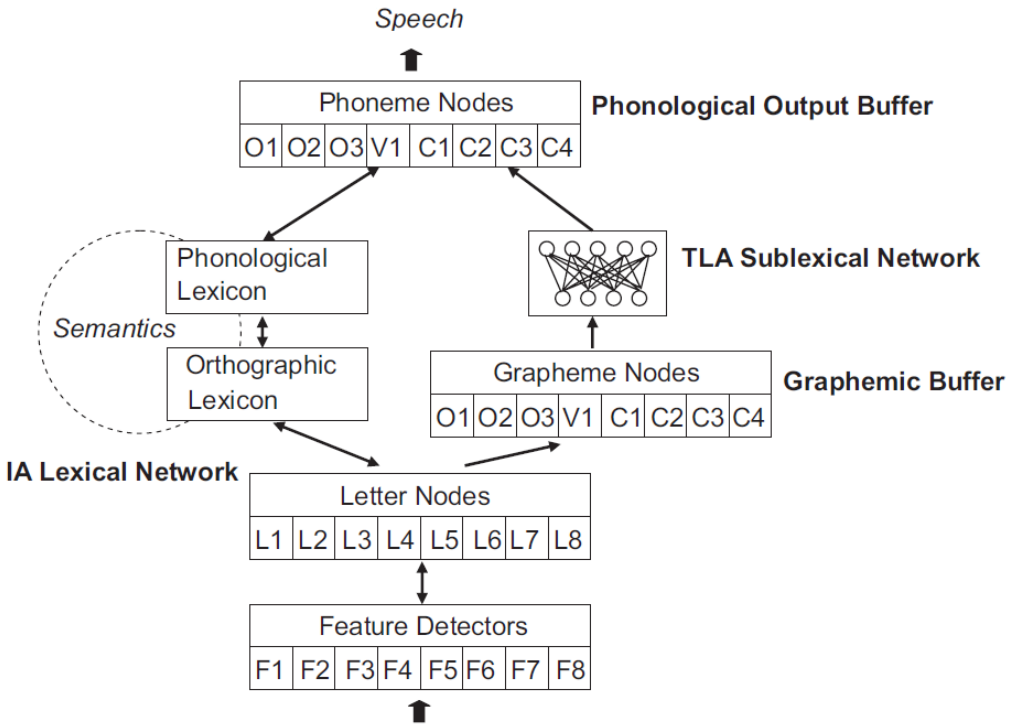


Figure 1. 3 Architecture of the CDP+ model (Perry et al., 2007). F: feature; L: letter; IA: interactive activation; O: onset; V: vowel; C: coda; TLA: two-layer assembly (adapted from Perry et al., 2007).

This model offers an impressive fit to item-level naming data (Perry et al., 2007) and the CDP architecture currently appears to be a leading computational model of reading aloud. It captures more item-level variance of words than the DRC and it is better in simulating consistency effects. However, the DRC theory and its modelling implementation present certain qualities and strengths that are difficult to oversee. Recent attempts to compare performance between the DRC and CDP models focused on nonwords, given that the different sublexical architectures between the two systems would give rise to differences in the pronunciation of such items. Pritchard, Coltheart, Palethorpe and Castles (2012) collected nonwords for which the two models produce different pronunciations and asked human readers to ream them aloud. Their comparisons showed the DRC model to produce higher agreement to the human data than the CDP+ (or its successor, CDP++, that is examined in a subsequent section). The prominent level of variability in the pronunciations of human readers led to a hierarchical clustering analysis aiming to identify whether there are classes of human readers behaving similarly (Robidoux & Pritchard, 2014). Again, CDP was found to merge with the most homogeneous cluster hence capturing the responses of a large number of subjects and to outerperform CDP, which failed to match the profile of any specific cluster. Consequently, the researchers concluded that the CDP architecture failed both in comparison to DRC but also as a stand-alone attempt of fitting any human reader's response pattern.

However, discussion of modelling approaches in this section has focused on model implementations that can only accommodate monosyllabic input. This is clearly limiting because in most languages monosyllabic words constitute a limited set of their lexical battery. Additionally, such models cannot address questions related to issues such as supra-segmental phonological assembly, stress assignment, and syllabification. Following a review of the literature in the reading research involving stress, implementations based on these three modelling approaches that have attempted to address the issue of polysyllabic words will be presented.

1.6 Reading literature on stress

Several sources of information that influence the stress assignment mechanism have been identified by research in different languages. These include orthographic diacritics (e.g. Greek; Protopapas, 2006), language-specific rules (e.g. Spanish; Gutiérrez-Palma & Palma-Reyes, 2008), lexical representations (e.g. English; Rastle & Coltheart, 2000), the tendency of stress to fall on a specific syllabic position, typically termed as the default pattern (e.g. Italian; Colombo, 1992), distributional properties emerging from sub-groups of words in a given linguistic system such as stress neighbourhood (e.g. Italian; Burani & Arduino, 2004), morphological information (e.g. English; Rastle & Coltheart, 2000), and orthographic regularities at the beginning and end of words that do not necessarily map onto morphological units (affixes) (Arciuli, Monaghan, & Seva, 2010; Monaghan et al., 2016). The linguistic characteristics of each orthography certainly do not allow all such sources to be active for any given language; not all languages mark stress position with diacritics neither do all present a statistical preponderance of words stressed on a given position. However, it is typical that more than one sources are available and engage in an interplay amongst them for the task of stress assignment. A typical example of the interplay of such sources is the stress regularity by frequency interaction. Within this pattern, whether the presence of canonical or non-canonical stress in a word affects the time it takes to be recognised and pronounced depends on the word's frequency of occurrence (e.g. Colombo 1992; Rastle & Coltheart, 2000). In the following section, experimental evidence regarding this issue is reviewed and discussed.

1.6.1 The stress regularity by frequency interaction

According to the universal hypothesis, whether sublexical processes come about in reading largely depends on the word's frequency, with high-frequency words favouring direct lexical retrieval. A number of studies have attempted to extend this pattern to the supra-segmental domain. Colombo (1992) tapped direct lexical retrieval (under the assumption that this also

includes direct retrieval of stress position) against sublexical assignment of stress on the basis of stress regularity. This is considered to be the conformance to the default metrical bias of stress on the penultimate (prefinal) syllable due to a higher number of words stressed on this position in the Italian language. She found that low-frequency words were read faster when they had regular compared to irregular stress but observed no such difference with high-frequency words. She also observed the same pattern in error rates but not reaction times in a written word recognition task. This led her to conclude that, dependent upon frequency, stress is either computed or retrieved. Similarly, Monsell et al. (1989) found the same interaction in English with the pattern of results following the expected trend as English language also shows the same preponderance of words stressed on the penultimate syllable. However, these results suffered from less stringent statistical procedures regarding the alpha level for statistical significance and replication of the pattern in by-subject and by-item analysis. Indeed, Rastle and Coltheart (2000) failed to replicate this interaction and did not find an advantage for regularly stressed words neither for reading aloud high- or low-frequency stimuli. However, they observed this interaction in error rates when they defined stress regularity according to a set of rules regarding the morphological affixes of words and the stress position that is statistically associated with each affix. They also found this interaction to be confirmed with the reading times but only in the by-subject and not the by-item analysis.

1.6.2 Alternative notions of regularity

Conflicting findings with regards to stress regularity on the basis of the default bias towards the penultimate syllable have given rise to alternative ways of assessing whether a word has regular stress or not. One such approach was proposed for Italian by Burani and Arduino (2004) who argued that regularity of stress depends on whether the neighbourhood of words that share the same phonological ending with the target word present a certain pattern towards stress on a given syllable. If the target word has many stress friends within this

neighbourhood then it is considered stress consistent and when it has many enemies it is considered inconsistent. Burani and Arduino orthogonally manipulated these two variables and found only stress consistency to have an effect on naming Italian words. Consequently, they attributed the effect of stress regularity found by Colombo (1992) to extraneous variables and poorly matched stimuli. Interestingly, a model of reading aloud (CDP++, Perry, Ziegler, & Zorzi, 2014a, discussed in a subsequent section) is able to simulate the results of the reading aloud experiments from both these studies. This suggests that the two accounts might not be mutually exclusive and seems to support the view that the superficially contradictory results might indeed be due to the specific characteristics of the experimental materials. This highlights the importance of using well-matched experimental materials and the need for statistical databases that report stress information (see Chapter 4). More recently, Colombo and Sulpizio (2015) also manipulated these two variables in a series of word recognition and naming tasks. In lexical decision, they found a main effect of stress regularity in response times and accuracy and no effect of consistency. Reading aloud yielded the opposite pattern, with a main effect of stress consistency but no effect of regularity. The latter was only observed in the error rates however because the stimuli were not assessed as adequately balanced for a response times analysis.

In a similar approach, albeit originating from the orthography rather than phonology, it has been found that orthographic patterns of letter combinations at the beginnings and ends of words bear information and present statistical regularities with respect to stress position (Arciuli et al., 2010; Monaghan et al., 2016). Behavioural experiments have shown that this information is utilised by the reader. In both word recognition and naming tasks, Kelly, Morris and Verrekia (1998) found that English words with consistent orthography to their stress position were responded to faster and more accurately than those with a conflicting spelling and stress position. Behavioural experiments with nonwords by Arciuli et al. (2010) showed that as reading skill develops, word endings are more likely to inform the stress assignment mechanism than word beginnings. However, this does not mean that word

beginnings are entirely neglected for stress assignment when reaching reading maturity. In a corpus analysis of disyllabic English words, Kelly (2004) observed that the probability of prefinal stress is positively correlated with the number of consonants on the word's onset. Kelly showed the behavioural dimension of this pattern in a reading aloud task in which nonwords with two initial consonants were more likely to be assigned first syllable stress than those with one initial consonant.

Alternatively, a body of research has focused on the interaction between stress position and grammatical class and has shown that the dominant pattern of stress position within a grammatical category can elicit higher reading performance for regularly stressed stimuli compared to irregularly stressed stimuli. Accordingly, Arciuli and Cupples (2006) found an advantage in the error rates for the dominant stress position of English disyllabic verbs and nouns (final and prefinal syllable respectively) in a word recognition and a reading aloud task. An earlier study by the same researchers (Arciuli & Cupples, 2003) had shown that native English speakers do make use of this statistical pattern within each grammatical category in order to complete a grammatical classification task. When deciding on whether a disyllabic word they read was a verb or a noun, they gave faster responses for typically stressed verbs (final syllable) and nouns (prefinal syllable) than for those with atypical stress. Similarly, Jouravlev and Lupker (2014) reported an advantage on speed and accuracy in word recognition and naming for Russian adjectives - the only major grammatical category that presents such preponderance in this language - stressed on the dominant syllable that was not observed with nouns and verbs.

1.6.3 Stress in the Greek reading literature

In Greek, research on stress assignment has largely focused on the different sources of information on stress position and their relative contributions to the reading system. Across a series of reading aloud experiments, Protopapas and colleagues have shown that processing of diacritics, lexical retrieval, and the default metrical pattern are all active sources of stress information with considerable interplay operating amongst them (Protopapas, 2006; Protopapas, Gerakaki, & Alexandri, 2006; 2007; Protopapas & Gerakaki, 2009). In their experiments, they systematically manipulated stress position among the three possible stressed syllables (final, penultimate, antepenultimate) in lowercase nonwords that were either minimally (one letter away) different from the real word they were generated from or maximally changed beyond recognition. Hence, they were able to see how the different sources of stress operate and how they contrast to one another in different instances, such as when the lexical activations of the root word indicate a different stress position than the diacritic or when the diacritic position contrasts the default metrical bias.

Experimental results with children attending primary school, secondary education, and adults allowed Protopapas and his colleagues to conclude that the interplay among the different sources of stress information appears to be rooted in reading development. In the early stages of reading development, there is a heavier reliance on lexical information to assign stress position but this shifts as the reader becomes more skilled towards utilising information from orthographic diacritics. Studies with Greek developing readers (second to seventh grade) have shown that lexical sources are the first point of reference in assigning stress when reading aloud and remain a consistent strategy across development (Protopapas et al., 2006; Protopapas & Gerakaki, 2009). Reliance on diacritics gradually increases, until visual orthographic cues become the dominant strategy used by skilled Greek readers to assign stress position in written words. Lexical contributions, however, remain a reliable strategy, even with skilled adult readers of Greek and there are substantial interactions amongst different sources of stress assignment information (Protopapas et al., 2007). This is evidenced by errors

made when the position of the diacritic in nonwords contradicts lexical information (from the root word), thus indicating the influence of lexical processes. For example, the nonword *γιμόνται* is sufficiently similar to its root word *γίνονται* that it is generated from, but stress diacritics are placed on a different syllable (penultimate vs. antepenultimate, respectively). When this nonword is read with stress on the antepenultimate by conformance to its root word, it suggests that the similarity of the orthographic code has activated the phonology of the root word. This is indicative of stress being encoded at the phonological whole-word level, without this precluding encoding at other levels of representation as well. It should be noted, however, that, in most cases, nonwords are read and stressed correctly (Protopapas et al., 2007, Experiment 1) by skilled readers, which suggests that by this stage the diacritics seem to be successfully decoded. Consequently, in Greek skilled reading, stress is not expected to be encoded solely at the level of phonology.

The interplay among different sources of information also involves a contribution from the default stress pattern, which in Greek is the tendency to stress the penultimate syllable. This metrical bias has been found to influence skilled adult Greek readers (Protopapas et al., 2007) but its effect is relatively limited compared to other sources of information. This might be because in Greek, the statistical dominance of words stressed on the penultimate syllable is not as strong (Protopapas, 2006) as in other languages (e.g. Italian, see Colombo, 1992).

Despite the considerable progress on the knowledge about stress assignment in Greek that resulted from the pioneering studies by Protopapas and his colleagues, there are still major issues that require further investigation before this mechanism is fully resolved. Indicatively, it is impossible to establish whether there is a shift in utilising different sources of stress information depending on the specific characteristics of words read aloud as in other languages (Colombo, 1992; Rastle & Coltheart, 2000). Factors such as word frequency and lexicality that reflect certain processing strategies have so far not been manipulated in relation to stress assignment because the experiments reported above used nonword stimuli. Additionally, in a language that consistently marks stress in lowercase, it has not been

established how the diacritics are processed and how this interacts with other sources of information on stress position such as direct lexical retrieval or computations involving the language's statistical regularities. This is related to the way and the locus that stress is encoded in the mental representations. For example, it is known that stress information is present in the phonological representations because uppercase words are stressed correctly, but given the consistent presence of the diacritics in lowercase, it seems untenable that this is the only locus where stress is represented in the lexicon (as also confirmed by Protopapas et al., 2007). Accordingly, the diacritics might be computed separately, they might be part of the whole-word orthographic specification or they might be encoded at the letter level. These possibilities are further discussed in a subsequent section of this chapter as well as in the discussion of the aims and objectives of this thesis.

In a previous section, the state-of-the-art computational models of reading were reviewed. At present, no computational model of reading has been developed in Greek neither has one been adapted from another language, be it monosyllabic, let alone polysyllabic. Monosyllabic models have been considered a solid basis to simulate benchmark effects in reading before an extension to the polysyllabic domain is attempted because this entails considerably higher complexity (Rastle & Coltheart, 2000). However, in Greek, the choice of developing a monosyllabic model could be challenged due to several reasons. In Greek, monosyllabic words comprise a very limited set (less than 500 according to Protopapas & Vlahou, 2009). Hence, developing a model that can only simulate reading of such a tiny portion of the language's vocabulary would be arguably open to critique regarding generalisability. More importantly, a typical way of assessing a computational model is to take its output with experimental materials used in studies with human participants and compare it with the behavioural data acquired (e.g. Perry et al., 2014a). However, such a comparison would not be possible for a monosyllabic model in Greek because there are no behavioural data available for monosyllabic stimuli. This issue is addressed directly in this thesis by providing new behavioral datasets on stress assignment in Greek (Chapters 2 & 3) and an initial attempt

at a primary computational model for Greek (Chapter 6). Outside the Greek-specific domain, reading research has recently shown some advancement with respect to developing computational models that can process polysyllabic input. Of integral role in such model extensions is how the problem of assigning stress is addressed. The most notable approaches in tackling this issue are reviewed in the following section.

1.7 Computational approaches in stress assignment

1.7.1 Rastle and Coltheart (2000)

An initial attempt to extend computational models of reading to disyllabic words has been presented by Rastle and Coltheart (henceforth R&C, 2000). Their algorithm for stress assignment was developed within the DRC framework and is based on a set of rules derived from morphological affixes. For unknown words and nonwords in which stress position is not specified through the phonological representations, stress is computed via a two-step process. Initially, the algorithm looks for any prefix and affix in the word by comparing the letter strings against a pre-defined affix list and confirms that item-level conditions are met before identifying the string as a morphological affix (e.g. the initial letter sequence *ap-* needs to be followed by the letter *p* in order to be considered a prefix). Subsequently, stress is assigned to the position that the identified affix is associated with (based on work by Fudge, 1984; Garde, 1968). This approach resulted in 89% accuracy of stress assignment and naming all the disyllabic words in an English lexical database (CELEX, Baayen et al., 1993) and 85% agreement with human participants naming nonword items.

The importance of morphological prefixes as cues for sublexical stress assignment was recently confirmed by Ktori, Tree, Mousikou, Coltheart, and Rastle (2016) who asked surface dyslexia patients (i.e. patients that have limited access to lexical processes) to name English disyllabic real words. Their responses for words with stress on the final syllable but also with a prefix associated with stress on the prefinal showed a very strong tendency to follow the sublexical cue and produce a stress error. They also simulated this pattern with the R&C algorithm, which was expected when this operates solely on sublexical cues and does not incorporate lexical knowledge. However, a problem that might be identified with this approach is that if the algorithm does not recognise any affix then stress is automatically assigned to the prefinal position (in accordance to the majority of words in English that receive prefinal stress). Seva, Monaghan, and Arciuli (2009) have highlighted this

inefficiency and noted that the nonword set used to compare the model's performance with participant responses was somewhat biased as it contained a high number of items with affixes included in the model's list.

1.7.2 Stress assignment as a probabilistic problem

An alternative approach in modelling stress assignment comes from the connectionist tradition and considers this sub-task of the reading system in a similar manner to the problem of mapping orthographic to phonological units. Specifically, it is proposed that the statistical regularities in the orthography with respect to stress position are adequate to predict stress without the use of explicit linguistic rules or employment of specific morphological units. Corpus analyses in English and other languages (Arciuli et al., 2010; Monaghan et al., 2016) have confirmed this. Hence, it is suggested that the grammatical status of the morphological affixes is not a prerequisite for bearing information on stress position but rather their orthographic forms is; different letter strings that do not hold this grammatical status can be equally informative regarding stress position. Computational implementations of such models (Arciuli et al., 2010; Seva et al., 2009) have proven to handle items that do not contain affixes equally efficiently hence present an advantage over the rule-based approach (e.g. R&C). Simulations by Arciuli et al. (2010) also showed that such a model can present a similar developmental trajectory with children of ages between 5-12 years. When assigning stress to nonwords, the different training phases of the model with appropriate age-related materials showed a similar gradual learning of the statistical regularities that characterise orthographic cues and stress position in English.

An alternative approach within the connectionist framework is the Junction model (Kello, 2006) that uses simple recurrent networks (SRN). Although based on the learning principles of back-propagation, this model departs from both the architectures described earlier because

it assumes one joint level of representation rather than separate ones for orthography, phonology and semantics. Instead, fixed-width representations of letters, phones and semantics are integrated with the use of 'junction' nodes that function as an intermediate layer and allow the model to learn the mappings between input letters and output phones. However, the main problem of this approach is poor performance on nonword reading (lower than 30%).

An adaptation of the Junction model to address this issue (Sibley, Kello, & Seidenberg, 2010) showed improved performance on nonwords but still considerably high error rates (35% for disyllabic input). The model by Sibley et al. (2010) used sequence encoders (Sibley, Kello, Plaut, & Elman, 2008) to address the problem of spatial coding as an alternative to the typical slot-based representations. Within this framework, SRNs process one element of a given sequence at a time and attempt to predict the subsequent element instead of learning representations that encode all the positions and elements of a given sequence. This was implemented to address the dispersion problem introduced when using input that substantially varies on its length (number of letters). This is an alignment issue manifesting itself in languages that do not have one-to-one but rather many-to-many relationships between letters and phonemes and the size of mapped units varies in size. Simulations performed by Sibley et al. (2010) led them conclude that adopting this approach was not the reason for the model's poor performance with nonwords. Finally, Sibley and colleagues' model implemented additional nodes for stress position of disyllabic words in order to simulate the effect of stress regularity. However, developers of the model acknowledge that it needs substantial work until it can be considered a full computational model of reading hence it is not further considered as a competing theoretical framework under which results are discussed in this thesis.

1.7.3 Problems identified with these approaches

A problem that the R&C algorithm as well as connectionist approaches would need to address is how exception words are stressed correctly by readers. If there are no localist representations and consequently no phonological code that includes stress specification for each word, then all words need to be stressed according to their orthographic cues. However, most such cues present a high but not perfect association with a given stress position. Therefore, such models need to account for the fact that words which are irregular in that they do not receive stress in the position predicted by the orthographic cues are still stressed correctly by human readers. Even the R&C algorithm that has been developed by modellers within the dual-route tradition has only been implemented and tested as a purely sublexical mechanism (Ktori et al., 2016; Rastle & Coltheart, 2000). Full integration within a network containing localist representations is yet to be implemented.

Furthermore, an additional problem that these models cannot address is how stress is assigned to words that are orthographically identical but have different meanings based on their stress position (stress minimal pairs). This is also related to the absence of a lexicon. Within the framework of monosyllabic models, this could be addressed by the approach that models such as DRC have adopted with respect to homophones (words with the same phonology) and homographs (words with the same orthography). Specifically, homophones with different orthography (e.g. *so* and *sew*) have different units in the orthographic lexicon but share the same unit in the phonological lexicon. Homographs with different phonology are treated in the corresponding manner. Similarly, the triangle model (Plaut et al., 1996) includes homographs with different phonology (e.g. *read*, /rEd/ vs. /red/) in each training phase. Besides, the developers of the triangle model argue that semantic involvement is clearly necessary for correct pronunciation of homographs such as *read* (Plaut et al., 1996). This issue is investigated in Chapter 5 of the present thesis by exploring the factors that influence the naming and stress assignment of this type of words. As these words have exactly the

same orthography, when presented in isolation they provide ideal stimuli to investigate default stress assignment mechanisms in English.

Overall, it should be mentioned that none of these two approaches, although computationally implemented, has been fully integrated with a working model of their respective tradition yet. Rastle and Coltheart (2000) provide a theoretical account of how their algorithm could be integrated with DRC but it is unknown whether this has been attempted so far. Similarly, Seva et al. (2009) highlighted that their algorithm has only been developed for stress assignment but extending a currently monosyllabic connectionist model of reading to the polysyllabic domain is not a trivial task. However, a dual-route approach that extended to polysyllabic input and combines characteristics of both modelling traditions is presented and discussed below.

1.7.4 The CDP++ model

CDP++ (Perry et al., 2010; Perry, Ziegler, & Zorzi, 2013) is an extension of the CDP+ model of reading aloud (Perry et al., 2007) reviewed earlier and was developed to further accommodate disyllabic input. This dual route model builds on the IA and DRC architecture for the lexical pathway but relies on a trained network to establish the mappings between graphemes and sounds in the sublexical pathway. In the polysyllabic domain, major challenges that models need to address are the syllabic parsing of the input into the constituent syllables and correct assignment of stress to the appropriate one. While the CDP++ lexical pathway is kept identical to its predecessor (CDP+), the sublexical pathway presents several modifications to address these issues (see Figure 1.4). Firstly, the feature and letter levels as well as the graphemic buffer (that splits each syllable into the onset, vowel, and coda syllabic structure) can take up to 16 characters, double the original eight positions for monosyllables. More importantly, the two-layer sublexical network (TLA) learns the

associations between orthography and stress position in the exact same manner that it learns the mappings between graphemes and phonemes. Once this network is trained, it is able to produce pronunciations of the orthographic input and also produce the prediction of stress position (final or prefinal syllable). It is reminded that the final stage of the CDP+ model is the assembly of the phonological code that connects the two parts by receiving information both from the phonological representation of the lexical route and the TLA network of the sublexical route. In the CDP++, an additional module has been added at this final level that regards stress assignment and similarly interacts with the output of the two pathways. At all stages, stress is represented by two nodes, one for each syllabic position.

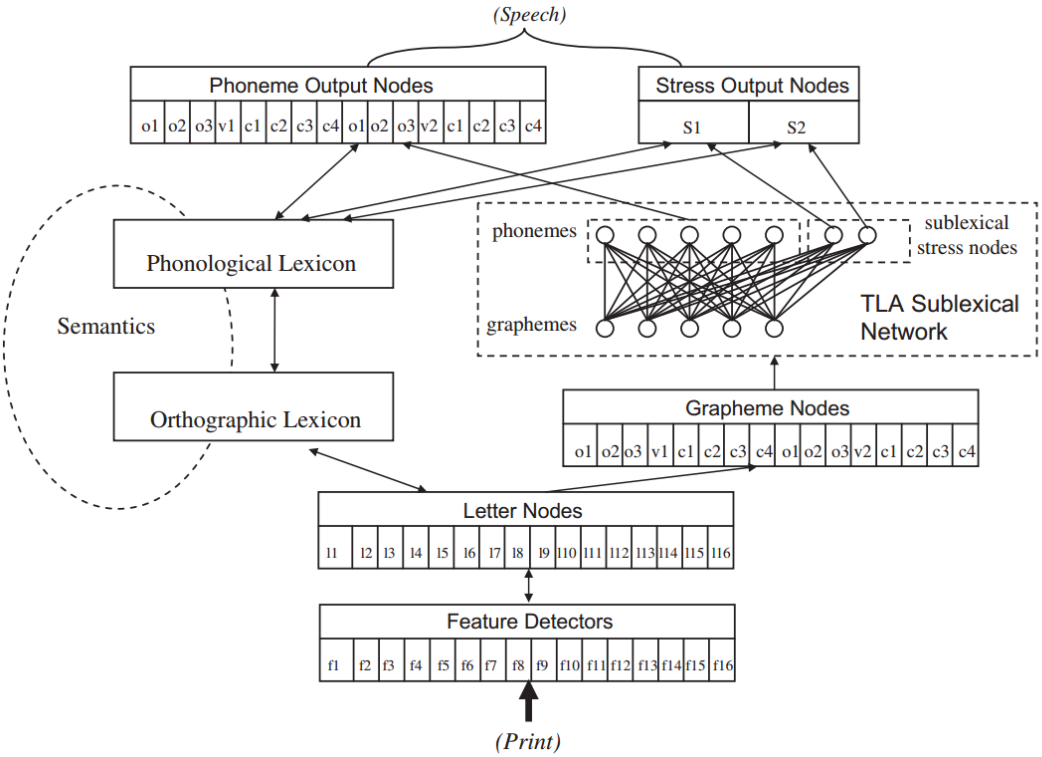


Figure 1. 4 Architecture of the CDP++ model (Perry et al., 2010). f: feature; l: letter; o: onset; v: vowel; c: coda; TLA: two-layer assembly; S1 = first syllable stress; S2 = second syllable stress (adapted from Perry et al., 2010).

In order to address the problem of syllabifying disyllabic input, in this case the graphemic buffer performs an additional task in conjunction to graphemic parsing, which is syllabic parsing. To carry out this task, this graphemic buffer uses a combination of the rule-based and connectionist approaches. The main problem that needs to be dealt with is how intervocalic consonants are distributed between the coda of the first syllable and the onset of the second syllable because this can change the output phonology. CDP++ applies the linguistic constraint of onset maximisation (Hall, 2006) which posits that, if possible, the consonants should go to the onset of the second syllable. Additionally, statistical information captured from the training phase of the TLA network is also used given that the training input as well as the orthographic and phonological representations are organised into syllabic units. In a more recent work, Perry et al. (2013) proposed a fully trained network based on the exact same principles that TLA is trained and integrated it with CDP++. Comparisons with behavioural data showed that the model behaves in a similar manner to human readers in ambiguous cases where more than one options of grapho-phonemic alignment are possible and presents a high level of accuracy overall.

CDP++ has also been adapted for the Italian (Perry et al., 2014a) and French (Perry, Ziegler, & Zorzi, 2014b) languages in both of which it has been extended to accept trisyllabic input. In Italian, only minor adaptations in comparison to the English model have been applied in order to decrease unnecessary complexity of the associative network given the considerably higher level of grapho-phonemic consistency of Italian language. In French, given that it is a language that does not have lexical stress (Dupoux, Pallier, Sebastián, & Mehler, 1997), the stress nodes and the module that predicts stress position were not implemented. Overall, CDP++ model can simulate a number of benchmark effects and outperform the other competing models of reading. The well-documented frequency by regularity interaction (e.g. Paap & Noel, 1991) has been successfully simulated by this model. It has been shown that this interaction can be extended to the stress domain by considering stress regularity (Colombo, 1992) and stress consistency (Burani & Arduino, 2004). The interaction of these

variables with frequency was also simulated by the Italian version of the CDP++ model (Perry et al., 2014a). This effect has also been acquired with error rates in naming English words (Rastle & Coltheart, 2000) and it has also been successfully simulated by the English version of CDP++ (Perry et al., 2010).

The process of assigning stress to minimal pairs when seen in isolation, that is, without any biases from taking context into account, is also pertinent here as an additional scrutiny on the model's performance. It is also informative because these are ideal stimuli to investigate default stress assignment mechanisms in English. Simulations with such items are not reported for any version of the model by its developers. The approach followed with homographs and homophones is similar to the one reported for DRC (Coltheart et al., 2001) and the triangle model (Plaut et al., 1996). Furthermore, word frequencies of homophones in the phonological lexicon and homographs in the orthographic lexicon are the added frequencies of each word the unit represents. Inspection of the word database revealed that stress minimal pairs did have double entries in the lexicon. Consequently, it can be expected that the outcome of stress assignment for such items will be largely dependent upon the lexical route and the frequency of each of the two phonological units corresponding to each homograph. Indeed, a simulation that was performed with CDP++ in our lab (see Chapter 5) confirmed this prediction. Even for minimal pairs that the TLA network predicted stress on the position contradicting the one emerging from the lexicon's frequencies, the latter information typically governed the final output position. Such an example is presented in Table 1.3.

Table 1. 3 Example output of the CDP++ model with the word ‘compact’ as input. The word is stressed on the first syllable despite the TLA network’s higher activation for the stress node on the second syllable, due to the higher frequency of the minimal pair’s phonological unit with stress on the prefinal (/ˈkɒmpakt/)

	Database frequency		**TLA network activations**		**Output layer**	
Input word	**Stress 1**	**Stress 2**	**Stress 1**	**Stress 2**	**Stress 1**	**Stress 2**
COMPACT	110	39	0.457	0.512	0.408	0.197

Note. Stress 1: Stress on the first syllable (prefinal), Stress 2: Stress on the second syllable (final).

Finally, extending the CDP++ model for Greek would not be trivial because it would require theoretical justification on how stress is encoded on any level of representation in this language. Greek has an orthography with unique characteristics in that stress is fully transparent in lowercase but its position is unpredictable in uppercase. Hence, behavioural data from this very language are vital for any theoretical assumptions of model implementations to be justified. For example, CDP++ has been adapted to accommodate French input (Perry et al., 2014b), a language that also includes letters bearing stress diacritics. This was achieved by including stressed and unstressed versions of vowel characters on the letter level. However, French is a language that does not have variant stress so even the stress nodes were removed from this version of the model as irrelevant even for polysyllabic input. Consequently, this approach on its own would be insufficient with respect to Greek language. This is also confirmed by another model that can accommodate polysyllabic input solely in French language, namely the Multi-trace memory model (Ans, Carbonnel, & Valdois, 1998). This model also does not have a procedure to deal with stress assignment given that the non-variant nature of stress in French does not necessitate addressing this issue. Hence, a model of Greek polysyllabic reading requires answering the question of where stress is represented because it could be encoded on different levels of representation. The orthographic and phonological lexicons are both strong contenders as stress encoding loci. However, a question that has not been addressed yet is how the diacritics are processed and whether the stress assignment mechanism is independent of other reading processes (e.g. sequential processing vs lexical retrieval). Until such questions are answered specifically for Greek language, the implementation of a reading model would require choices to be made by its developers that might not be theoretically justifiable entirely.

1.7.5 A Bayesian model of stress assignment

A more recent approach to address the issue of assigning stress to polysyllabic words comes from the work by Jouravlev and Lupker (2015) who approached this challenge as a purely probabilistic problem. In this framework, the reader's mind is regarded as a probability estimator that makes evaluations about the likelihood of an event in the context of the Bayesian theory rather than considering each choice as the output between discrete outcomes (e.g. true or false, stress on the final or prefinal etc.). The model developers performed corpus analyses in Russian which showed that three cues, namely the orthography of the word's first syllable, the second syllable, and of the ending of the second syllable are independent factors probabilistically associated with stress position of Russian disyllables (Jouravlev & Lupker, 2015). Consequently, they deployed this information by calculating the posterior probability of a given stress pattern for each word based on the prior probabilities emerging from these stress cues.

Simulations with word stimuli (Jouravlev & Lupker, 2015) showed that the algorithm performed with 78% accuracy regarding stress assignment which was assessed by the developers as reasonably successful performance. The model performed considerably better presenting 90% consistent stress assignment with the responses of human participants to nonword stimuli. However, consistent with the non-discrete nature of the Bayes calculations outcome, the model failed to decide on the stress position of 8% of nonwords. This should be attributed to the fact that this algorithm makes use of information based on solely three cues mentioned earlier to decide on stress position. Yet, for several of these words, participants did show a preference over of the two positions suggesting that additional cues are at play that are not accounted for by the model.

It should be highlighted, however, that there has been criticism of the assumption that the human mind functions as a probability estimator based on the lack of empirical evidence in favour of this view as well as the problem of undermining the relevant biological and

evolutionary constraints in the theoretical justification of such theories (Bowers & Davis, 2012). Additionally, it should be noted that, similarly to R&C and the connectionist algorithms (Arciuli et al., 2010; Seva et al., 2009), this stress assignment algorithm is not a fully implemented model of reading but solely aims to simulate this specific reading sub-task. Hence, it likewise suffers from lack of holicity as a fully implemented model that offers a theoretical framework in understanding the reading process. It remains to be implemented and shown how such an algorithm would interact with other reading processes and whether it would adhere to the principles of nested incremental modelling which posit that several benchmark reading effects should be replicated before a model could be evaluated as a valid theoretical progression in modelling reading.

Finally, since Russian is a language with different linguistic characteristics (e.g. does not mark stress orthographically, does not show an overall metrical bias towards a given syllable, etc.) it cannot be very informative with respect to different levels of representation that stress might be encoded, similar to the other models discussed earlier. It is also acknowledged by the developers of this model that its behaviour needs to be tested in languages where stress has different linguistic characteristics because it is unknown whether the Bayesian approach will successfully manage to pick these properties. To consider the different levels that stress could be represented and encoded in English, Greek and other languages, a review of stress effects in the word recognition literature is presented below.

1.8 How is stress represented and encoded?

1.8.1 Stress processing in word recognition

It has so far been established that in word production of polysyllabic words, stress needs to be assigned to the appropriate syllable. However, it has been argued that the prosodic structure is applied in silent reading as well (Fodor, 1998). Ashby and Clifton (2005) have also suggested that lexical stress is assigned in silent reading. In an eye-tracking study, they found that words receiving secondary stress took longer to process than words with one stressed syllable. However, it has been argued that word recognition, a task that does not involve word production, could be performed without accessing phonology but rather solely on the basis of the orthographic code (Ferrand, Segui, & Grainger, 1996; Seidenberg & McClelland, 1989). Yet stress effects in lexical decision tasks reported earlier are indicative that stress holds a role in the recognition of single words (e.g. Arciuli & Cupples, 2006; Colombo, 1992; Colombo & Sulpizio, 2015; Kelly et al., 1998). Since these studies have been conducted with languages that do not explicitly mark stress orthographically, this suggests that stress affected processing on the phonological rather than the orthographic level. Within the context of the CDP++ model, such effects would emerge from the phonological lexicon which interacts via forward and, importantly here, backward activations with the phoneme and stress output nodes (see Figure 1.4). However, CDP++ has not been developed to simulate the lexical decision task but only reading aloud. Similarly, phonological effects in word recognition are simulated by the DRC (which is a monosyllabic model) because the phoneme system, where the phonology of the word is assembled (see Figure 1.1), receives input from the GPC module and then through backward activation interacts with the phonological lexicon and this in turn with the orthographic lexicon (Coltheart et al., 2001). In contrast, in languages that consistently mark stress position with diacritics, orthographic contributions in the recognition process may also be at play in a more direct manner.

An alternative question that could be raised is whether stress holds a pre-lexical role in the sense that it facilitates word recognition or a post-lexical role by being assigned to the word following a successful lexical retrieval. In the context of the computational models discussed above (CDP++, DRC), the latter alternative could emerge from a process commencing at the feature and letter levels that leads to the successful prevalence of a candidate unit at the word level, from which stress position is directly retrieved given that it is encoded on the phonological lexicon. Accounts from languages varying in orthographic transparency and stress predictability (such as Spanish and English) suggest that stress is an additional phonological unit that comes about at a late stage of lexical processing. Ashby and Clifton (2005) arrived at this conclusion because when recording eye movements in silent reading, lexical stress affected only mean gaze duration but not the number of fixations or first fixation that is generally susceptible to other factors that affect word recognition such as frequency (Rayner, 1998). They attributed longer gaze durations for words with two stressed syllables compared to those with one to the longer time needed to assemble more phonological units for the task of phonological recoding. They argued against a pure pre-lexical role because they did not observe any differences emerging from the frequency manipulation that should otherwise affect the lexical search. Accounts suggesting that stress effects emerge at a late stage of processing are in line with the multi-step process that is required in the models described above until phonological effects and/or stress effects emerge in lexical decision. They are also in line with the fact that stress assignment naturally needs to follow a series of steps such as visually process the word, phonologically decode it, segmentally assemble it, organise it into syllables, and determine the stressed one.

Gutiérrez-Palma and Palma-Reyes (2008) also proposed that stress is processed at the late stages of lexical access. The researchers asked participants to recognise Spanish words in uppercase that were primed with the same word in lowercase either having a stress mark on the correct, wrong position or no stress mark at all. They observed an advantage for the congruent condition only when the Stimulus Onset Asynchrony (SOA) between the prime and

the target was 143 ms. but not in shorter SOAs (33, 66, 100) and a disadvantage for the incongruent condition at SOAs of 100 and 143 ms. Hence, they concluded that processing of stress is completed at around 100ms. It should be mentioned, however, that, in Spanish, consistent use of the diacritics is not needed because in many instances stress position can be predicted by rule. Equally importantly, the correct spelling of these words would be without a stress mark so their orthographic representations should not have diacritics. Hence, these effects might be phonological in nature by activation of metrical frames with a congruent or incongruent stress position to the target word. Indeed, the researchers arrived at this conclusion because they found a difference between the correct-stress and mis-stress conditions, the only comparison that isolates a phonological mismatch, but no difference between the no-stress and correct-stress conditions, the only comparison that isolates the orthographic mismatch.

In Greek, on the contrary, stress effects do not necessarily need to operate in the phonological domain because stress consistently has an orthographic dimension realised by the diacritics. However, the process that could give rise to such effects is unknown because it is currently not established how stress is encoded in the mental lexicon. For example, stress diacritics could be embedded in the orthographic representations or constitute an independent unit that is processed separately. The following section is concerned with the issue of stress representations in the lexicon of the Greek reader.

1.8.2 The nature of stress representations in Greek

The consistent presence of the diacritic in lowercase Greek, which is the common case type for written communication, makes it an obvious first point of reference with regards to stress position for the Greek reader. However, whether this orthographic mark is typically fully processed as an independent unit is still under debate. Indicative against the contrary is the fact that more than 99% of Greek words would be stressed correctly on the basis of lexical knowledge as there is a very limited set of minimal stress pairs in Greek that are only differentiated by the diacritic position (Protopapas, 2006). Additionally, it is very common practice in written Greek to omit the diacritic in informal contexts on the internet without this omission hindering communication. Hence, it might be that the cognitive cost of decoding the diacritic especially in early developmental stages is too demanding and early readers cannot afford to allocate additional resources for this reading sub-task. In fact, the experiments with nonwords by Protopapas and colleagues reported earlier have confirmed that allocating stress following successful lexical retrieval is the first source of choice for early readers.

However, Protopapas (2016) argues that, in adult reading, the diacritic is processed when nonwords introduce a competition regarding stress position between the position of the stress mark and the lexical activations from the root words that the nonwords are designed to resemble. Protopapas et al. (2007) designed one of their groups of experimental materials by only altering one letter of real words (e.g. *εξωτερικών* /eksoteri'kon/ -> *εξωδερικών* /eksoδeri'kon/) and then confirmed the intended lexical activations by asking an independent group of participants to identify the words that the nonwords resembled. A more direct method of investigating the use of diacritics in stress assignment in Greek is to compare processing of the same experimental stimuli when presented in lowercase, with diacritics present, to uppercase, where diacritics are absent. Thus, this case manipulation allows for exploration of the use of diacritics in orthographically identical stimuli. When word familiarity (words and nonwords) and word frequency (high and low) are introduced as factors in addition to case (lowercase – diacritics, compared to uppercase – no diacritics) on

which to manipulate experimental stimuli, this affords investigation of how stress is processed using different processing routes (lexical and sublexical). This approach encompasses a high degree of experimental control and was identified as lacking in previous research so was adopted for behavioural studies of stress assignment in Greek in this thesis (Chapters 2 & 3).

Furthermore, manipulation of the diacritic availability via case manipulation in words and nonwords in order to investigate stress assignment is deemed a preferable approach over using solely stressed and unstressed nonwords due to an additional reason. Although developing readers do not heavily rely on decoding the diacritic at early stages, from the start of their reading experience they see diacritics on written words. Consequently, diacritics might be gradually embedded in the lexical orthographic representations. Following this, it could be argued that the diacritic is not decoded as an independent sublexical unit even by adult readers but is part of the full orthographic specification of known words. Manipulating word frequency and lexicality across the same experimental items presented in lowercase, with diacritics, and uppercase, without diacritics, enables direct investigation of this hypothesis. Then, in the context of sight-word reading, its position can only affect performance when it is misplaced thus introducing a hindering effect. In a dual-route reading framework, this would mean that the diacritic is independently decoded only when sublexical processing is engaged. The fact that the diacritics are fully processed in nonword reading and are not susceptible to lexical influences even when nonwords can clearly activate lexical representations can be attributed to the apparent need of sublexical processing for the nonwords to be read correctly.

This discussion illustrates why extending the CDP++ model for Greek would not be a trivial task as it would require a theoretical justification on how stress is represented on the orthographic level. For example, the assumption that stress is finally an embedded part of the whole-word orthographic representations could be implemented by including additional letter nodes for the stress versions of the vowels. In contrast, the assumption that the diacritics are

fully processed would require additional stress nodes that would be processed at the stage of the graphemic buffer and would determine the stressed syllable after syllabification is accomplished. Subsequently, this would need to interact with the stress output nodes as well as the lexical route. The first approach has been used in the adaptation of CDP++ for French input (Perry et al., 2014b) but it has been justified elsewhere why this would constitute an inefficient approach to model stress in Greek language. Results of the behavioural experiments in word recognition reported in Chapter 3, informed the simulations performed with a computational model that accommodates polysyllabic input reported in Chapter 6.

1.9 Research objectives and structure of the thesis

To enhance understanding of the mechanisms used in the stress assignment process in Greek and English this thesis addresses the following issues.

First, the initial aim that was set involved investigating whether the interaction between frequency and stress regularity based on the default metrical pattern reported in other languages would also be replicated in Greek reading. Additionally, a further aim was to investigate whether this interaction would be observed in lowercase, uppercase or both. Uppercase resembles languages such as Italian that do not mark stress orthographically. Importantly, replication of this interaction in lowercase would be informative regarding the way that stress diacritics are processed. Alternatively, it could be expected that, in lowercase, the abundance of converging information on stress position (e.g. orthographic cues, lexical knowledge) would not allow this interaction to come about due to performance reaching ceiling levels. This has been reported by Protopapas et al. (2007) who observed that when lexical and orthographic information converged to a given stress position, then the metrical bias was not strong enough to attract stress assignment on the penultimate syllable. Furthermore, the reading aloud experiments reported in Chapter 2 was a way to assess our methodology and see whether we would obtain comparable results to those reported in the experiments by Protopapas and colleagues. For example, as these researchers have highlighted, the metrical bias that lags behind the other two sources in adult reading is nonetheless active and affects the mechanism of stress assignment. Here, this bias was evaluated in a gradual manner with high-frequency, low-frequency words and with nonwords and it was elucidated when it becomes important in the gradual elimination of the other sources.

Additionally, a further aim was to disentangle any effects emerging from the presence of the diacritics from potential effects emerging from case type itself. For this purpose, an experiment was conducted that utilised monosyllabic words, the only items in the Greek

lexical battery that truly differ only in the aspect of the different scripts used for the two case types. Every other lexical item in the Greek vocabulary will also retain the difference of bearing stress marks or not between the two case types. Theoretical models of reading (e.g. DRC) have typically adopted the assumption that letters are encoded as abstract identities independent of case. In Greek, this assumption could be challenged from the additional information that lowercase letters carry from the addition of the stress marks. Therefore, if any differences were observed between the patterns of lower *vs* uppercase in polysyllabic as opposed to monosyllabic stimuli, these could be attributed to the presence of the diacritics and a potential facilitation in word identification or production.

The data collected to address the aims reported for this chapter were evaluated with a variety of metrics. Indicatively, in conjunction to analysing response times, the production of nonwords in upper case endorsed the reader to stress the items at whichever position they preferred. Hence, it allowed investigation of the presence of the metrical bias in the absence of other sources or not. Error rate analysis was also particularly important because in many cases of stress assignment experiments, significant effects were observed in accuracy but not reading latencies (e.g. Arciuli & Cuples, 2006; Rastle & Coltheart, 2000). Finally, duration times, which have been suggested to reflect post-recognition processes (Balota, Boland, & Shields, 1989), were calculated as an additional insight to the effect stress has in reading, in line with the suggestion that stress assignment occurs as a final reading phase (Ashby & Clifton, 2005; Gutiérrez-Palma & Palma-Reyes, 2008).

Consequently, the purpose of the reading aloud experiments reported in Chapter 2 was threefold. Firstly, to validate our methodology and confirm that we would acquire patterns that corroborate previous research findings in the Greek stress assignment literature. Secondly, to investigate if the frequency by stress regularity interaction is replicated in Greek and reveal on what level of representation it occurs, i.e. whether, when diacritics are present, they allow this interaction to emerge or not. And thirdly, to disentangle the effects of

orthographic diacritics and case type that could be considered as confounded in polysyllabic words.

Second, in Chapter 3, lexical decision tasks were utilised in an identical design to the one used in the reading aloud experiments (manipulating lexicality, frequency, case, and stress position). The purpose of these experiments was to investigate the locus of stress effects in Greek language and the level of representation that it is encoded. First off, if positional effects of stress were observed in lexical decision, this would corroborate findings in other languages suggesting stress assignment does not only concern the word production phase of reading. If such effects were observed with uppercase letter strings, this would indicate a phonological origin because in uppercase, stress is not marked orthographically. If, however, stress effects were observed only in lowercase, this would provide evidence in favour of an orthographic process. If they were consistently observed across both cases, this would provide support for phonological activations with potential contributions from the orthography. Additionally, predictions of potential effects and their corresponding interpretations can be made within the context of a dual-route reading model. It has already been established why stress is expected to be encoded on the phonological level which in the framework of DRC would be the phonological output lexicon. That is because readers are known to be able to stress uppercase words in Greek correctly despite uppercase lacking orthographic stress marks. However, given that nonwords are not represented as independent units in the lexicon, if stress effects are present with such stimuli, this would be plausible via backwards activation from the phoneme system to the phonological output lexicon (see Figure 1.1). The situation could be different, however, in lowercase that has orthographic diacritics indicating stress position. Again, the lexicality distinction between words and nonwords appears particularly pertinent in this case. If stress effects are acquired with nonword stimuli and these do not emerge in uppercase, this would provide evidence that stress is encoded as an independent unit on the letter level. On the contrary, the absence of such effects with nonwords but their presence with real words in lowercase would showcase the orthographic input lexicon as a strong

contender for the locus of stress encoding on the orthographic level. This would be in line with accounts suggesting that stress might not be processed as an independent unit but be part of the whole word's orthographic representation (see Protopapas, 2016). However, it could not exclude the possibility of the diacritics being processed independently when need be, that is, in the processing of nonwords, an issue that the reading aloud experiments presented earlier would be in the position to address.

Third, in recent years, the reading literature involving stress assignment has highlighted several variables that affect this mechanism and determine whether a word receives canonical stress or not according to different notions of regularity. This, in turn, has an impact on this reading sub-process. Indicatively, it has been shown that in languages such as English (Arciuli & Cupples, 2003; 2006) and Russian (Jouravlev & Lupker, 2014) whether stress position is regular or not depends on the word's grammatical category. Alternatively, Colombo (1992) as well as Burani and Arduino (2004) introduced stress neighbourhoods in Italian, according to which the neighbourhood of words that share the same phonological ending determine whether a word within this neighbourhood is a 'stress friend' (i.e. stress according to the majority) or a 'stress enemy'. Finally, corpus analyses in English and other languages have shown that the beginning and ending of words present specific patterns regarding stress position as they are often associated with stress on a given syllabic position (Arciuli et al., 2010; Monaghan et al., 2016; Kelly, 2004). These have been also confirmed to have a behavioural dimension as the regularity of stress position affected participant performance in a variety of tasks (Arciuli et al., 2010; Kelly, 2004; Kelly et al., 1998). Monaghan et al. (2016) showed that such statistical regularities are also present in Greek orthography as word beginnings and endings have predictive power on stress position. A thorough review of the databases currently available for psycholinguistic investigations in Greek revealed that none of these variables was available. Hence, a Greek database that had been initially developed in this lab (GreekLex, Ktori, van Heuven, & Pitchford, 2006) was further enhanced to include all these variables (GreekLex 2, Kyparissiadis, van Heuven,

Pitchford, & Ledgeway, 2017). Additionally, the database was also extended to include many new variables that are essential in psycholinguistic research but were not available in the previous version. This allowed novel analyses of several statistical properties of Greek language. Indicatively, it was found that the overall metrical statistical bias towards stress on the prefinal syllable is not universal in Greek because in adjectives, stress on the prefinal is disfavoured.

Finally, the new measurements allowed the behavioural investigation of the default metrical pattern in relation to grammatical category reported in the word recognition experiments of Chapter 3. This is particularly important because, as it has been also noted elsewhere (e.g. Protopapas, 2006), although the default bias towards the penultimate syllable appears as a general property of the Greek reading system, it does not emerge as a uniformal statistical property of Greek language; the number of words that receive stress on this position does not surpass the overall number of words in the language but only each individual group stressed elsewhere (as opposed to Italian, Colombo 1992). Statistical calculations reported in this chapter show that this pattern is also not uniform across grammatical categories hence making its behavioural investigations particularly pertinent. Prior investigations with respect to its nature have shown that it does not seem to originate in cumulative activations from the lexicon in the working memory (Protopapas et al., 2007) hence failing to falsify the structural hypothesis that this pattern emerges from general properties of Greek language. Here, it was explored whether the dependence of the pattern's statistical predominance upon grammatical category would reflect the same dependence of the metrical bias in the participants' reading patterns or alternatively would emerge uniformly across any statistical category. The latter outcome would further enhance the view that the metrical pattern might not be the direct outcome of the language's statistical properties and their corresponding activations emerging from the mental lexicon.

The development of the GreekLex 2 database along with a review of the currently existing psycholinguistic tools in Greek and their limitations that led to this project are presented in Chapter 4.

Fourth, in Chapter 5, the mechanisms of stress assignment in English were investigated using disyllabic stress minimal pairs, a category of words that are orthographically identical but only differ in the position of stress (either first or second syllable). This is a critical category of words to investigate the stress assignment mechanisms because in a reading aloud experiment participants can freely assign stress on any position without producing a naming error. If there is an overall statistical bias in English towards stress on the prefinal syllable it could be expected that participants would show a preference towards this syllabic position when naming such words. Data supporting this view have been reported in (Monsell et al., 1989) but have not been subsequently replicated (Rastle & Coltheart, 2000). In contrast, if the relative frequencies of the different phonological units that correspond to the same orthographic form are important in this process, as would be suggested by computational models such as the CDP++ (Perry et al., 2010), then it would be expected that participants would show a preference towards the most 'dominant' phonological form of each orthographic entry. Data were acquired and compared to the output of simulations performed with the above-mentioned model. Additionally, word naming performance was compared to disyllabic words used as baselines that were unambiguous with regards to stress position as they could only be stressed in one of the two syllables (e.g. 'doctor'). The purpose of this was to investigate whether the ambiguity in stress position of minimal pairs would introduce a conflict reflected in slower response times for this category.

Furthermore, in an additional experiment, it was investigated whether priming minimal stress pairs with stress position on a given syllable, either final or prefinal, would affect the stress assignment preferences of participants. Information about stress position was induced by the disyllabic baselines that acted as stress primes in each of two blocks, either favouring the first

or the second syllable. Within dual-route models such as the CDP++, the phonological representation of the stress pair that has similar stress position to the disyllabic baseline could be expected to reach its activation threshold quicker. Alternatively, the higher frequency of the 'dominant' phonological entry might still be strong enough to result in the supremacy of this candidate regardless of the increased activation of the competing one. Since priming was induced within blocks rather than on the item level, adaptation of current computational models to perform simulations comparable to the behavioural experiment would not be a trivial process to implement.

Fifth, and finally, the results from the behavioural experiments in English and Greek are summarised and discussed in the last section of this thesis (Chapter 6). Additionally, the theoretical implications regarding the stress assignment mechanism in Greek that resulted from the current experiments were implemented in an initial attempt to model word recognition in Greek. The development of a primitive, Greek computational model for the lexical decision task is briefly presented and the output of several simulations performed is compared to the behavioural data acquired. The model is based in the IA tradition (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) but is extended to accommodate polysyllabic input as well as encode stress information.

CHAPTER 2

EFFECT OF DIACRITICS AND WORD FREQUENCY ON THE STRESS ASSIGNMENT MECHANISM IN NAMING WRITTEN GREEK WORDS

A main aim initially set in this thesis was to evaluate whether sublexical processes in stress assignment interact with lexical retrieval when real word materials are presented to the reader. An additional aim was to assess how the presence of the diacritic affects this process. This chapter reports results from two reading aloud tasks with skilled Greek readers involving written Greek words. In Experiment 1, it was examined how stress position affects word naming when diacritics are present (lowercase words) and when they are not (uppercase words). Thirty-two Greek skilled readers performed a written word-naming task with bisyllabic words and nonwords either stressed on the first or the second syllable (e.g. τάξη, ψιλή) in which frequency and case were manipulated. Analyses revealed that with uppercase words (no diacritics), low-frequency words were read more accurately when stressed on the first syllable, consistent with the default metrical pattern and indicative of sublexical processes. In Experiment 2, twenty-four Greek skilled readers performed a reading aloud task with a set of monosyllabic words that do not have stress diacritics. Results showed that case effects observed in Experiment 1 remained, which is interpreted as a general higher familiarity of lower over uppercase words. Important constraints on current reading models are discussed regarding the mechanism encoding stress assignment in Greek as well as implications for current reading theories.

2.1 Introduction

It has already been discussed earlier in this thesis how Greek readers can determine the position of stress in lowercase words directly from orthography, since diacritics explicitly mark the stressed syllable (e.g. *τάξη, ψιλή*). This is not the case for most other languages with lexical stress in which stress position is not obvious from visual marks (e.g. English, German etc.). Importantly, in Greek, stress position is marked orthographically only in lowercase words but not in uppercase words (*ΤΑΞΗ, ΨΙΛΗ).* This means that case should influence the assignment of stress when naming aloud written Greek words but should have no effect on stress assignment in pronouncing, say, written English words.

Inconsistencies across orthographies such as the ones regarding stress described above have implications for universal models of reading aloud which need to accommodate different sources of stress information. As stress assignment is marked in Greek (diacritics on lowercase words) but not in English, the architecture of current models of reading single words need to be adapted for Greek. Furthermore, current models of reading aloud have overlooked differences in performance between lowercase and uppercase stimuli. When reading single English words, case should not affect stress assignment. In contrast, in Greek, written word naming performance could be expected to vary across lowercase and uppercase stimuli, as the diacritics on lowercase stimuli should facilitate stress assignment compared to uppercase stimuli where no stress cues are given to disambiguate pronunciation.

2.1.1 Stress assignment in the context of reading strategies

Experiments in different languages (Italian: Colombo, 1992; English: Rastle & Coltheart, 2000) have shown that the sources of stress information that are most prominently used for stress assignment might depend on the type of processing strategy that is employed by the reader. This, in turn, has been argued to depend on the transparency of the orthography being

read aloud. Native speakers of transparent languages have been argued to predominantly rely on sublexical strategies because lexical access can be preceded by phonological computations encouraged by the consistency between graphemes and their corresponding sounds (ODH, Katz & Frost, 1992). In contrast, native speakers of opaque languages such as English need to rely on orthographic processing and direct lexical access due to the highly inconsistent correspondences between letters and sounds (e.g. "come" and "home") as well as many irregular pronunciations (e.g. "gnome"). The well-documented effects in reading behaviour of lexicality (advantage for reading aloud words over nonwords) and frequency (advantage for reading aloud high- compared to low-frequency words) are specifically attributed to lexical processing (e.g. Frost, 2008; Traficante & Burani, 2014). In contrast, if pronunciation is generated entirely pre-lexically, no such effects should be expected to be observed.

However, the universal hypothesis in reading (see Frost, 2008, for a review) posits that lexical access occurs in all languages; even in shallow orthographies, the visual form of high-frequency words can generate a match in the mental lexicon before sublexical computations are complete. For low-frequency words, the level of visual familiarity will not be sufficient for the word-level channel to generate a match before sublexical processing is accomplished (Seidenberg, 1985). Thus, word frequency determines the extent to which lexical processes influence the naming of written words, which in turn could affect the stress assignment mechanism particularly in a language such as Greek. This is because the Greek language offers both possibilities to determine stress position, i.e. either compute it sublexically or directly retrieve it from the whole-word phonological representations. This mirrors the well-documented interaction between frequency and regularity in the pronunciation of English words, where irregular pronunciations only seem to hinder reading when phonology is derived sublexically (with low-frequency words) but not when it is directly retrieved (with high-frequency words). This effect in English has been successfully simulated using the Dual Route Cascaded (DRC) model (Coltheart et al., 2001).

2.1.2 Stress assignment in Greek reading aloud

Previous research conducted by Protopapas and colleagues (Protopapas, 2006; Protopapas et al., 2006; 2007; Protopapas & Gerakaki, 2009) has identified three sources of information that influence the stress assignment mechanism in Greek language; processing of the diacritics, lexical retrieval, and the default metrical pattern. To investigate how these sources operate and interact, the researchers asked their participants to read aloud nonwords with stress diacritics on any of the three final positions. Their items were either minimally (one letter away) different from the real word they were generated from or changed beyond recognition. With this design, they aimed to isolate and contrast the different sources of stress information and assess their participation in the stress assignment mechanism. For example, when the stress mark on a nonword is not on the default penultimate syllable or when the lexical activations of the root word indicate a different stress position than the syllable that bears the diacritic, then, if all these sources of information are active, the reader needs to resolve such conflicts in order to stress the nonword correctly.

An important conclusion that these experimenters reached was that despite the consistent presence of the diacritics in lowercase Greek, in skilled reading, lexical contributions are consistently active as a strategy for assigning stress (Protopapas et al., 2007). This is evidenced by a high number of errors that are made when the position of the diacritic in nonwords contradicts lexical information (from the root word), thus indicating the influence of lexical processes. However, decoding of the stress diacritics is also evidenced, given that the majority of nonwords were read and stressed correctly. Besides, it has been argued that by reading maturity this process is expected to be automatic and flawless (Protopapas, 2016). Finally, Protopapas et al. (2007) found contributions from the default stress pattern to be present but with relatively limited effect when compared to the other sources. Quantitative analyses performed by Protopapas (2006) and furthered by work undertaken for this thesis (see Chapter 4) have highlighted a potential reason behind the relative weakness of this source; the statistical dominance of words stressed on the penultimate syllable is by no means

unanimous in Greek as opposed to other languages (e.g. Italian, see Colombo, 1992). Consequently, if the default metrical pattern emerges from statistical predominance, it could be expected to manifest weaker effects relative to the other sources when compared to how it manifests itself in languages such as Italian. Hence, it is not very surprising that, especially when both the other two sources were contrasting the default pattern (i.e. diacritic on another syllable and root word stressed on another syllable), the readers appeared unlikely to resort to this strategy in order to assign stress in the experiments by Protopapas and colleagues.

2.1.3 Rationale for the present study

From the research that has investigated stress assignment in Greek reading to date, it is impossible to establish whether there is a shift in utilising different sources of stress information depending on the specific characteristics of words read aloud. Factors such as word frequency and lexicality that reflect certain processing strategies have so far not been manipulated in relation to stress assignment because the experiments reported above used nonword stimuli (for the purpose of controlling the contribution of lexical retrieval of stress position in stress assignment). What has been manipulated is the frequency (low *vs* high) of root words used to generate minimally changed nonwords with the aim of activating the underlying word representations. But this manipulation did not yield any differences in the reading times or stressing strategies neither in adult (Protopapas et al., 2007) nor developing readers (Protopapas et al., 2006). The authors attributed this to either the statistical procedure not being adequately robust to showcase such differences, or the real word materials used to generate nonword stimuli not being appropriate to elicit the frequency effect. Furthermore, differences between minimally changed nonwords and nonwords changed beyond recognition (in the same experiments) are not directly comparable to the lexicality manipulation because even minimally changed nonwords cannot be read solely by employing a lexical strategy but rather necessitate sublexical processing in order to be read correctly. In Protopapas and

Gerakaki (2009), either minimally changed nonwords (Exp. 1) or real words (Exp. 2) were compared to nonwords changed beyond recognition. Stimuli were presented with diacritics on the correct syllable, a wrong syllable, or no diacritics at all. The naming latencies revealed that patterns in stress assignment did not differ between Experiments 1 and 2. However, word frequency was not manipulated in this study. Additionally, these experiments were conducted with developing readers (grades 2-4). Early readers have been shown to present a dominant reliance on lexical retrieval of stress position, rather than deriving stress assignment sublexically by decoding the diacritics. Consequently, we don't yet know whether frequency could be moderating the stress assignment mechanism in skilled Greek readers.

Yet, the influence of word frequency on stress assignment has been demonstrated in several languages. In Italian, Colombo (1992) used trisyllabic words where stress position was either consistent or inconsistent with the distributional properties of the language (i.e. a strong metrical bias towards the penultimate syllable) and she found that this affects the reading latencies of low-frequency but not high-frequency items. This suggests that for the latter, stress position was retrieved from the phonological lexicon directly without the need for sublexical phonological assembly. In English, Rastle and Coltheart (2000) replicated such findings by manipulating stress regularity emerging from a set of rules based on morphological affixes that indicated the expected stress position in each word. As with Italian, Rastle and Coltheart found an interaction between stress regularity and word frequency in reading aloud English words, hence providing further evidence that the stress assignment mechanism is influenced by both lexical and sublexical processes.

Neither Italian nor English mark stress position with diacritics so it is currently unknown whether or not word frequency influences the processing of stress in languages that mark this information orthographically such as Greek. This is important because there is a crucial difference between Greek and languages such as English and Italian; in the latter languages, sublexical assignment of stress needs to rely on computations that emerge from the lexicon

activations due to more entries being stressed on a given position. In contrast, sublexical stress assignment in Greek can be performed independent of the lexicon by decoding the orthographic mark. However, the fact that diacritics are only marked in lowercase allows exploration of the differential effects of word frequency and diacritics in the stress assignment mechanism by manipulating systematically case and word frequency. For upper case stimuli, the situation is the same as for languages that do no mark stress, such as English and Italian. Thus, readers need to retrieve stress position from the phonological representations, that should intrinsically code stress, but this might be the case more predominantly for frequently encountered words. In contrast, stress assignment for low-frequency words could rely more heavily on sublexical processes such as the metrical bias towards the typical stress pattern. Hence, a frequency by stress position interaction might be expected. Furthermore, an additional source of stress information, the orthographic diacritics, is available in lowercase, thus its contributions to the stress mechanism can be explicitly investigated when compared to uppercase. Manipulating the availability of the diacritics through case manipulation provides a more naturalistic experimental comparison in contrast to presenting multisyllabic lowercase words without a diacritic (as in, for example, Protopapas & Gerakaki, 2009).

Previous research on the influence of case in recognising and naming written words has produced conflicting findings. Some authors suggest that lowercase benefits the reading process because it is more visually distinctive (Paap, Newsome, & Noel, 1984) and is more familiar (Perea & Rosa, 2002) to the reader than uppercase due to higher exposure. Other authors have found no advantage for lowercase words over uppercase words in written word naming tasks (Mayall & Humphreys, 1996)[1]. In that study, Mayall and Humphreys also did not seem to find an interaction between frequency and case in reading aloud[2]. Importantly, case has not been manipulated so far in an orthography that differentially uses diacritics to

[1] A case effect is reported due to the AlTeRnATiOn condition, not the lower and uppercase comparisons.
[2] Although the authors did not report this specific statistical analysis, the difference between lower and uppercase was 7 ms for high-frequency and 15 ms for low-frequency words.

indicate stress position and consequently does not provide the same amount of pronunciation information for both case types. In computational modeling, it is a widespread agreement even among models that focus at the front-end of word recognition such as letter position encoding (e.g. Davis, 2006) that it is the abstract letter identities that are being encoded independently of case and other characteristics (e.g. font, colour, etc.).

This study sought to differentiate the effects of word frequency, case, and diacritics on the naming of written words in Greek by skilled readers. Previous studies of stress assignment in Greek have not manipulated word frequency, yet word frequency is known to affect reading processing strategies and subsequently might thus differentially affect the stress assignment mechanism. In addition, no studies, to our knowledge, have investigated so far the influence of case on reading aloud written Greek words. A difference between upper and lowercase could be expected because only the lowercase words include explicit stress information for pronunciation. Here, for the first time, we manipulated the factors of case and frequency in two experiments, each of which utilised a word-naming task.

Furthermore, experiments employing the reading aloud task typically rely on the accuracy of responses and on reaction times which are calculated from the point the stimulus appears on screen until the onset of the participant's response. As an additional insight to the effect variables such as word frequency have in reading, calculation of duration times has been suggested to reflect post-recognition processes (Balota et al., 1989). Duration of production is measured as the time between the onset of word production until the offset of the word's last sound. Within an interactive activation framework (e.g. McClelland & Rumelhart, 1981), the cascade-like fashion of activations between neighbouring levels of representation (e.g. letter units –word units) posits that activations will continue being reinforced without a clear cutting point at any particular stage of processing. While a specific threshold needs to be set in order for computational implementations of such models to perform the lexical decision task, this is not needed in the word naming task. If processing is not terminated after the onset, then

variables such as word frequency are expected to also affect duration of production. Seen conversely, frequency effects observed in duration of responses could be taken as additional proof for the employment of lexical processes in the reading task. It has been argued by Gould, Cummine and Borowsky (2012) that there is an inverse relation between the length of duration time and the extent to which a word is read lexically. Additionally, comparison of patterns of results emerging from response latencies and durations can potentially provide an additional insight about which of the manipulated variables present an effect only at the initial stages of processing and which ones retain their influences, hence remain active, at later stages.

2.2 Experiment 1

This experiment investigated the influence of word frequency, case (presence or absence of diacritics), and stress position (prefinal or final syllable) in the naming of written Greek words and nonwords by skilled readers to determine their role in the stress assignment mechanism. To test this, Greek disyllabic words and nonwords, stressed on either the prefinal or final syllable, were presented to participants in both lowercase and uppercase.

2.2.1 Hypotheses and predictions

Certain predictions can be made according to the different sources of stress information that could be operating in the stress assignment mechanism. If processing and assignment of stress is performed purely sublexically, then effects of frequency, lexicality and stress position would not be expected whereas an effect of case would be predicted because only lowercase stimuli have stress diacritics. However, it is already known that this is untenable. If words are named through access to the mental lexicon, then frequency and lexicality effects should be observed but no effect of stress position would be expected, as stress will be retrieved directly from the lexicon. Finally, if stress is assigned using a strategy based on adopting the default metrical pattern, then a difference in stress position would be expected with higher accuracy for words stressed on the prefinal compared to those stressed on the final. Additionally, an interaction between case and stress position would be expected with no effect of stress position for lowercase stimuli but superiority in naming uppercase words stressed on the prefinal syllable. Furthermore, these predictions could be modulated by word frequency, as word frequency is known to alter the strategy employed by the reader to name different types of stimuli and consequently can also alter the sources of stress information that are utilized in each case. Accordingly, a higher order interaction involving case, stress position and frequency might be expected, with the case and stress position interaction effects being shown

only for low-frequency words and not high-frequency words because for high-frequency words stress position will be directly retrieved from the mental lexicon.

2.2.2 Method

Participants

Thirty-two native Greek speakers (*age range* 22-32 years, *mean age* 27.1 years, *SD* 3.2 years) were recruited from the undergraduate and postgraduate populations at the University of Nottingham. Nineteen were females. All participants had normal or corrected-to-normal vision and none of them reported any diagnosed learning or reading difficulties.

Materials

Stimuli were disyllabic Greek words and nonwords of either four or six letters. The total set consisted of 80 words (20 items per condition of frequency and stress position) and 80 nonwords. Syllable length (in number of letters) was matched across stimuli following the traditional spelling rules of syllabification in Greek. Stimulus sets were further matched for length, word neighbourhood (Coltheart's N, as defined in Coltheart et al., 1977), and positional bigram frequency of the linking letter cluster between the two syllables ($p > .5$). Analysis of the real word items revealed that they also did not statistically differ ($p > .5$) in mean stress neighbourhood. This analysis was conducted post-hoc, when this metric was calculated and became available in the work reported in Chapter 4. Stress neighbourhood is defined as the proportion of items having stress on the same syllabic position as the item of interest over all entries sharing the same ending with it.

Word frequencies were retrieved from *SUBTLEX-GR* (Dimitropoulou, Duñabeitia, Avilés, Corral, & Carreiras, 2010), because subtitle databases provide a more realistic estimate of word frequencies than counts determined from written sources (Brysbaert & New, 2009). The *IPLR* database (Protopapas, Tzakosta, Chalamandaris, & Tsiakoulis, 2012) was used to obtain

syllabic information (syllabic length and frequencies) and *GreekLex* (Ktori et al., 2008) was used to obtain lemmas to keep morphological complexity to a minimum. *GreekLex 2* (Kyparissiadis et al., 2017) was used to retrieve stress neighbourhoods. Frequencies from SUBTLEX-GR were transformed to the Zipf scale (see van Heuven, Mandera, Keuleers, & Brysbaert, 2014). The upper limit of low-frequency words was 2.955 in Zipf scale (1 appearance per million) and the lower limit for high-frequency words was 4.778 (65 appearances per million). The frequencies were matched between the stimuli groups with stress on the prefinal and final, both for high-frequency words and for low-frequency words.

Nonwords were generated from the word stimuli. Within each stimulus set, words were split into the two composite syllables, resulting in two syllable groups based on their position in the word (prefinal or final syllable). To maintain the syllable position within the nonword stimuli, with respect to the original position in which they appeared in the root word, each 'prefinal' syllable was randomly combined with a 'final' syllable, to generate a nonword[3]. The only constraint was that the bigram linking the syllables had to be a legal letter combination in Greek and the mean frequency of the linking bigram was matched across nonword sets. This ensured that the mean positional syllabic frequencies were kept constant across the sets of nonword and word stimuli. Statistical characteristics of the stimulus sets are presented in Table 2.1 and a full list of the stimuli can be found in Appendix A.1. English translations of all word stimuli used in this experiment are provided in Appendix A.2.

[3] E.g. From the words ζώ-νη and τά-ξη the nonwords ζώ-ξη and τά-νη would be generated.

Table 2. 1 Experiment 1: Statistical properties of the bisyllabic stimuli used. Zipf mean, min, max and range given, as well as Coltheart's mean N, mean letter length, and linking mean bigram frequency.

	High frequency words		Low frequency words		Nonwords	
	prefinal	final	prefinal	final	prefinal	Final
Zipf mean	5.592	5.454	2.465	2.624	-	-
Zipf min	4.778	4.832	1.633	1.633	-	-
Zipf max	6.593	6.563	3.961	3.909	-	-
Zipf range	1.815	1.731	2.328	2.276	-	-
Coltheart's N	3.75	3.6	3.7	3.6	3.65	3.58
Length (letters)	4.3	4.3	4.3	4.3	4.3	4.3
Link. bigram freq.	16955	17256	15776	15777	17794	16582.6
Stress N	80.2	85.2	82.7	84.6	-	-

Notes. Zipf frequency was computed as defined in van Heuven et al. (2014) and Coltheart's N was computed as defined in Coltheart et al. (1977). Linking bigram frequency refers to the frequency of the bigram between the last letter of the prefinal syllable and the first letter of the final one (e.g. *τρό**π**ος*). Stress N was computed as defined in Colombo (1992).

Design, apparatus, and procedure

A repeated-measures design was employed in which the independent variables were lexicality (word, nonword), word frequency (high, low), case (lower, upper), and stress position (first syllable - prefinal, second syllable - final). Accuracy of responses and naming latencies measured from the point that the stimulus appeared on screen until the onset of the participant's vocal response were recorded. In addition, duration of production was measured by the time difference between the onset of word production and the offset of the last sound in the word (Balota et al., 1989).

Stimuli were presented on a 19-inch CRT screen (1024x768 pixels, 85 Hz) connected to a PC running Windows XP. Stimulus presentation and response recording was controlled with DMDX (Forster & Forster, 2003, version 4). Participants were seated approximately 40 cm away from the computer screen. Responses were recorded with a head-mounted microphone and participants were instructed to be as fast and accurate as possible. The accuracy of the onset of the vocal responses was checked, and adjusted where appropriate, with CheckVocal (Protopapas, 2007). This software was also used to mark the offset in order to calculate the duration of production. The duration of production was standardized per letter by dividing the total duration production time by the number of letters in the stimulus because stimuli differed in length.

The blocks of uppercase and lowercase stimuli (160 trials per block, 320 in total) were counterbalanced across participants. Within each block of upper and lowercase stimuli, presentation of word and nonword stimuli was randomized with DMDX. Stimuli were presented in 14-point Courier New, a non-proportional font in which all letters occupy the same amount of space. Each trial started with the presentation of a fixation cross (+) for 500 ms, followed by a blank screen for 250 ms and then the presentation of the stimulus, which remained on the screen for 500 ms. A naming response (or the 3 second time out) triggered onset of the next trial. The inter-trial interval was 1000 ms. Participants were given a short

break half way through and between the blocks of lowercase and uppercase stimuli. The experiment took approximately 35 minutes to complete.

A practice session preceeded commencement of each of the lowercase and uppercase trials. In each case, the proportion of practice items matched the proportion of experimental stimuli resulting from the variable manipulations. Specifically, four high-frequency items, four low-frequency items (in each case, two stressed on the prefinal and two on the final) and eight nonwords (four stressed on the prefinal and four on the final) were presented to participants before the lower or uppercase blocks, resulting in 16 items in total for each case. The practice items preceding the uppercase trials were also presented in uppercase.

To check that the low-frequency stimuli were known by the participant, a printed list of the low-frequency words was given to 14 of the participants and they were asked to produce a definition or a synonym for each item. All words with defined with 100% accuracy, indicating that these words were known to the participants.

2.2.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies greater than 3.5 SDs away from the mean were excluded from the analysis. No responses were below the low cut-off point of 300 msec, so exclusion of low latencies was not needed. Mean reaction times for correct responses, duration production times, and error rates were calculated and submitted for analysis across participants and across items. Correct naming of lowercase words and nonwords required stress to be applied in the position of the diacritic. Correct naming of uppercase words also required stress to be applied correctly as these were unambiguous words that could only take stress on a specific syllabic position despite the absence of the diacritics. For uppercase nonwords, correct naming was taken as correct pronunciation of the constituent letters, independent of the position where stress was applied. Descriptive statistics for

response times and accuracy rates are reported in Table 2.2 and item-level data of these measurements are provided in Appendices A.5 (words) and A.6 (nonwords).

For both dependent variables, three separate ANOVAs were conducted. First, a 2-way repeated-measures ANOVA was conducted to investigate the effects of lexicality and case. Second, a 3-way repeated-measures ANOVA was conducted with the word stimuli only, to explore the effects of word frequency, case and stress position. Third, a 2-way ANOVA was conducted with the nonword stimuli only, to investigate the effects of case and stress position.

Table 2. 2 Experiment 1: Mean reaction times (milliseconds) and accuracy rates (percentage correct) in the disyllabic word-naming task. Standard deviation given in parenthesis.

Response latencies (ms)						
	Words				Nonwords	
	High frequency		Low frequency			
Stress	prefinal	Final	prefinal	final	prefinal	final
Lowercase	466 (49)	455 (46)	479 (51)	471 (48)	500 (54)	494 (52)
Uppercase	506 (49)	497 (44)	525 (46)	528 (53)	572 (54)	
Accuracy (% correct)						
	Words				Nonwords	
	High frequency		Low frequency			
Stress	prefinal	Final	prefinal	final	prefinal	final
Lowercase	99.8% (0.9)	99.4% (2.1)	99.8% (1.0)	98.4% (3.4)	98.2% (2.0)	96.5% (3.4)
Uppercase	99.2% (1.8)	98.1% (4.6)	98.4% (2.9)	88.3% (11.9)	96.6% (5.0)	

Naming latencies

A 2x2 repeated-measures ANOVA with lexicality and case revealed that words were read 45 ms faster than nonwords, $F_1(1, 31) = 352$, $p < .001$, $\eta_p^2 = 0.92$, $F_2(1, 316) = 153$, $p < .001$, $\eta_p^2 = 0.33$, lowercase stimuli were read 60 ms faster than uppercase stimuli, $F_1(1, 31) = 67.6$, $p < .001$, $\eta_p^2 = 0.69$, $F_2(1, 316) = 277$, $p < .001$, $\eta_p^2 = 0.47$, and there was a significant interaction between lexicality and case, $F_1(1, 31) = 62.8$, $p < .001$, $\eta_p^2 = 0.67$, $F_2(1, 316) = 15.9$, $p < .001$, $\eta_p^2 = 0.05$. Decomposition of the interaction showed that the case effect was larger for nonwords, $t_1(31) = 8.6$, $p < .001$, $d = 1.4$, $t_2(158) = 12.9$, $p < .001$, $d = 2.0$, than for words, $t_1(62) = 7.0$, $p < .001$, $d = 0.96$, $t_2(158) = 10.5$, $p < .001$, $d = 1.7$, and the lexicality effect was larger for uppercase, $t_1(31) = 16.5$, $p < .001$, $d = 1.2$, $t_2(158) = 10.3$, $p < .001$, $d = 1.6$, than lowercase, $t_1(31) = 12.6$, $p < .001$, $d = 0.58$, $t_2(158) = 6.8$, $p < .001$, $d = 1.1$.

A 2x2x2 repeated-measures ANOVA performed on words varying in frequency, case and stress position revealed that high-frequency words were read 20 ms faster than low-frequency words, $F_1(1, 31) = 83.2$, $p < .001$, $\eta_p^2 = 0.73$, $F_2(1, 152) = 21.3$, $p < .001$, $\eta_p^2 = 0.12$, and lowercase words were read 46 ms faster than uppercase words, $F_1(1, 31) = 48.22$, $p < .001$, $\eta_p^2 = 0.61$, $F_2(1, 152) = 125$, $p < .001$, $\eta_p^2 = 0.45$. No effect of stress position was found ($p > .2$) and none of the interactions were significant ($ps > .24$).

A 2x2 repeated-measures ANOVA performed on nonwords, with case and stress position, revealed that nonwords presented in lowercase were read 75 ms faster than nonwords presented in uppercase, $F_1(1, 31) = 79.5$, $p < .001$, $\eta_p^2 = 0.72$, $F_2(1, 156) = 165.9$, $p < .001$, $\eta_p^2 = 0.52$, but neither the main effect of stress position nor the interaction was significant ($ps > .28$).

Error analysis

A 2x2 repeated-measures ANOVA with lexicality and case revealed no main effect of lexicality $F_1(1, 31) = 2.11$, $p = .16$, $F_2(1, 316) = 1.76$, $p = .19$, but there was a significant main

effect of case, $F_1(1, 31) = 13.5$, $p < .001$, $\eta_p^2 = 0.30$, $F_2(1, 316) = 14.1$, $p < .001$, $\eta_p^2 = 0.04$, indicating that lowercase stimuli were read with higher accuracy than uppercase stimuli. The interaction between lexicality and case was significant, $F_1(1, 31) = 13.4$, $p < .001$, $\eta_p^2 = 0.30$, $F_2(1, 316) = 5.83$, $p = .016$, $\eta_p^2 = 0.02$. Decomposition of this interaction showed that lowercase words were read more accurately than lowercase nonwords, $t_1(31) = 4.27$, $p < .001$, $d = 1.04$, $t_2(94.6) = 3.60$, $p < .001$, $d = 0.59$, but no significant difference was found in the accuracy of naming words and nonwords in uppercase (*p*s > .39). Additionally, words were read more accurately in lowercase than in uppercase, $t_1(31) = 5.1$, $p < .001$, $d = 1.1$, $t_2(87.5) = 4.47$, $p < .001$, $d = 0.71$, whereas there was no difference between case for nonwords (*p*s > .27).

A 2x2x2 repeated-measures ANOVA performed on words varying in frequency, case and stress position revealed high-frequency items were named 2.9% more accurately than of low-frequency items, $F_1(1, 31) = 26.4$, $p < .001$, $\eta_p^2 = 0.46$, $F_2(1, 152) = 25.9$, $p < .001$, $\eta_p^2 = 0.15$, lowercase words were named 3.4% more accurately than uppercase words, $F_1(1, 31) = 25.5$, $p < .001$, $\eta_p^2 = 0.45$, $F_2(1, 152) = 35.2$, $p < .001$, $\eta_p^2 = 0.19$, and words stressed on the prefinal were named 3.2% more accurately than words stressed on the final syllable, $F_1(1, 31) = 26.3$, $p < .001$, $\eta_p^2 = 0.46$, $F_2(1, 152) = 33.2$, $p < .001$, $\eta_p^2 = 0.18$. The 3-way interaction was also significant, $F_1(1, 31) = 11.0$, $p = .002$, $\eta_p^2 = 0.26$, $F_2(1, 152) = 12.7$, $p < .001$, $\eta_p^2 = 0.08$. Decomposition of this 3-way interaction showed that it was driven by low-frequency words presented in uppercase which were named more accurately when stressed on the prefinal rather than on the final syllable, $t_1(31) = 4.35$, $p < .001$, $d = 1.14$, $t_2(27.6) = 4.91$, $p < .001$, $d = 1.55$. This difference in stress position was not apparent when the items were presented in lowercase, ($p > .14$) or with high-frequency stimuli ($p > .15$).

A 2x2 repeated-measures ANOVA performed on nonwords, with case and stress position, revealed no significant main effects and no significant interaction (*p*s > .20).

Error type analysis

Across the entire dataset, 246 naming errors were made. To explore the nature of these errors they were classified into seven different categories: alternations e.g. *φόλα* [ˈfola] as *φόρα* [ˈfora]; dysfluencies e.g. *κινώ* as [ci .. ciˈno]; insertions e.g. *πόκα* [ˈpoka] as [ˈpokra]; mis-stressings e.g. *ΠΑΤΩ* [paˈto] as [ˈpato]; self-corrections e.g. *ζάρι* as [ˈzan .. ˈzari]; and lexicalization of nonwords e.g. *χάκω* [ˈxako] as *χάνω* [ˈxano].

Table 2.3 reports the frequency of each of the different error types made across the dataset. As can be seen, mis-stressings was the most frequent error type. Furthermore, 60 of the mis-stressings were made to low-frequency words presented in uppercase that take stress on the final syllable. Participants incorrectly applied stress to the prefinal syllable of this stimulus category significantly more times compared to low-frequency words presented in uppercase that take stress on the prefinal and low-frequency words presented in lowercase, $\chi^2(3) = 133$, $p < .001$.

Table 2. 3 Experiment 1: Categorisation of error types produced in the word-naming task. Frequency counts listed per type of error in relation to the total number of errors made by the group of participants.

Error type	Counts
Alternations	20
Dysfluencies	62
Insertions	22
Mis-stressings	89
Self-corrections	36
Lexicalisation	17
Total number of errors	246

Nonword stress patterns

To explore the stress pattern applied to correct pronunciation of nonwords, an additional analysis at the item level was conducted by coding, for each participant, the syllable (prefinal or final syllable) to which stress was applied. Regardless of whether participants were presented with uppercase or lowercase stimuli first, there was a strong tendency to stress correctly-pronounced nonwords on the prefinal syllable (78% and 73% of responses for participants first exposed to uppercase and lowercase stimuli respectively, with $p < .001$ in both cases in binomial tests).

Durations of production

Mean durations of production for correct responses were calculated and submitted for analysis across participant and across item. Descriptive statistics are reported in Table 2.4 where duration times are standardised per phoneme to control for differences in phoneme length across stimuli. A 2x2 repeated-measures ANOVA with lexicality and case across the whole dataset revealed a significant main effect of lexicality in the subject analysis, $F_1(1, 31) = 46.5$, $p < .001$, $\eta_p^2 = 0.6$, which just failed to reach significance in the item analysis, $F_2(1, 316) = 3.74$, $p = .054$, $\eta_p^2 = 0.01$. There was no significant effect of case ($p > .45$) and the interaction was significant only in the by-subject analysis, $F_1(1, 31) = 9.95$, $p = .004$, $\eta_p^2 = 0.24$; $F_2(1,316) = 0.56$, $p = .46$.

A 2x2x2 repeated-measures ANOVA performed on words varying in frequency, case and stress position revealed durations were 7 ms per phoneme faster for high-frequency compared to low-frequency items, $F_1(1, 31) = 229$, $p < .001$, $\eta_p^2 = 0.88$, $F_2(1, 152) = 12.0$, $p < .001$, $\eta_p^2 = 0.07$, no significant main effects of case and stress position, and the interactions were not significant ($ps > .21$) except for the interaction between frequency and case which was significant by subjects, $F_1(1, 31) = 6.42$, $p = .017$, $\eta_p^2 = 0.17$, but not by items, $F_2(1, 152) = 0.14$, $p = .70$, $\eta_p^2 = 0.009$.

A 2x2 repeated-measures ANOVA performed on nonwords, with case and stress position, revealed no significant main effects or interaction (all *p*s > .25).

Table 2. 4 Experiment 1: Mean duration of pronunciations (milliseconds) in the word naming task, standardised per phoneme to control for different word lengths. Standard deviation given in parenthesis.

Mean durations of pronunciation (ms)						
	Words				Nonwords	
	High frequency		Low frequency			
Stress	prefinal	final	prefinal	final	prefinal	final
Lowercase	109 (17)	108 (14)	115 (17)	114 (15)	113 (16)	114 (15)
Uppercase	108 (16)	108 (14)	116 (17)	114 (14)	115 (16)	

2.2.4 Discussion

This experiment investigated the effect that case (presence or absence of diacritics), word frequency and stress position have on skilled reading in Greek. Clear effects of lexicality and word frequency were found, which are indicative of lexical activation during reading aloud. The present results corroborate those found in another transparent language, Italian, and suggest that the lexical route is prominently active when reading aloud (Pagliuca et al., 2008; Spinelli et al., 2005). Furthermore, the effects of lexicality and word frequency shown in the duration of production analysis are consistent with the results reported by Gould et al. (2012) who showed that word frequency affects the duration of production and argued in favour of an inverse relation between the pronunciation duration and the extent to which a word is read lexically. Shorter durations have been interpreted as further evidence of lexical activation during reading aloud compared to longer durations, which are indicative of the utilisation of sublexical, serial, grapheme-to-phoneme correspondences. Overall, these data provide support for the utilisation of both lexical and sublexical processes in reading aloud written words by skilled Greek readers, consistent with a dual-route theory (Coltheart et al., 2001).

The present results also revealed a reliable effect of case in response latencies and error rates across the whole dataset. Words and nonwords presented in lowercase were named faster and more accurately than words and nonwords presented in uppercase. However, for response latencies, the case effect was larger for nonwords than for words. This could be attributed to the uncertainty of the reader on where to position stress in the production of uppercase nonwords that, in contrast to lowercase nonwords, are not marked with diacritics. Research on effects of case in word naming is scarce because studies typically focus on how case affects the front-end of the reading process in visual word recognition, with most studies focusing on case alternation (e.g. AlTeRnAtIoN) (e.g. Mayall, Humphreys, & Olson, 1997; Perea & Rosa, 2002). Computational models of word naming (e.g. DRC, Coltheart et al., 2001; "triangle" model, Plaut et al., 1996) generally assume abstract letter representations independent of case. Therefore, these models are unable to account for the case effect. This might be an

idiosyncratic characteristic of Greek because other languages with stress marks typically retain them in uppercase (e.g. Spanish).

The stress effects observed in this experiment were mostly exhibited in error analyses but not in reaction times or the duration of production. Importantly, the effects seemed to originate from the metrical bias, rather than from the position of the diacritics *per se*. This is because participants tended to stress nonwords on the first syllable when these did not have diacritics indicating stress position. Additionally, participants showed lower accuracy rates with low-frequency uppercase words presented without diacritics. Further analyses showed that these errors to low-frequency uppercase words were mainly mis-stressings indicating that participants demonstrated a tendency to stress even real words on the default position. This suggests that participants tended to read low-frequency words serially and without heavily relying on lexical contributions that would lead them to correct assignment of stress. In contrast, when the diacritics were available for these low-frequency words (i.e. when presented in lowercase), they were pronounced with the correct stress assignment. These results are consistent with the pattern reported by Colombo (1992) when adult readers named Italian disyllabic words. A limitation of the current experiment, however, is that case was confounded with the presence (lowercase) or absence (uppercase) of diacritics. As such, it is not possible to establish if the observed case effects originate from the presence or absence of orthographic diacritics or in the general lower familiarity of the visual system to uppercase compared to lowercase letters.

2.3 Experiment 2

To disentangle the confounding factors of case and diacritics in Experiment 1, we conducted a second experiment with monosyllabic words, whose correct orthographic form even in lowercase is without diacritics. Participants read aloud monosyllabic stimuli (words and nonwords) presented in lower and uppercase. If a lowercase advantage was observed, this would provide evidence of genuine effects of case that are not bound to orthographic diacritics. If a case effect was not observed, this would have different implications for the results of Experiment 1; the locus of the lowercase advantage found in disyllabic words would seem to originate from the presence or absence of orthographic diacritics.

2.3.1 Method

Participants

Twenty-four native-Greek adults (*age range* 25-35 years, *mean age* 29.1 years, *SD* 0.6 years) were recruited in a city of northern Greece. To be comparable to the sample in Experiment 1, all of the participants had an academic qualification of an undergraduate degree or higher. Fourteen were females and ten were males. All participants had normal or corrected-to-normal vision and none of them reported any diagnosed learning or reading difficulties.

Materials

Stimuli were monosyllabic Greek words and nonwords of three to five letters. Manipulating lexicality, word frequency and case resulted in eight sets each consisting 20 items (160 items in total). The four groups emerging from lexicality and frequency manipulations were

matched for length, orthographic neighbourhood and bigram frequency ($p > .5$)[4]. Frequency boundaries were kept the same as reported for Experiment 1.

Nonwords were generated from different monosyllabic words by changing the onsets and/or nuclei. Statistical characteristics of the experimental items are presented in Table 2.5. Since monosyllabic words are very limited in Greek (Protopapas & Vlahou, 2009), there were not adequate candidate items that would also satisfy the frequency boundaries criteria. To increase the number of items, inflected forms were also considered and drawn from the *IPLR* database (Protopapas et al., 2012). As in Experiment 1, questionnaires completed at the end of the session determined that participants knew all of the low-frequency items. A full list of all the stimuli and of the real words that the nonwords were generated from is provided in Appendix A.3. English translations of the real-word stimuli are provided in Appendix A.4.

[4] Syllabic frequencies were not a reliable measurement here because in some instances the high overall word frequency of a specific item raises the syllabic one. Additionally, in other instances, the letters comprising the word or nonword appear to have low syllabic frequency because when combined with more letters within other words, the syllabification is different; hence, for such items this measurement is not reliable.

Table 2. 5 Experiment 2: Statistical properties of the monosyllabic stimuli used. Zipf mean, min, max and range given, as well as Coltheart's mean N, mean letter length, and linking mean bigram frequency.

	High frequency words	Low frequency words	Nonwords
Zipf mean	5.223	2.581	-
Zipf min	4.767	1.827	-
Zipf max	6.157	2.957	-
Zipf range	1.390	1.130	-
Coltheart's N	3.3	3.1	3.1
Length	3.9	3.9	3.9
Link. bigram freq.	0.88	0.76	0.83

Notes. Zipf frequency was computed as defined in van Heuven et al. (2014) and Coltheart's N was computed as defined in Coltheart et al. (1977). Linking bigram frequency refers to the frequency of the bigram between the last letter of the prefinal syllable and the first letter of the final one.

Design, Apparatus and Procedure

A repeated-measures design was employed in which the independent variables were lexicality (word, nonword), word frequency (high, low) and case (lower, upper).

Stimuli were presented on a 17-inch LCD screen (1024x768 pixels, 60 Hz) connected to a PC running Windows 7. Stimulus presentation and response recording was controlled with DMDX software (Forster & Forster, 2003, version 4). Participants were seated approximately 40 cm away from the computer screen. Responses were recorded with a head-mounted microphone and participants were instructed to be as fast and accurate as possible. The accuracy of the naming latencies was checked and adjusted where appropriate with CheckVocal (Protopapas, 2007).

The procedure was identical to Experiment 1. Sessions took place in a private school in Greece, in an isolated environment without any distractions. A practice session preceeded commencement of each of the lowercase and uppercase trials. In each case, the proportion of practice items matched the proportion of experimental stimuli resulting from the variable manipulations. Specifically, four high-frequency items, four low-frequency items and eight nonwords were presented to participants before the lower or uppercase blocks, resulting in 12 items in total in each case. The practice items preceding the uppercase trials were also presented in uppercase.

2.3.2 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies were greater than 3.5 SDs away from the mean and were excluded from the analysis. No naming latencies were lower than 300 msec, so truncation for low latencies was not necessary. Mean reaction times for correct responses and error rates were calculated and submitted for analysis across participants and across items. Descriptive statistics for response times and accuracy are

reported in Table 2.6 and item-level data of these measurements are provided in Appendices A.5 (words) and A.6 (nonwords).

For both dependent variables, three separate analyses were conducted. First, a 2-way repeated-measures ANOVA was conducted to investigate the effects of lexicality and case. Second, a 2-way repeated-measures ANOVA was conducted with the word stimuli only to explore the effects of word frequency and case. Third, a pairwise comparison was conducted with the nonword stimuli to investigate the effect of case. Data were submitted to separate by-subject and by-item analyses.

Table 2. 6 Experiment 2: Mean reaction times (milliseconds) and accuracy rates (percent correct) in the monosyllabic word-naming task. Standard deviations given in parenthesis.

Response latencies (ms)			
	Words		Nonwords
	High frequency words	Low frequency words	
Lowercase	435 (31)	443 (29)	463 (41)
Uppercase	451 (34)	460 (34)	480 (36)
Accuracy (% correct)			
	Words		Nonwords
	High frequency words	Low frequency words	
Lowercase	99.1% (1.8)	98.5% (2.7)	95.2% (5.6)
Uppercase	98.1% (3.4)	97.3% (3.5)	94.3% (8.4)

Naming latencies

A 2x2 repeated-measures ANOVA with lexicality and case revealed significant main effects of lexicality, $F_1(1, 23) = 77.2$, $p < .001$, $\eta_p^2 = 0.77$, $F_2(1, 156) = 23.3$, $p < .001$, $\eta_p^2 = 0.13$, indicating that words were read 24 ms faster than nonwords and case, $F_1(1, 23) = 14.2$, $p = .001$, $\eta_p^2 = 0.38$, $F_2(1, 156) = 12.1$, $p < .001$, $\eta_p^2 = 0.07$, indicating that lower case stimuli were read 17 ms faster than uppercase stimuli, but no interaction ($p > .81$).

A 2x2 repeated-measures ANOVA performed on words varying in frequency and case revealed significant main effects of frequency, which was only confirmed in the subject analysis, $F_1(1, 23) = 14.4$, $p < .001$, $\eta_p^2 = 0.40$, $F_2(1, 76) = 2.29$, $p = .13$, $\eta_p^2 = 0.03$, and case, $F_1(1, 23) = 15.3$, $p < .001$, $\eta_p^2 = 0.40$, $F_2(1, 76) = 7.0$, $p = .010$, $\eta_p^2 = 0.08$, indicating that lowercase words were read 17 ms faster than uppercase words, but no interaction ($p > .75$).

A pairwise comparison between lower and uppercase nonwords revealed 18 ms faster naming times for lower than uppercase items, $t_1(23) = -3.2$, $p = .004$, $d = 0.65$, $t_2(78) = -2.3$, $p = .024$, $d = 0.52$.

Error analysis

A 2x2 repeated-measures ANOVA with lexicality and case revealed that words were read 3.5% more accurately than nonwords, $F_1(1, 23) = 10.7$, $p = .003$, $\eta_p^2 = 0.41$, $F_2(1, 156) = 14.65$, $p < .001$, $\eta_p^2 = 0.09$, but no effect of case or their interaction (ps > .27).

A 2x2 repeated measures ANOVA performed on words varying in frequency and case did not reveal any significant main effects or interactions and the same pattern of results was found using a matched-pairs t-test between lower and uppercase nonwords (ps > .16).

2.3.3 Discussion

This experiment sought to identify the origin of the effect of case shown by skilled readers of Greek when reading aloud written words. Results showed a consistent effect of case even with monosyllabic words and nonwords. This provides evidence against the hypothesis that in written Greek lowercase has an advantage over uppercase due to the absence or presence of orthographic diacritics that are used to denote stress position. Rather, the present results suggest that the case effect observed with skilled readers of Greek originates from greater familiarity of words written in lower than uppercase. Consequently, it challenges the assumption that case is not coded in the reading process as well as models of reading aloud that do not differentiate upper and lowercase stimuli (e.g. DRC, Coltheart et al., 2001; "triangle" model, Plaut et al., 1996).

The present results agree with those of Perea and Rosa (2002) who suggested that readers should be more familiar with lower than uppercase given their continuous exposure to lowercase in processing texts. Additionally, Paap et al. (1984) have described how the ascending, descending or neutral shapes of lowercase words can be more distinctive visually than the same-size letters comprising uppercase items. With respect to modeling case effects, the architecture of computational models of reading would need to be adapted in order to simulate this pattern. Within, for example, the DRC model, the difference between lower and uppercase letters could be coded at the letter feature level, where the specific visual characteristic of each letter shape is determined. In contrast to this analytical approach, high frequency of word occurrence has been suggested to introduce *holistic*, word-level codes as an alternative route to word identification (Allen, Wallace, & Weber, 1995). However, theories that suggest a fast, visual-based access to a word's representation would also need to represent feature units on the word level. This would also imply that the case effect should interact with frequency and lexicality effects, with a potential loss or diminishing of case effects in less familiar material (i.e. low-frequency stimuli and nonwords) and more marked case effects in high-frequency items. However, present results did not show a case by

frequency interaction in reading aloud monosyllabic stimuli and the case by lexicality interaction observed with disyllabic Greek stimuli in Experiment 1 operated in the opposite direction (larger differences for nonwords).

2.4 General discussion

This chapter presented investigations on the effects of case and stress on reading aloud by skilled readers of Greek. Results suggested that these two factors contribute independently to the reading process in that stress position effects were observed when the diacritics were absent but case effects were observed even when case manipulation did not affect the diacritics availability (i.e. with monosyllabic stimuli). In addition, stress assignment seems to interact with the processing strategy employed in reading aloud (lexical or sublexical) as evidenced by accuracy rates analyses. With uppercase stimuli that lacked diacritics, low-frequency items showed evidence of stress assignment consistent with applying the default metrical pattern. A tendency to stress in accordance to the sublexical mechanism of the default bias was also observed in naming novel nonword stimuli. In contrast, for high-frequency stimuli, no difference was observed with respect to stress position both when the diacritics were available and when they were not.

The effect of case observed in the present experiments seems to be located at the early stages of the reading process because no interaction of case with frequency and lexicality were found. Although consistent case effects were observed with reading times and accuracy rates across both experiments, they were not observed in durations of production (Experiment 1), hence they appear to progressively diminish during the course of pronunciation. That is, although case may exert an effect relatively early on in the initial stages of recognition, at least in Greek, at successively later levels of word analysis, the influence of letter shape diminishes. Additionally, the inconsistency between the emergence of the effect in early processing (reflected in RTs) and its absence in later stages of processing (reflected in durations) has important implications with regard to the origin of the case effect (i.e. absence of stress diacritics *vs* genuine case effect). Accounts proposing that stress information is a factor that guides lexical access (e.g. Cubelli & Beschin, 2005) might entail that the case effect is related to the absence of the diacritics. That is because this factor would be mostly relevant for the early phase of pronunciation. Conversely, proposing that stress assignment

constitutes the completing stage of lexical access (Ashby & Clifton, 2005; Gutiérrez-Palma & Palma-Reyes, 2008) would suggest these are genuine case effects not related to the diacritics availability. This interpretation is also commensurate with the view that in word production, stress assignment comes last because it necessarily needs to follow a series of other processes such as visually process the word, phonologically decode it, segmentally assemble it, determine the stressed syllable and finally associate it with stress (Protopapas & Gerakaki, 2009). Accordingly, the inconsistency of case effects in the two measurements suggests that it does not originate from the absence of stress information from the diacritics in uppercase, an interpretation further supported by the results of Experiment 2.

Manifestation of stress effects in the error analysis with a simultaneous absence in the naming latencies is a pattern that seems to warrant further investigation. A careful review of the literature on stress seems to reveal that a number of studies exemplify this pattern. This was initially highlighted by Arciuli and Cuples (2006) who failed to find the regularity effect (advantage when stress is on the default syllable) in response latencies in reading aloud (Exp. 1) and lexical decision (Exp. 2) but they did observe the effect in error rates in both tasks. Similarly, in lexical decision (Exp. 2), Colombo (1992) showed the stress regularity by frequency interaction but only in the error rates. Additionally, Rastle and Coltheart (2000) found the interaction between stress regularity (according to a set of morphological affixes) and frequency (Exp. 3) only in the error rates and not the response latencies. Such patterns are in accordance with the regression analyses on reading aloud responses to 1000 disyllabic words performed by Chateau and Jared (2003). They showed that stress position was a far more important predictor for accuracy compared to response times.

A formal model of reading aloud has yet to be fully developed for Greek and it is not straightforward to apply the present findings to models of reading in other languages due to the idiosyncrasy of Greek to mark stress position with diacritics. The empirical findings suggest the operation of a dual-route pathway in Greek, with clear effects of lexical and

sublexical reading. The CDP++ model (Perry et al., 2010) is able to simulate reading aloud of disyllabic words. It employs two separate routes in reading with training algorithms for the sublexical route in order to learn the relationships between orthography and phonology. It has an additional level with two stress nodes, one for each syllabic position, which is also trained similarly to the grapho-phonemic network in order to pick up the regularities between the orthography and stress position. The CDP++ model has been successfully adapted for Italian (Perry et al., 2014a) and is able to simulate effects emerging from the default pattern acquired in behavioural experiments (e.g. Colombo, 1992). Such effects could emerge in the model from the lexical route through stronger activations for words with typical over atypical stress. That is because the model applies a *stress node naming criterion* which governs that even when the phonology of the word is ready, if an activation threshold for stress position has not been reached, the word cannot be produced. Naturally, this will take longer to pass the threshold with irregular words that have weaker connections.

Additionally, given that many of the effects yielded in the present study were observed only in error rates but not reaction times, the version of CDP++ for English (Perry et al., 2010) is particularly pertinent. That is because for several stress studies in English, effects were solely or mainly acquired for accuracy rather naming latencies (e.g. Arciuli & Cuples, 2006; Rastle & Coltheart, 2000) and such effects were simulated by CDP++. For example, when using Rastle and Coltheart's (2000) stimuli in which regularity was defined on the basis of morphological affixes as cues to stress position, the model also produced higher error rates for irregular items compared to those with regular stress. Interestingly, when strategically setting the stress node naming criterion to a higher threshold, they observed this pattern in the reaction times rather than error rates, which suggests a trade-off between the two. This appears in line with Rastle and Coltheart's results as they acquired a clear-cut effect in the error rates but only an effect of marginal significance for the naming latencies.

However, extending the CDP++ model for Greek would not be trivial because it would require a theoretical justification on how stress is represented on the orthographic level. For example, the assumption that stress is finally embedded as part of the whole-word orthographic representations could be implemented by including additional letter nodes for the stressed versions of the vowels. The assumption that the diacritics are independently processed would require additional stress nodes that would be activated at the stage of graphemic buffer and would determine the stressed syllable after syllabification is accomplished. Subsequently, this would need to interact with the stress output nodes as well as the lexical route. Finally, any computational model of reading aloud in Greek would need to accommodate the possibility of different stress patterns depending on the case type.

In conclusion, this study presented clear case effects in skilled Greek reading as well as stress position effects, which were dependent upon the reading strategy employed by the reader and the availability of orthographic diacritics indicating stress position. These findings provide challenges for computational models and universal theories of reading that would need substantial adjustments to accommodate such results. To allow for further analyses on the present data sets to be possible, and to provide a battery of response times and accuracy rates for the stimuli used in these experiments, all results involving these measurements on the item level are provided in the Appendices section. This information also allows performance of computational simulations with the aim of generating these effects, can also facilitate the development of Greek computational models of reading by functioning as benchmark data, and are further pertinent to this thesis as they have been utilised in the simulations reported in Chapter 6. This approach is adopted throughout the thesis as all experimental data acquired are provided in detail on the item level.

CHAPTER 3

STRESS EFFECTS IN VISUAL WORD RECOGNITION OF WRITTEN GREEK WORDS

This chapter reports results from three behavioural experiments with Greek skilled readers in visual word recognition investigating the mechanism of stress assignment in Greek. Experiment 1 utilised the same stimuli materials that were used in Experiment 1 of the previous chapter in word naming. The purpose was to disentangle orthographic from phonological effects and also disentangle different levels of orthographic representation of stress. Results suggest both orthographic and phonological contributions to the stress assignment mechanism, the function of stress diacritics as independent orthographic units that are being decoded during the reading process, but they also suggest the possibility that the diacritic is -at least at the late reading skill stages- part of the word's orthographic representation in the mental lexicon. Experiment 2 aimed to disentangle syllabic position confounds between first-second, left-right, and ultimate-penultimate-antepenultimate syllables by manipulating syllabic length and asking participants to recognise trisyllabic and tetrasyllabic words of high or low frequency. It also utilised case manipulation in order to differentiate between orthographic and phonological contributions to stress assignment. A uniformal and a priori not predicted positional disadvantage observed when stress was on the antepenultimate led to further investigations of the nature of the default metrical bias towards the prefinal syllable in Experiment 3. In this experiment, trisyllabic uppercase stimuli stressed in any of the three possible positions yielded default metrical advantage towards the prefinal syllable both with verbs, whose pos-specific stress distribution shows a statistical preponderance of the prefinal position, but also with adjectives, a grammatical category that does not show such dominance. This quite accented perseverance of the default metrical pattern led to the questioning of the experimental conditions of Experiment 2 and whether the

results acquired could have been affected by extraneous variables. Also, it led to the discussion of the nature of default bias that showed a remarkable uniformity and the mechanisms through which it originates in the language's statistical stress position distribution.

3.1 Introduction

To correctly read aloud a multisyllabic word, the reader needs to assign stress to the appropriate syllable. There is consistent evidence from a variety of languages that stress affects the reading times and/or accuracy rates of proficient readers as certain syllabic positions present a processing advantage regarding stress and others are disfavoured (e.g. Italian: Colombo & Sulpizio, 2015; English: Rastle & Coltheart, 2000; Greek: Protopapas et al., 2007; Chapter 2 of this thesis). It has already been discussed how such effects emerge from the specific characteristics of each given language such as the stress information its orthography provides, its statistical regularities regarding stress position, and the stress assignment strategies it consequently encourages. However, investigating the cognitive mechanisms mediating stress assignment with words read aloud does not provide an insight to the specific stage of processing that stress comes about. Specifically, it cannot determine whether stress is assigned before phonological assembly or whether it holds a pre or post-lexical role, that is, whether it functions as a cue that guides lexical access. Experimental tasks such as lexical decision that focus on word recognition are more appropriate for this purpose as they isolate this reading stage from the production phase. Therefore, lexical decision experiments have been conducted and their results are reported in this chapter with the aim of investigating the effects of stress in visual word recognition of native-Greek skilled readers.

3.1.1 The role of stress in word recognition

Stress has been suggested to hold both a pre-lexical role (Black & Byng, 1986; Cubelli & Beschin, 2005; but see Cutler, Howard & Patterson, 1989) or a post-lexical role in word recognition (Ashby & Clifton, 2005; Gutiérrez-Palma & Palma-Reyes, 2008). Accounts proposing that stress constitutes the final stage of phonological processing are consistent with the fact that its assignment necessarily needs to follow a series of other processes such as

visually encoding the word, phonologically decoding it, segmentally assembling it, determining the stressed syllable and finally associating it with stress (Protopapas & Gerakaki, 2009). Importantly, even at a late stage of processing, stress can still have a pre-lexical role. Gutiérrez-Palma and Palma-Reyes (2008) suggested that the time window of 100-143 ms needed to process stress, as suggested by their data, might be sufficient for syllabic parsing to be completed. When stress is orthographically marked, it can also constitute a visual cue that guides lexical access as suggested by the findings of Cubelli and Beschin (2005) in Italian, who observed improved reading performance of neglect dyslexia patients when words had a stress diacritic.

Additionally, it has been argued that during silent reading, stress is imposed (Rayner & Pollatsek, 1989) and prosodic information is generated and applied even when it is not provided by the orthography (Fodor, 1998). There is strong evidence indicating that phonology is used in word recognition (see Frost 1998; 2008 for a review) and stress position is part of the phonological specification. Assuming that phonological representations mediate lexical decisions, it follows that stress effects should be expected to be observed in this task. However, it has also been suggested that lexical decision can be performed solely on the basis of the orthographic code (Seidenberg & McClelland, 1989). Even if this is the case, the presence of explicit orthographic cues to stress (e.g. diacritics) might be expected to influence word recognition. Consequently, stress effects in word recognition could be originating in two distinct ways, via orthographic or phonological processing.

3.1.2 Stress effects in the lexical decision task

Investigations of stress effects in lexical decision tasks have produced conflicting findings. In Italian, Colombo (1992) reported higher accuracy rates in recognition of regularly stressed

trisyllabic words in comparison to irregularly stressed words[5] on the basis of stress appearing on the penultimate or antepenultimate syllable respectively. Since, in Italian, stress position is not indicated orthographically, the author attributed this pattern to the default bias towards regular stress by either the phonological code being activated prior to the orthographic representation, or by words with irregular stress being more easily mistaken for nonwords. However, Burani and Arduino (2004) argued in favour of a stress mechanism that is sensitive to stress regularity on specific stress neighbourhoods -that is, the statistically dominant position specifically for each group of words ending in the same phoneme sequence[6]. Since they observed higher reading performance with regularly stressed stimuli on the basis of stress neighbourhood in reading aloud but not lexical decision, they argued in favour of the phonological rather than orthographic nature of this effect. However, Colombo and Sulpizio (2015) aimed to shed more light on this debate by orthogonally manipulating both these two variables in a series of lexical decision tasks and in all they observed effects consistent with the default pattern but not stress neighbourhood. Interestingly, the behavioural data from reading aloud of both Colombo (1992) (similar patterns with lexical decision) and Burani and Arduino (2004) (neighbourhood effects) were successfully simulated by a dual-route computational model of reading aloud (CDP++: Perry et al., 2014a) which suggests that the two accounts might not be mutually exclusive. However, it is not known whether a word recognition model would be able to simulate both these seemingly contradictory patterns in the behavioural results, similarly to the reading aloud model.

Research involving stress effects in word recognition is relatively scarce in other languages. In a lexical decision experiment in Spanish, Gutiérrez-Palma and Palma-Reyes (2008) primed disyllabic words that do not receive stress diacritics with identity primes which either had stress marks on the correct syllable, wrong syllable, or no mark. They observed slower

[5] In Italian, there is a great preponderance of trisyllabic words that are stressed in the prefinal syllable in comparison to the other stress positions.
[6] From the nucleus phoneme of the prefinal syllable up to the final phoneme of the word.

reaction times when words were primed on the wrong stress position but only with stimulus onset asynchronies of 100 ms or longer, which led them conclude that stress effects occur at relatively late stages of lexical access and that such effects share a phonological and orthographic basis. Additionally, the interaction between stress position and grammatical class has also been highlighted with the dominance of each stress pattern being observed within specific grammatical categories (Arciuli & Cupples, 2006; Jouravlev & Lupker, 2014). Importantly, the emergence of such patterns in both reading aloud and lexical decision has led Arciuli and Cupples (2006) to challenge its purely phonological origin. Finally, both corpus analyses and word recognition experiments have focused on spellings of word endings in English. They have found that many final letter sequences are predictive of stress position (Arciuli & Cuples, 2006) and may facilitate word recognition (Kelly et al., 1998; Mundy & Caroll, 2013).

3.1.3 Stressing Greek words

It has already been described how Greek words are orthographically marked with stress position only in lowercase but not in uppercase. This does not create major problems in reading uppercase because the vast majority of Greek words constitute unique letter strings (Protopapas, 2006) that can be stressed correctly without the need for the diacritic. However, it has also been established that it would not be adequate for the Greek reader to encode stress position only on the phonological level. This existence of ambiguous words such as minimal pairs dictates the decoding of orthographic information to resolve stress position for such cases. Also, Protopapas et al. (2007) have confirmed that even when lexical activations direct readers to stress nonwords on a position contrasting the one of the stress mark, they nonetheless typically decode the diacritic successfully and name the nonword correctly -that is, stress according to the diacritic position. Furthermore, Protopapas and colleagues observed in their entire series of experiments that decoding the diacritic to determine the stressed syllable is an active source of stress information and a strategy that consistently interacts with

lexical activations and informs the stress assignment mechanism (Protopapas, 2006; Protopapas et al., 2006; Protopapas et al., 2007; Protopapas & Gerakaki, 2009). However, what cannot be concluded from these studies is whether reliance on the orthographic stress marks is a strategy induced from the nature of the experimental materials. The experiments conducted by Protopapas and colleagues involved solely nonwords in which stress position cannot be efficiently extracted unless the diacritic is decoded. Despite observing reliance on the other available sources in this context, decoding the diacritic is the only option for the reader in order to be sure that the word is stressed correctly. It is not known whether this strategy is still active in more naturalistic reading environments with real words that offer the option of lexical retrieval.

As reported in the results of the reading aloud experiments (Chapter 3), stress assignment can be directly affected by the type of processing strategy employed by the reader. Less frequent words, that are more likely to be processed sublexically, present an accuracy advantage when they are stressed on the prefinal syllable over those stressed on the final syllable, in accordance to the default metrical pattern. This only occurs when stress position is not marked orthographically with diacritics (i.e. in uppercase). This pattern is not observed with high-frequency words, which encourage lexical processing, hence raising the possibility that in this case stress position is retrieved directly from the mental lexicon. This is consistent with dual-route theories and computational models of reading (DRC, Coltheart et al., 2001; Perry et al., 2010) which suggest that a grapheme-to-phoneme route operates serially (e.g. for unfamiliar words) by assembling each letter consecutively into phonological units. In contrast, in the lexical route used for familiar words, letter positions are processed in parallel so that the orthographic form of the word is activated in the lexicon before phonology is generated. Similarly, manipulating the availability of stress diacritics through the manipulation of case allows orthographic and phonological stress effects in visual word recognition to be distinguished. While Greek is a unique language in offering this natural

manipulation of orthographic information on stress position, effects of case *per se* have been investigated in other languages with the use of lexical decision tasks.

3.1.4 Case type effects in reading

In general, lowercase has been argued to present an advantage over uppercase due to the reader's greater exposure to it and its more distinguishable visual characteristics (Paap et al., 1984). Several studies (e.g. Lavidor, Ellis & Pansky, 2002; Paap et al., 1984) have investigated the effects of other psycholinguistic variables such as letter length, word frequency, lexicality, and overall shape frequency within each of the two cases as well as case aLtErNaTiOn presentation. For example, although faster decision latencies are typically reported for lower versus uppercase, a factor that seems to be modulating the case effect is word frequency. In lexical decision experiments conducted in English (Mayall & Humphreys, 1996) and Spanish (Perea & Rosa, 2002), it was shown that the case effect occurred only for relatively low-frequency words and not high-frequency words. This interaction has been interpreted as evidence against holistic models of visual word recognition (e.g. Allen et al., 1995) that suggest that a whole-word shape channel is activated by highly visually familiar items. This is because such models would predict the opposite pattern with high-frequency items being most affected by the case manipulation. Alternatively, analytical models (Grainger & Jacobs, 1996; McClelland & Rumelhart, 1981) suggest that words are processed in terms of their constituent letters and the shape these take is irrelevant for reading as their visual form is lost in early phases of the reading process. Manipulation of case in Greek word recognition not only allows for the generality of these findings to be tested further, but, uniquely, it also enables the availability of phonological information such as stress position to be manipulated in a wholly naturalistic manner. The latter analytical theory is partly confirmed by the reading aloud experiments reported in the previous chapter because case effects were manifested in word naming but these were present only in the analysis of response times but not in durations of production. That is because duration of production

reflects later stages of processing whereas response times capture the earlier processing phase. But in a language such as Greek that case type does not only differentiate the visual form of the letter but also the availability of orthographic information on stress, it was shown that even when these two factors were disentangled (Experiment 3), case effects did endure in the response times of the participants.

3.2 Experiment 1

3.2.1 Rationale

The purpose of the first experiment was to identify the locus of stress effects and whether stress is generated before phonological assembly. If stress becomes available pre-lexically, then it can act as an additional cue that guides lexical access. If stress is assigned post-lexically, then it means it should be retrieved from the word-level representations in the mental-lexicon. To investigate these possibilities, a lexical decision experiment was employed involving disyllabic words and nonwords that are either stressed on the prefinal or the final syllable. Words were either high- or low-frequency, and all stimuli were presented in both lower and uppercase. If positional effects of stress are observed, this would corroborate findings in other languages suggesting stress assignment does not only concern word production when reading aloud. If such effects are observed in lexical decision using uppercase letter strings, this would indicate a phonological origin because in uppercase stress is not marked orthographically. If, however, stress effects are observed only in lowercase, this would provide evidence in favour of an orthographic process. If they are consistently observed across both cases, this would provide support for phonological activations with potential contributions from the orthography. With respect to the stress position, it is expected that less familiar items that encourage sublexical reading will show a positional advantage on the prefinal syllable in accordance with the default bias, whilst high-frequency items that encourage lexical access will not.

Additionally, this experiment aimed to shed light on the locus of representation of stress in Greek language. The phonological lexicon is an obvious contender but the orthographic dimension of stress in Greek means that it should also be additionally encoded through the diacritics. In the context of reading models discussed throughout this thesis such as the DRC (Coltheart et al., 2001) and CDP++ (Perry et al., 2010; 2014), nonwords access the phonological output lexicon once the phoneme system has been activated via backward

activation. This means that stress effects with nonwords can be interpreted to arise from the phonological representations. But stress effects on the lexical decision task with recognising lowercase nonwords, that bear stress marks, should be interpreted as evidence that stress must be represented at the letter level. In contrast, stress effects only with lowercase words but not nonwords, on a lexical decision task, could be interpreted as evidence that stress is also represented at the orthographic input lexicon. Manipulation of lexicality and case, that, in Greek, overlaps with diacritics availability, allows investigation of these hypotheses regarding the mechanism of stress assignment.

3.2.2 Method

Participants

Thirty-two native-Greek participants (*age range* 22-32 years, *mean age* 27.1 years, *SD* 3.2 years) were recruited from the undergraduate and postgraduate populations at the University of Nottingham. Nineteen were females and 13 were males. All participants had normal or corrected-to-normal vision and none reported any diagnosed learning or reading difficulties.

Materials

The experimental materials were identical to those used in reading aloud Experiment 1 (see Chapter 2, section *2.2*); disyllabic Greek words and nonwords of four or six letters were matched for letter length, syllabic length, word neighbourhood (Coltheart's N, as defined in Coltheart et al., 1977) and positional bigram frequency of the linking letter cluster between the two syllables (see Table 2.1).

Design, apparatus, and procedure

A repeated-measures design was employed in which the independent variables were stimulus type (low-frequency word, high-frequency word, nonword), case (lower, upper), and stress position (prefinal, final). Accuracy of responses and response times were measured from the

point that the stimulus appeared on screen until the participant input a response through a response box either corresponding to a real word or a nonword.

The experimental conditions and apparatus used where again identical to Experiment 1 in Chapter 2 with the only difference being the response box used to record participant responses.

3.2.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies were greater than 3.5 SDs away from the mean and were excluded from further analyses. No response was given earlier than the predefined low cut-off point of 250 msec, so truncation for low latencies was unnecessary. Mean reaction times for correct responses and error rates were calculated and submitted for analysis across participants and across items. Descriptive statistics for response times and accuracy rates are reported in Table 3.1 and item-level data of these measurements are provided in Appendix B.7 (words) and B.8 (nonwords).

For both dependent variables, a 3-way repeated-measures ANOVA was conducted to investigate the effects of stimulus type (low-frequency word, high-frequency word, nonword), case (lower, upper), and stress position (prefinal, final). Data were submitted to separate by-subject and by-item analyses.

Response times

A 3x2x2 repeated-measures ANOVA with stimulus type, case and stress position revealed significant main effects of stimulus type ($F_1(2, 62) = 229$, $p < .001$, $\eta_p^2 = 0.88$, $F_2(2, 308) = 260$, $p < .001$, $\eta_p^2 = 0.64$) and stress ($F_1(1, 31) = 12.23$, $p = .001$, $\eta_p^2 = 0.28$, $F_2(1, 308) = 21$, $p < .001$, $\eta_p^2 = 0.07$). The main effect of case was not significant ($F_1(1, 31) = 0.15$, $p = 0.7$, $\eta_p^2 = 0.01$, $F_2(1, 308) = 1.94$, $p = .17$, $\eta_p^2 = 0.01$) but there was a significant 3-way interaction

($F_1(2, 62) = 7.18$, $p = .002$, $\eta_p^2 = 0.15$, $F_2(2, 308) = 3.16$, $p = .044$, $\eta_p^2 = 0.02$) among all independent variables. Stimuli stressed on the prefinal were overall recognised faster than those stressed on the final. To decompose the interaction, two 3x2 repeated-measures ANOVAs were conducted with lower and uppercase stimuli separately.

In a 3x2 repeated-measures ANOVA with lowercase stimuli, there was a main effect of stimulus type ($F_1(2, 62) = 121$, $p < .001$, $\eta_p^2 = 0.78$, $F_2(2, 154) = 148$, $p < .001$, $\eta_p^2 = 0.67$), no effect of stress ($p > .3$) and a significant 2-way interaction between stress and stimulus type ($F_1(2, 62) = 25.1$, $p < .001$, $\eta_p^2 = 0.45$, $F_2(2, 154) = 15.6$, $p < .001$, $\eta_p^2 = 0.18$). With regards to the main stimulus type effect, pairwise comparisons revealed significant differences among all groups. High-frequency words were recognised faster than the other two categories and low-frequency words were recognised faster than nonwords (all *p*s < .001). To decompose the stimulus type by stress position interaction, three pairwise comparisons were performed with high- and low-frequency words and nonwords between items stressed on the final and prefinal syllable. High-frequency items stressed on the final were recognised faster than those stressed on the prefinal ($t_1(31) = 3.85$, $p < .001$, $d = 0.45$, $t_2(38) = 4.1$, $p < .001$, $d = 1.37$). No difference was observed with low-frequency words ($p > .3$). Nonwords stressed on the prefinal were recognised faster than nonwords stressed on the final ($t_1(31) = 8.6$, $p < .001$, $d = 0.55$, $t_2(67.3) = 5.24$, $p < .001$, $d = 1.17$).

For uppercase, first a one-way repeated measures ANOVA was conducted with stimulus type as a within-subjects variable that revealed a significant effect ($F_1(2, 62) = 202.8$, $p < .001$, $\eta_p^2 = 0.81$, $F_2(2, 157) = 109$, $p < .001$, $\eta_p^2 = 0.60$). Post-hoc pairwise comparisons revealed significant differences among all groups. Uppercase high-frequency words were recognised faster than the other two categories and low-frequency words were recognised faster than nonwords (all *p*s < .001). Subsequently, a 2x2 repeated measures ANOVA only on word stimuli in uppercase with frequency (high, low) and stress position (final, prefinal) as within-subjects variables revealed a significant effect of frequency ($F_1(1, 31) = 212$, $p < .001$, $\eta_p^2 =$

0.87, $F_2(1, 76) = 85$, $p < .001$, $\eta_p^2 = 0.56$), an effect of stress that was only confirmed by subjects ($F_1(1, 31) = 8.38$, $p = .007$, $\eta_p^2 = 0.21$) but not by items ($F_2(1, 76) = 2.59$, $p = .11$, $\eta_p^2 = 0.04$) and a significant interaction ($F_1(1, 31) = 4.48$, $p = .043$, $\eta_p^2 = 0.13$, $F_2(1, 76) = 4.12$, $p = .046$, $\eta_p^2 = 0.13$). Uppercase high-frequency words were recognised faster than low-frequency words and words stressed on the prefinal were recognised faster than words stressed on the final. Decomposing the interaction showed no difference emerging from stress position for high-frequency items ($p > .3$) but low-frequency words in uppercase were recognised faster when stressed on the prefinal compared to when stressed on the final ($t_1(31) = 3.36$, $p = .002$, $d = 0.59$, $t_2(38) = 2.6$, $p = .013$, $d = 0.54$).

To further explore the stress effect observed with the high-frequency words, a 2x2 repeated measures ANOVA was conducted involving only these stimuli with case (lower, upper) and stress position (prefinal, final) as within-subject variables. This revealed a main effect of stress position ($F_1(1, 31) = 5.26$, $p = .029$, $\eta_p^2 = 0.15$, $F_2(1, 76) = 4.47$, $p = .038$, $\eta_p^2 = 0.06$), no effect of case ($p > .3$) and a significant interaction ($F_1(1, 31) = 14.6$, $p < .001$, $\eta_p^2 = 0.32$, $F_2(1, 76) = 8.42$, $p = .005$, $\eta_p^2 = 0.11$). Items stressed on the final were read faster than those stressed on the prefinal. Decomposing the interaction showed that for items stressed on the prefinal, there was no difference between lower and uppercase ($p > .3$) while for items stressed on the final, lowercase was identified faster than uppercase ($t_1(31) = 3.46$, $p = .004$, $d = 0.59$, $t_2(38) = 3.00$, $p = .007$, $d = 1.06$).

Table 3. 1 Experiment 1: Mean reaction times (milliseconds) and accuracy rates (percentage correct) in the lexical decision task with disyllabic words. Standard deviations are given in parenthesis.

Response latencies (ms)						
	Words				Nonwords	
	High frequency		Low frequency			
Stress	prefinal	final	prefinal	final	prefinal	final
Lowercase	543 (104)	503 (74)	633 (115)	634 (116)	656 (90)	712 (111)
Uppercase	526 (89)	532 (44)	615 (96)	649 (111)	692 (108)	
Accuracy (% correct)						
	Words				Nonwords	
	High frequency		Low frequency			
	prefinal	final	prefinal	final	prefinal	final
Lowercase	98 (3.7)	99 (2.2)	91 (6.8)	90 (8.9)	95 (7.1)	90 (13.3)
Uppercase	98 (3.8)	97 (3.8)	92 (9.3)	89 (12.6)	90 (11)	

Error analysis

A 3x2x2 repeated-measures ANOVA with stimulus type, case and stress position revealed significant main effects of stimulus type ($F_1(2, 62) = 13.8$, $p < .001$, $\eta_p^2 = 0.30$, $F_2(2, 308) = 18.1$, $p < .001$, $\eta_p^2 = 0.20$), stress position ($F_1(1, 31) = 19.6$, $p < .001$, $\eta_p^2 = 0.27$, $F_2(1, 308) = 10.1$, $p < .001$, $\eta_p^2 = 0.12$), and case which was only confirmed by subjects ($F_1(1, 31) = 19.6$, $p < .001$, $\eta_p^2 = 0.32$) and not by items ($F_2(1, 308) = 3.31$, $p = .070$, $\eta_p^2 = 0.03$), and no interactions. Stimuli stressed on the prefinal were recognised more accurately than those stressed on the final. Performance with lowercase was better than uppercase. Post-hoc pairwise comparisons revealed that high-frequency items were recognised more accurately than the other two categories (*p*s < .001) but there was no significant difference between low-frequency words and nonwords.

3.2.4 Discussion

This experiment aimed to investigate whether stress, a linguistic phenomenon predominantly phonological in nature, would influence performance on a lexical decision task, which does not involve the production phase. The purpose was to identify the locus of stress effects and distinguish between its orthographic and phonological contributions in reading. It also aimed to distinguish between the different levels that stress might be orthographically encoded. The advantage yielded for lowercase high-frequency words stressed on the final syllable did not emerge in the uppercase, which indicates its orthographic origin, resulting from the presence of stress diacritics in lower but not uppercase. The advantage observed for uppercase low-frequency stimuli stressed on the prefinal syllable, which is consistent with the operation of a sublexical default metrical bias favouring the prefinal position, suggests that phonology was also activated in this task. The purely phonological nature of this effect is also supported by the fact that it was not observed when the diacritics were present. Hence, results showed a combination of orthographic and phonological effects. Also, stress effects with nonwords bearing stress diacritics showed that stress seems to behave as an independent orthographic

unit but also position effects acquired with high-frequency lowercase words suggest that it can also be encoded in the orthographic lexicon. These conclusions are further discussed in the subsequent sections. Interestingly, case effects did not manifest themselves consistently in this task as the lowercase advantage only occurred in the error rates but was not observed in the response latencies. This appears consistent with the interpretation regarding the case effect in the word naming study (Experiment 1, Chapter 2) when considering the response times of the lexical decision responses. In those results, the emergence of case effects in response times but not durations of production was interpreted as a gradual fade out dependent on the time course of processing. Indicatively, mean naming reponse latencies of the different stimuli groups in the reading aloud experiment ranged between 450 and 570 ms. In this experiment, mean group response latencies ranged between 530 and 710 ms.

The advantage observed in low-frequency words stressed on the prefinal in uppercase supports the hypothesis made on the basis of a dual-route reading theory. In accordance with this, the prediction was that sublexical stress assignment mechanisms favouring the prefinal syllable would operate with less familiar stimuli but not with highly familiar stimuli. But the final-syllable advantage that emerged between the two stress positions for high-frequency items in lowercase was not expected a priori, and neither can it be explained within this framework. Furthermore, the robust frequency and lexicality effects that were consistent across all conditions and both dependent variables provide clear evidence that, despite Greek being a highly transparent orthography, lexical-based processing was operating in this task (Frost, 2008). This is in line with findings from other transparent languages (e.g. Italian, Pagliuca et al., 2008) suggesting that the lexical route might be the one predominantly used in skilled reading in such languages as well.

The pattern of findings observed in uppercase corroborates the results from reading aloud disyllabic words in Greek, as reported in the previous chapter Experiment 1. In that experiment, low-frequency words stressed on the prefinal syllable showed higher accuracy

rates than those stressed on the final syllable when they were presented in uppercase, that is, without stress diacritics. Also, the default bias manifested itself in the production of uppercase nonwords that showed a strong tendency to be pronounced with stress on the prefinal syllable. The results from the current lexical decision task show an analogous pattern in the response times analysis. Overall, the body of results from both tasks suggests that the default bias seems to be utilised only in the absence of orthographic information on stress position. This finding is commensurate with the conclusion drawn by Protopapas et al. (2007) about the diminishing strength of the default bias as reading skill reaches maturity. While early readers exhibit a stronger tendency to resort to the default pattern, for skilled readers the diacritic is predominantly used to disambiguate stress assignment in reading. Additionally, the results of the current study are consistent with the interaction of stress position with frequency observed by Colombo (1992) in lexical decision tasks in Italian. The error rates of Italian adult readers showed the same pattern. This is not surprising as Italian, irrespective of case, is similar to Greek uppercase in that stress position is not typically marked explicitly and therefore must be retrieved from the mental lexicon and/or inferred from the default pattern. On the other hand, Greek lowercase differs in that it provides one additional source of information regarding stress position that is indicated by the position of the diacritics. The fact that the presence of stress marks yielded a positional difference in the reaction times to both word and nonword stimuli offers support to the theory that, in Greek, the diacritics are encoded and consequently decoded during reading as independent units on the letter level. Emergence of the effect with otherwise well-matched nonwords suggests that this might be taking place prior to the access to the orthographic lexicon as nonwords do not have orthographic representations. Hence, even if stress is gradually embedded to the orthographic representations, as has been previously suggested (e.g. Protopapas, 2016), this does not seem to be the only locus of its orthographic encoding.

The effect observed in high-frequency words presented in lowercase, i.e. faster recognition for items stressed on the final syllable in comparison to those stressed on the prefinal, should

be attributed to the presence of the diacritics. As this effect did not appear in uppercase, it suggests that orthography plays a key role in stress assignment in Greek skilled adult readers. It also highlights that in skilled reading, stress assignment retains its orthographic dimension despite the fact that the majority of Greek words could, in principle, be correctly stressed without relying on orthographic cues, but rather solely retrieving stress position by means of successful lexical access. Thus, a lack of ambiguity, given the very limited number of stress minimal pairs that need stress diacritics (or context) for disambiguation, does not preclude the utilisation of diacritics, when these are available, by the skilled reader.

However, it would be difficult to explain the final syllable advantage of high-frequency lowercase words within dual-route theories of reading because according to this framework high-frequency items are in principle expected to be read lexically. In further exploring this aspect of the data, the analysis focusing only on high-frequency words revealed an interaction between stress position and case. Specifically, items in lowercase stressed on the final syllable were recognised fastest. Items in lowercase stressed on the prefinal syllable were actually recognised with a similar latency to those presented in uppercase. This suggests that the items stressed specifically on the final syllable are acquiring an advantage from the presence of the diacritics on this position. This resonates with behavioural findings in Italian. In this language, although the vast majority of words do not receive stress marks, approximately 2% of the vocabulary is marked with a diacritic sign indicating stress on the last vowel (e.g. *facoltà*) (Thornton, Iacobini, & Burani, 1997). In a study with neglect dyslexia patients, Cubelli and Beschin (2005) found that the diacritics on that position can act as cues that facilitate lexical access given they only observed this advantage with words but not with nonwords. They concluded that both typical and atypical readers will make use of any lexical information towards the end of the word (such as the diacritic or inflectional suffixes) in the bottom-up process of matching the input to an entry in the orthographic input lexicon to constrain word candidates in the recognition process. Given that Greek language typically presents the open consonant-vowel (CV) or CCV syllabic structure, when the stressed syllable

is the final one, stress is most likely to fall on the final letter as well, as it is marked on the nucleus vowel of the syllable. In the present study, 17/20 high-frequency items stressed on the final syllable had the diacritic on the last letter as well. Hence, a similar advantage to Italian might be emerging from the presence of the diacritic on the final letter position. This constitutes evidence suggesting that, in Greek, the diacritic might also be encoded in the orthographic lexicon.

With respect to the exterior position advantage of the high-frequency words, models from the letter position encoding literature such as the Sequential Encoding Regulated by Inputs to Oscillating Letter Units (SERIOL, Whitney, 2001; 2007) or the spatial coding model (Davis, 2010) could provide an account of this effect. In the spatial coding model, exterior letters are explicitly marked with *dynamic end-letter marking* to accommodate the spatial status of the external positions. Specialised representations encode these positions with the use of letter banks containing one node for each letter of the alphabet and having excitatory connections with the word level. Hence, in conjunction to the activation of the final letter similarly to the letters in the other positions, additional excitation to the word level is induced from the final letter by means of this mechanism. In the SERIOL model, both lexical and sublexical routes receive input from representations on the letter level while only the lexical route also receives input from open-bigram representations (Whitney & Cornelissen, 2008). In the most recent version of the model, bigram representations also include edge units that encode the word's initial and final letter. While letter firing gradually degrades across the letter string, the last letter receives higher activation than the preceding ones. The reason for this is the lack of inhibition to the activation of the final letter due to the lack of subsequent letters. In this framework, the final letter advantage only emerges in high-frequency but not low-frequency words because the lexical route is predominantly employed with highly familiar items. However, the issue of interaction between the two routes and the potential lexical contributions emerging from orthographic processing lies beyond the scope of letter position encoding models.

The present results have implications for current theories in reading research. They can be interpreted as evidence that in Greek skilled reading, stress assignment is a multifaceted task that lies on different levels of representation. In conjunction with the phonological representations, the orthographic lexicon also showed evidence for encoding stress, while the interpretation of the current results should also consider diacritics to be an independent orthographic unit that, when available, is utilised by the reader in orthographic processing. Consequently, a universal theory of reading would need to consider the relative contribution of such units in relation to their functionality in any given language. An equally important implication derives from the activation of different reading pathways depending on the idiosyncratic characteristics of different sets of stimuli, as suggested by the present findings. Current models of visual word recognition that could accommodate the present data more easily are those that propose two separate routes in reading, lexical and sublexical. A traditionally efficient model of this approach that can simulate lexical decision data is DRC (Coltheart et al., 2001). Its implementation involves activations from the letter level and the orthographic lexicon that are fed back and forth between levels of representation in a cascaded-like manner resulting in interaction between the two pathways. The architecture of DRC for the lexical decision task imposes that phonology is activated by the assembly of a phonological string sent to the phonological lexicon subsequently interacting with the orthographic lexicon. But this model has been developed to perform with monosyllabic stimuli, which do not need stress assignment. Such stimuli constitute an extremely limited and unrepresentative set of Greek vocabulary, as content words in Greek are almost exclusively multisyllabic. Thus, the model, as it stands, may be ill-suited to account for skilled reading in Greek. Rastle and Coltheart (2000) developed an algorithm within the dual-route framework that assigns stress to all disyllabic words of the CELEX database (Baayen et al., 1993) with 90% accuracy. This was based on morphological affixes and the stress position they indicate. Although classification of morphemic units within the clear binary distinction between lexical and sublexical information is somewhat ambiguous, it is remarkable that such an algorithm

did not need to rely on stress information embedded in the lexical representations. However, this approach has not been integrated into the DRC model and it is uncertain as to how exactly stress would be specified (e.g. segmentally vs. suprasegmentally). The CDP++ model (Perry et al., 2010; 2014), which is also a dual-route model, has been developed to accommodate multisyllabic input and determines stress position by introducing an additional stress node. However, this model has been implemented for languages such as English and Italian that, unlike Greek, do not represent stress orthographically. Additionally, this model does not simulate word recognition, but rather only reading aloud, so it remains to be seen if such an approach could be extended to accommodate lexical decision in Greek.

3.3 Experiment 2

Several different ways to indicate stress position appear in the stress assignment literature of reading research. Indicatively, for languages in which stress can fall on any of the three final syllables such as Italian and Greek, the terminology of ultimate, penultimate and antepenultimate syllable (i.e. final, prefinal and third from the end respectively) is typically adopted (e.g. Colombo, 1992; Protopapas, 2006). Alternatively, trochaic and iambic stress patterns in disyllabic words correspond to stress on the first and second syllable respectively (e.g. Arciuli & Cuples, 2003). Additionally, in disyllabic words, first and second syllable also overlap with the left and right syllable. However, while in a disyllabic word the first syllable is the penultimate one, and when stressed there is a trochaic pattern, this is not the case for polysyllabic words with more than two syllables. In such words, the different ways of representing stress position do not overlap. Furthermore, while in disyllabic words the default metrical pattern of stress on the prefinal overlaps with the first syllable of the word, this is not the case for polysyllabic words with more than two syllables. The relation of syllabic position of stress in regards to the syllabic length of a polysyllabic word is depicted in Figure 3.1. The purpose of Experiment 2 was to disentangle the influence of relative stress positions such as first vs. second, left vs. right, and ultimate vs. penultimate vs. antepenultimate in lexical decision.

Disyllables:		1st	2nd	
		PU	U	
Trisyllables:	1st	2nd	3rd	
	APU	PU	U	
Tetrasyllables:	1st	2nd	3rd	4th
		APU	PU	U

Figure 3. 1 Relation of syllabic position of stress in regards to the syllabic length of a polysyllabic word.

3.3.1 Rationale

In order to disentangle the positional confounds regarding stress previously described, a lexical decision experiment was performed with native-Greek skilled readers who were asked to recognise trisyllabic and tetrasyllabic high- and low-frequency words stressed on any of the three possible positions, and presented both in lower and uppercase. If stress assignment is relative to the end of a word (i.e. ultimate, penultimate etc.) regardless of syllabic length, similar patterns would be expected to be observed for the trisyllabic and tetrasyllabic stimuli. If stress assignment is related to the syllabic position relative to the centre of the word (i.e. internal vs. external syllables), then a similar pattern would be expected for stress on the antepenultimate and penultimate syllable in tetrasyllabic words as well as the penultimate syllable in trisyllabic words. Additionally, in disyllabic words, which were used in Experiment 1, the default stress position overlaps with the first syllable of the word. Consequently, in a reading context heavily shaped by serial processing, it is not clear whether advantages emerging from this position are due to the statistical preponderance of stress on the prefinal syllable or due to the fact that this information is processed at an earlier phase due to the seriality of the reading strategy. If this advantage is emerging from the stressed syllable's relative position to the end rather than the beginning of the word, then it is expected to manifest on stimuli of any syllabic length.

3.3.2 Method

Participants

Thirty-two native-Greek adult participants (*age range* 20-31 years, *mean age* 26.2 years, *SD* 2.9 years) were recruited from the undergraduate and postgraduate populations at the University of Nottingham. Seventeen were females and 15 were males. All participants had normal or corrected-to-normal vision and none of them reported any diagnosed learning or reading difficulties.

Materials

Stimuli comprised 12 sets of words each consisting of 20 items that were all generated from the IPLR psycholinguistic database (Protopapas et al., 2012). Twelve word groups emerged from the frequency (high, low), number of syllables (three, four) and stress position (ultimate, penultimate, antepenultimate)[7] manipulations. Statistical characteristics of the stimuli are presented in Table 3.2. Word groups were matched for number of letters, frequency (within the two frequency categories, HF > 65 words per million, LF < 10 words per million), orthographic neighbourhood density (Coltheart's N - Coltheart et al., 1977), and mean token syllable frequency. For this purpose, the SOS algorithm (Armstrong, Watson, & Plaut, 2012) was employed to generate the mostly challenging high-frequency groups as much as possible since the candidates were much fewer in this case. Candidate populations had to be stripped from entries such as minimal stress pairs, foreign-rooted words, function words etc., which is information not available in the database, and hence could not be fed into the algorithm. Subsequently, low-frequency groups were generated manually because the task of stripping groups with thousands of candidates from undesirable items would not be trivial.

Nonwords were created by initially generating 12 groups of low-frequency words and then changing one consonant at a random position for each item in a balanced manner. Nonwords mirrored the syllabic length (trisyllabic, tetrasyllabic) manipulation of words, the distribution of items across the three stress positions and did not differ in average letter length from the corresponding word groups. Additionally, half of the nonwords retained the original stress position of their root word and half of them were stressed on either of the two other possible positions. A full list of the stimuli used in this experiment is provided in Appendices B.1 (real words) and B.4 (nonwords). English translations of all real-word stimuli are provided in Appendices B.2 (high-frequency items) and B.3 (low-frequency items).

[7] For purposes of consistency in the case of stimuli with 3 syllables or more, the final syllable is henceforth termed as the *ultimate*, and the prefinal as the *penultimate*.

Table 3. 2 Experiment 2: Statistical properties of the trisyllabic and tetrasyllabic stimuli used. Zipf mean, min, max and range given, as well as mean letter length, syllabic frequency, and Coltheart's mean N.

	High frequency						Low frequency					
	Trisyllabic			Tetrasyllabic			Trisyllabic			Tetrasyllabic		
	APU	PU	U	APU	PU	U	APU	PU	U	APU	PU	U
Zipf mean	5.308	5.275	5.278	5.272	5.249	5.281	3.338	3.336	3.333	3.336	3.333	3.322
Zipf min	4.945	4.952	4.981	4.973	4.975	4.968	2.081	2.724	0.101	1.875	2.324	1.875
Zipf max	5.821	5.875	5.772	5.623	5.520	5.741	3.892	3.960	4.364	3.979	3.833	3.975
Zipf range	0.874	0.923	0.791	0.651	0.545	0.773	1.811	1.237	4.263	2.105	1.509	2.1
Syl. Freq.	8.723	9.314	9.239	9.305	10.114	10.407	9.260	9.440	9.432	9.382	9.624	9.471
Length (let.)	7.500	8.000	7.900	7.950	8.000	8.100	7.850	8.000	8.000	7.950	8.000	8.000
Coltheart's N	1.650	1.523	1.452	1.457	1.446	1.354	1.554	1.532	1.543	1.527	1.454	1.538

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. Zipf frequency was computed as defined in van Heuven et al. (2014) and Coltheart's N was computed as defined in Coltheart et al. (1977). Zipf frequency values do not correspond to the same frequency per million values of Experiment 1 because stimuli of the two experiments are drawn from different databases with different size (see van Heuven et al.'s paper for the Zipf calculation formula).

Design, apparatus, and procedure

A repeated-measures design was employed in which the independent variables were frequency (high, low), syllabic length (trisyllabic, tetrasyllabic), stress position (ultimate, penultimate, antepenultimate) and case (lower, upper). Experimental conditions were kept identical to those reported for Experiment 1. To match the proportion of experimental stimuli resulting from the variable manipulations, three high-frequency items, three low-frequency items (in each case, one for each of the three possible stress positions) and six nonwords (two for each of the three possible stress positions) were used in the practice session. These were presented to participants separately before the lower and uppercase blocks, resulting in 12 items in total in each case. The practice items preceding the uppercase trials were also presented in uppercase.

3.3.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies were greater than 3.5 SDs away from the mean and were excluded from further analysis. No response was given earlier than the predefined low cut-off point of 250 msec, so truncation for low latencies was unnecessary. Mean reaction times for correct responses and error rates were calculated and submitted for analysis across participants and across items. Descriptive statistics for response times and accuracy rates are reported in Table 3.3 and item-level data of these measurements are provided in Appendix B.7.

For both dependent variables, a 4-way repeated-measures ANOVA was conducted to investigate the effects of frequency (low-frequency word, high-frequency word), case (lower, upper), and stress position (ultimate, penultimate, antepenultimate) and syllabic length (trisyllabic vs. tetrasyllabic). Data were submitted to separate by-subject and by-item analyses.

Table 3. 3 Experiment 2: Mean reaction times (milliseconds) and accuracy rates (percentage correct) in the lexical decision task with trisyllabic and tetrasyllabic words. Standard deviations are given in parenthesis.

Response latencies (ms)												
	High frequency						Low frequency					
	Trisyllabic			Tetrasyllabic			Trisyllabic			Tetrasyllabic		
	APU	PU	U	APU	PU	U	APU	PU	U	APU	PU	U
Lowercase	561 (92)	539 (101)	535 (97)	547 (90)	538 (96)	524 (95)	657 (106)	618 (118)	603 (118)	674 (130)	606 (107)	595 (106)
Uppercase	604 (118)	578 (104)	590 (101)	607 (108)	576 (123)	588 (118)	705 (135)	662 (135)	677 (133)	720 (133)	665 (133)	660 (128)
Accuracy (% correct)												
	High frequency						Low frequency					
	Trisyllabic			Tetrasyllabic			Trisyllabic			Tetrasyllabic		
	APU	PU	U	APU	PU	U	APU	PU	U	APU	PU	U
Lowercase	98 (3.7)	99 (2.0)	99 (3.2)	99 (1.3)	99 (1.7)	99 (2.6)	89 (5.8)	96 (6.1)	95 (12.4)	86 (10.8)	95 (5.6)	95 (5.7)
Uppercase	95 (2.9)	97 (5.3)	98 (7.8)	98 (3.2)	99 (4.9)	99 (3.6)	88 (9.5)	92 (11.8)	92 (11.7)	83 (13.4)	95 (7.7)	90 (11.0)

Note. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress.

Response times

A 3x2x2x2 repeated-measures ANOVA with stress position, frequency, case and syllabic length revealed significant main effects of frequency ($F_1(1, 31) = 257$, $p < .001$, $\eta_p^2 = 0.89$, $F_2(1, 464) = 359$, $p < .001$, $\eta_p^2 = 0.44$), case ($F_1(1, 31) = 22.4$, $p < .001$, $\eta_p^2 = 0.42$, $F_2(1, 464) = 114$, $p < .001$, $\eta_p^2 = 0.20$), and stress position ($F_1(2, 62) = 61.2$, $p < .001$, $\eta_p^2 = 0.66$, $F_2(1, 464) = 41.6$, $p < .001$, $\eta_p^2 = 0.08$), but no effect of syllabic length ($F_1(1, 31) = 2.32$, $p = .14$, $\eta_p^2 = 0.07$, $F_2(1, 464) = 0.447$, $p = .83$, $\eta_p^2 < 0.001$) and no interactions (all ps > .14). Overall, high-frequency words were recognised faster than low-frequency words and lowercase stimuli were recognised faster than uppercase. Pairwise comparisons among the three stress position categories, applying Bonferroni correction, showed that items stressed on the antepenultimate were recognised slower than those stressed on the penultimate ($t_1(255) = 8.44$, $p < .001$, $d = 0.53$, $t_2(292.8) = 3.80$, $p < .001$, $d = 0.43$) and ultimate ($t_1(255) = 9.99$, $p < .001$, $d = 0.63$, $t_2(306.7) = 4.29$, $p < .001$, $d = 0.48$) but there was no difference between the final two positions ($t_1(255) = 2.31$, $p = .065$, $d = 0.14$, $t_2(314) = 0.75$, $p = 1$, $d = 0.08$).

Error analysis

A 3x2x2x2 repeated-measures ANOVA with stress position, frequency, case and syllabic length revealed significant main effects of frequency ($F_1(1, 31) = 43.4$, $p < .001$, $\eta_p^2 = 0.58$, $F_2(1, 464) = 106$, $p < .001$, $\eta_p^2 = 0.19$), case ($F_1(1, 31) = 8.57$, $p < .001$, $\eta_p^2 = 0.22$, $F_2(1, 464) = 13.0$, $p < .001$, $\eta_p^2 = 0.03$), and stress position ($F_1(2, 62) = 34.9$, $p < .001$, $\eta_p^2 = 0.53$, $F_2(1, 464) = 30.1$, $p < .001$, $\eta_p^2 = 0.06$), but no effect of syllabic length ($F_1(1, 31) = 0.10$, $p = .75$, $\eta_p^2 = 0.003$, $F_2(1, 464) = 0.01$, $p = .91$, $\eta_p^2 < 0.001$) and a significant interaction between frequency and stress position ($F_1(2, 62) = 20.5$, $p < .001$, $\eta_p^2 = 0.44$, $F_2(1, 464) = 8.28$, $p = .004$, $\eta_p^2 = 0.02$) (all other interaction ps > .13). Overall, high-frequency words were recognised more accurately than low-frequency words and lowercase stimuli were recognised more accurately than uppercase. Pairwise comparisons among the three stress position categories applying Bonferroni correction showed that items stressed on the antepenultimate syllable were recognised less often than those stressed on the penultimate ($t_1(255) = 7.55$, $p <$

.001, d = 0.50, $t_2(318) = 4.87$, $p < .001$, d = 0.54) and ultimate ($t_1(255) = 8.33$, $p < .001$, d = 0.52, $t_2(318) = 4.35$, $p < .001$, d = 0.49) but there was no difference between the final two positions ($t_1(255) = 0.45$, $p = 1$, d = 0.03, $t_2(318) = 0.30$, $p = 1$, d = 0.03). Decomposition of the frequency by stress position interaction showed that while the stress position effect was not significant for high-frequency items ($p > .15$) , it was significant for low-frequency items ($F_1(2, 62) = 32.7$, $p < .001$, $\eta_p^2 = 0.14$, $F_2(1, 238) = 12.75$, $p < .001$, $\eta_p^2 = 0.05$).

3.3.4 Discussion

This experiment aimed to disentangle syllabic position confounds between first-second, left-right, and ultimate-penultimate-antepenultimate syllables. This was attempted by manipulating syllabic length and asking participants to recognise trisyllabic and tetrasyllabic words. It also utilised case manipulation in order to differentiate between orthographic and phonological contributions to stress assignment that in Experiment 1 were observed with disyllabic stimuli. For the same reason, it also differentiated between high- and low-frequency words as in the previous experiment it was shown that they seem to engage different stress assignment mechanisms. The pattern of results observed in the current experiment was relatively straight-forward. In all experimental items, there was a positional disadvantage regarding the speed of responding for the words stressed on the antepenultimate, the third from the end syllable, regardless of the frequency of occurrence or whether the items were presented in lowercase or uppercase. The same pattern was observed in the accuracy of responses but only with low-frequency stimuli, as potential ceiling effects with the high-frequency items did not allow a similar pattern to be observed.

In regard to the initial hypotheses, it is important to highlight that with these experimental items, the syllabic distance from the end of the word was the crucial criterion to explain the results. A disadvantage in reading times when a word with stress on the antepenultimate was presented was apparent regardless of whether the item was trisyllabic or tetrasyllabic. In other

words, it did not matter whether this syllable was the first or the second in the word, but rather critically that it was two syllables away from the final one. Additionally, the hypothesis regarding central vs. medial position was not supported because the disadvantage of the antepenultimate syllable was observed regardless of whether this was on an external or internal position in the word (with trisyllabic and tetrasyllabic items, respectively).

Furthermore, it should be highlighted that the effect, i.e. the disadvantage on the antepenultimate, consistently observed across all stimuli was phonological rather than orthographic in nature. That is because case did not participate in any interaction with other factors; the positional disadvantage of the antepenultimate was observed both with lower and uppercase stimuli or, put differently, regardless of whether the orthographic diacritics indicating stress position were present or absent. However, a quite profound inconsistency that deserves some theoretical justification is the fact that, in contrast to the previously mentioned experiments with disyllables as well as previously reported research findings, here, instead of a positional advantage for the penultimate, there was a positional disadvantage for the antepenultimate. The robustness of this effect and the consistency with which it was manifested across the whole data set warrants further investigation.

A possible explanation for these inconsistencies could be that in the current experiment considerably longer words were utilised as stimuli since letter length correlates positively with syllabic length. Inhibitory length effects in visual word recognition have been reported in several languages (e.g. English; Balota et al. 2004; French: O'Regan & Jacobs, 1992; Dutch: Hudson & Bergan, 1985) and have been interpreted as indicative of sublexical processes because, for example, in the dual-route framework, the nonlexical route processes letter strings sequentially in a left-to-right direction (Coltheart et al., 2001). It has been suggested that stress assignment occurs at a relatively late stage in reading process and is preceded by a series of operations such as orthographical processing of the word, assembling the phonological units, determining the syllables etc. When the word starts being identified stress

comes about to confirm that the reader recognises the word and submits a 'yes' response in the lexical decision task. But when stress is early in the word, before the recognition process is at a sufficiently late phase, then the reader might need to go back and apply stress while phonologically rehearsing the item in order to confirm they recognise it. This resonates with the view that stress necessarily needs to be assigned towards the end of the word reading process and is consistent with accounts for other languages (e.g. English: Ashby & Clifton, 2005; Spanish: Gutiérrez-Palma & Palma-Reyes, 2008) suggesting that stress assignment may be the completing phase of lexical access.

The novel and not a priori predicted disadvantage of the antepenultimate might also be related with the fact that, for purposes of consistency, experimental conditions were kept identical between the two experiments. This means that participants had 500 msec to visually process each item before it disappeared from the screen, regardless of whether this was four to five letters (Experiment 1) or eight letters long (Experiment 2) on average. This could have induced different strategies for the readers and might also be related with the case effect that was clearly observed in Experiment 2 but was not yielded with shorter stimuli, in Experiment 1. It is possible that when the reading system is pushed to its limits, then letter shape becomes important and the more familiar lowercase words are decoded more easily, hence faster than the less frequently encountered and less visually distinctive uppercase words. This is an important issue for future research in this area to address.

A final point that deserves some attention is the absence of a syllabic length effect after matching for letter length. The confound of letter length with syllabic length has been previously discussed in the literature (e.g. Whitney, 2008). The present results show that in Greek, visual word recognition does not seem to be affected by the number of syllables when letter length is carefully controlled.

3.4 Experiment 3

Results from Experiment 2 revealed a novel unexpected effect of a disadvantage for tri and tetrasyllabic words stressed on the antepenultimate syllable in comparison to those stressed on the penultimate and ultimate syllable. This was potentially attributed to extraneous factors such as the choice of experimental conditions; it was speculated that this might be due to the relatively brief presentation (500 ms) of relatively long stimuli (high number of syllables, 8-letter words). These results were inconsistent with those obtained with shorter, disyllabic stimuli in the previous experiments employing the reading aloud and lexical decision tasks because in those experiments, when orthographic information from the stress diacritics was unavailable (i.e. in uppercase), an advantage was observed when low-frequency stimuli were stressed on the penultimate syllable. This is a pattern that was attributed to applying the default bias and is consistent with behavioural data acquired by other experimenters in Greek (e.g. Protopapas et al., 2007) and other languages (e.g. Italian, Colombo, 1992). Hence, it was important to investigate whether the advantage on the penultimate syllable would be acquired with better controlled stimuli that were still longer than disyllabic ones in Greek word recognition.

Additionally, a corpus analysis that was performed after adding part-of-speech (PoS) information to the entries of *GreekLex* (Ktori et al., 2008) presented in Chapter 4, revealed that the statistical preponderance of words stressed on the penultimate syllable is dependent upon grammatical category (Kyparissiadis et al., 2017). More specifically, analyses showed that among the PoS categories taking up more than 98% of the database's entries, that is, nouns, adjectives, and verbs, the statistical dominance of words stressed on the penultimate syllable was observed for nouns and verbs but not for adjectives. This is important because the default bias towards stress on the penultimate syllable has been attributed to this statistical dominance of words stressed on this position in Greek (Protopapas, 2006) and other languages (Colombo, 1992). Experimental investigations in Greek (Protopapas et al., 2007)

aiming to reveal whether the default bias originates from the general structural properties of the language rather than inherent knowledge of the language's statistics failed to produce conclusive results due to, as attributed by the authors, limitations in the experimental methods available to explore this hypothesis. Consideration of the statistical preponderance of the default pattern within each PoS category is important because research in other languages (Arciuli & Cupples, 2006; Jouravlev & Lupker, 2014) has shown that words are processed as 'regularly' stressed or not depending on stress distribution within each grammatical class. For example, Jouravlev and Lupker (2014) reported an advantage in word recognition of adjectives –the only major grammatical category that presents such preponderance in Russian- stressed on the dominant syllable that was not observed with nouns and verbs. Therefore, it was important to control for this factor when investigating the default bias in Greek as well.

3.4.1 Rationale

The present experiment was performed with the purpose of investigating if the absence of the default bias in Experiment 2 was due to the specific experimental conditions employed (i.e. the relatively brief stimulus duration and the distribution of the grammatical categories of the words tested). Native-Greek skilled readers carried out a lexical decision task with polysyllabic (three- or four-syllable) low-frequency words stressed on any of the three possible positions and were either adjectives or verbs. High-frequency words were not used in order to induce predominantly sublexical reading strategies. Items were only presented in uppercase because, as the experiments with disyllabic items have shown, and in accordance with the conclusions by Protopapas et al. (2007), the default pattern seems to be applied in the absence of other sources of information on stress position such as the diacritics. The duration of presentation was also changed such that each stimulus remained on screen until the participant made a response rather than a fixed time-period. This approach was adopted to avoid inducing any task-specific strategies to the participants who might rush their responses

given that it did not become clear in Experiment 2 whether 500 ms of item presentation were adequate for them to fully process long, polysyllabic words. Since items of the same syllabic lengths were used in this experiment, it was expected that allowing participants to input responses at their own pace would guarantee more naturalistic reading conditions[8]. Howerver, participants were still asked to give their responses as fast and as accurately as possible. It was expected that the manipulation of stress position would elicit an advantage for stress on the penultimate. Additionally, to the extent that the discrepancy between verbs and adjectives in the statistical preponderance of the default position has a behavioural dimension in Greek reading, it was expected that the default bias might be observed only with verbs but not with adjectives, in accordance with the analogous effects reported in other languages.

3.4.2 Method

Participants

Twenty two native-Greek adult participants (*age range* 24-33 years, *mean age* 27.2 years, *SD* 2.5 years) were recruited from the undergraduate and postgraduate populations at the University of Nottingham. Thirteen were females and nine were males. All participants had normal or corrected-to-normal vision and none of them reported any diagnosed learning or reading difficulties.

Materials

Stimuli comprised six sets of words each consisting of 20 items that were all generated from the IPLR psycholinguistic database (Protopapas et al., 2012). Twelve word groups emerged from the stress position (ultimate, penultimate, antepenultimate syllable) and grammatical category (verb, adjective) manipulations. Statistical characteristics of the stimuli are presented

[8] The 3000 ms time-out was retained because any response not given within the three-second window would still constitute a problematic trial and would also most probably be trimmed out of further analysis as an outlier.

in Table 3.4. Word groups were matched for number of letters, Zipf frequency, and the OLD20 measurement of orthographic similarity (Yarkoni, Balota, & Yap, 2008). Syllabic frequencies could not be controlled for so they were included as a covariate. Materials were always presented to participants in uppercase.

Nonwords were created by initially generating six groups of low-frequency words and then changing one consonant at a random position for each item in a balanced manner. Nonwords were matched on the item level for syllabic length, grammatical category, and stress position and did not differ in average letter length from the corresponding word groups. A full list of the materials used in Experiment 3 is provided in Appendix B.5 and English translations of the real-word stimuli are provided in Appendix B.6.

Table 3. 4 Experiment 3: Statistical properties of the stimuli used. Zipf mean, min, max and range, mean letter length, and the Levenshtein distance OLD20 measurement are provided.

	Verbs			Adjectives		
	APU	PU	U	APU	PU	U
Zipf mean	2.657	2.602	2.710	2.725	2.671	2.687
Zipf min	1.327	1.327	1.327	1.05	1.327	1.327
Zipf max	3.707	3.716	3.962	3.912	3.479	3.624
Zipf range	2.380	2.389	2.635	1.807	2.152	2.297
Length (letters)	8.100	8.150	8.200	8.150	8.150	8.100
OLD20	2.397	2.401	2.418	2.374	2.414	2.443
Syllabic length	3.250	3.250	3.300	3.250	3.250	3.300

Note. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress.

Design, Apparatus and Procedure

A repeated-measures design was employed in which the independent variables were stress position (ultimate, penultimate, antepenultimate) and grammatical category (verb, adjective).

Stimuli were presented on a 17-inch screen (1024x768 pixels, 59 Hz) connected to a PC running Windows 7. Stimulus presentation and response recording was controlled with DMDX software (Forster & Forster, 2003, version 4). Participants were seated 40 cm away from the computer screen. Responses were recorded with a response box and participants were instructed to be as accurate and fast as possible.

Presentation of word and nonword stimuli was randomised with DMDX. Stimuli were presented in uppercase, in 14-point Courier New. Each trial started with the presentation of a fixation cross (+) for 500 ms, followed by a blank screen for 250 ms and then presentation of the stimulus which remained on the screen until a response was given. Participants were given a maximum time of 3 seconds to respond and if no response was given, the next trial was triggered. The inter-trial interval was 1000 ms. The task took approximately 10 minutes to complete.

A practice session preceeded commencement of the experimental trials. The proportion of practice items matched the proportion of experimental stimuli resulting from the variable manipulations. Specifically, three verbs, three adjectives (in each case, one for each of the three possible stress positions) and six nonwords were presented to participants resulting in 12 items in total. Similar to experimental materials, the practice items were also presented in uppercase.

3.4.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies were greater than 3.5 SDs away from the mean and were excluded from further analysis. No response was given earlier than the

predefined low cut-off point of 250 msec, so truncation for low latencies was unnecessary. Mean reaction times for correct responses and error rates were calculated and submitted for analysis across participants and across items. Descriptive statistics for response times and accuracy rates are reported in Table 3.5 and item-level data of these measurements are provided in Appendix B.9.

Table 3. 5 Experiment 3: Mean reaction times (milliseconds) and accuracy rates (percentage correct) in the lexical decision task with stress position and grammatical category. Standard deviations are given in parenthesis.

Response latencies (ms)			
	APU	PU	U
Verbs	788 (105)	747 (99)	792 (107)
Adjectives	798(113)	751 (92)	797 (103)
Accuracy (%)			
	APU	PU	U
Verbs	95 (5.5)	97 (3.4)	94 (6.1)
Adjectives	91 (7.6)	89 (5.9)	93 (6.4)

Note. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress.

For both dependent variables, a 2-way repeated-measures ANOVA was conducted to investigate the effects of stress position (ultimate, penultimate, antepenultimate) and grammatical category (verb vs. adjective). Data were submitted to separate by-subject and by-item analyses.

Response times

A 3x2 repeated-measures ANOVA with stress position and grammatical category revealed a significant main effect of stress position ($F_1(2, 42) = 6.94$, $p = .003$, $\eta_p^2 = 0.25$, $F_2(2, 113) = 4.31$, $p = .016$, $\eta_p^2 = 0.29$), a trend of a grammatical category main effect in the by-subject analysis ($F_1(1, 21) =$, $p = .06$, $\eta_p^2 = 0.12$) that was far from reaching significance in the by-item analysis ($F_2(1, 113) = 1.09$, $p = .29$, $\eta_p^2 = 0.02$) and no interaction ($p > .14$). Pairwise tests, corrected for multiple comparisons among the three stress position categories, showed that items stressed on the penultimate were recognised faster than those stressed on the antepenultimate ($t_1(43) = 3.43$, $p = .004$, $d = 0.52$, $t_2(78) = 3.32$, $p = .005$, $d = 0.43$) and the ultimate syllable ($t_1(43) = 3.33$, $p = .005$, $d = 0.50$, $t_2(78) = 3.13$, $p = .005$, $d = 0.38$) but there was no difference between those stressed on the antepenultimate and the ultimate syllable ($p \approx 1$).

Error analysis

A 3x2 repeated-measures ANOVA with stress position and grammatical category revealed a main effect of grammatical category ($F_1(1, 21) = 8.86$, $p = .007$, $\eta_p^2 = 0.10$, $F_2(1, 113) = 5.88$, $p = .017$, $\eta_p^2 = 0.05$), no effect of stress position ($p > .10$) and an interaction that was only confirmed in the subject ($F_1(2, 42) = 5.22$, $p = .010$, $\eta_p^2 = 0.04$) but not the item analysis ($F_2(2, 113) = 0.73$, $p = .48$, $\eta_p^2 = 0.01$).

3.4.4 Discussion

This experiment aimed to further investigate the default bias towards stress on the penultimate syllable in Greek visual word recognition that was observed in Experiment 1 with disyllabic items but not subsequently in Experiment 2 which used longer stimuli. Results showed that with different experimental conditions, i.e. longer stimulus presentation times and a balanced distribution of verbs

and adjectives, items stressed on the penultimate syllable showed an advantage over those stressed on the antepenultimate and the ultimate. Additionally, the factor of grammatical category was manipulated with a twofold purpose. First, to control for any potential extraneous influences introduced from the different statistical distributions of stress position within different PoS categories. Second, to investigate whether readers are sensitive to these differential distributions and specifically if they have an impact on the behavioural manifestation of the penultimate advantage depending on the word's grammatical category. This hypothesis was not supported as response latencies consistently showed an advantage of the default position irrespective of the grammatical category of the items so there is no evidence supporting the behavioural dimension of the metrical pattern's dependency on grammatical category. Interestingly, when Protopapas et al. (2007) asked participants to remember a word with stress on a different position from the default while reading nonwords, they failed to shift the metrical bias or deactivate the default pattern. This led them argue against the emergence of the default pattern from cumulative lexical activation in working memory. Taken together, these results raise further questions and warrant further research because it still remains unclear how this advantage emerges from the language's statistical distribution. Structural factors of the language should still be considered plausible contenders as reasons behind this bias, since neighbourhood lexical activation itself does not seem to be the reason behind its emergence with grammatical categories such as adjectives that do not present the overall statistical preponderance of stress on the prefinal syllable.

In terms of the main effect of the penultimate advantage, results are consistent with those of Experiment 1 and previous research suggesting that phonology is activated during visual word recognition since stress position was not indicated orthographically because only uppercase stimuli were used that do not take diacritics according to the rules of Greek orthography. It was also confirmed that the penultimate advantage observed with disyllabic stimuli can be plausibly attributed to the default bias. This was encouraged by the use of uppercase stimuli, as Experiment 3 has shown that the default bias seems to be most prevalent when there is no explicit orthographic information on stress position and functions as the last point of reference for the stress assignment mechanism (in line with Protopapas et al., 2007).

On the other hand, the fact that the penultimate advantage was observed not only with verbs, that show a statistical preponderance of words stressed on this position, but also with adjectives, that do not show this pattern, contradicts research findings in other languages (Arciuli & Cupples, 2006; Jouravlev & Lupker, 2014) showing that readers are sensitive to such statistical regularities of their native languages. However, what has not been established from such studies is the mechanism that makes this sensitivity come about. One explanation could be that information on grammatical category becomes available early in the reading process, specifically, earlier than stress position is retrieved by means of lexical access. Hence, early activation of grammatical category may assist readers in identifying the stimuli with regular stress within each category faster. But an alternative explanation could be that the same orthographic cues that lead to the identification of grammatical category could be cues for stress on specific positions as in such languges associations between orthography and stress position has been confirmed in behavioural studies. In that case, identification of grammatical category would not necessarily need to mediate this process.

A possibility that might be related to the absence of the interaction between grammatical category and the default bias on stress position might involve a specific idiosyncrasy of Greek orthography. While languages such as English have many suffixes that can belong to words of different grammatical categories (e.g. *harness* – *madness*, *augment* – *agreement*, *compute* – *acute* etc.), in Greek, suffixes tend to be parts of either nominals (i.e. nouns and adjectives) or verbs. To confirm this, an analysis was performed on *GreekLex 2* that considered all the polysyllabic words (> 99% of the entries). Word endings were considered the final letter string from the vowel of the penultimate syllable up to the end of the word. Of the 3300 unique word endings in the database, only 12 of them were common in both nominals and verbs. Additionally, nouns and adjectives can share the same suffixes or, put differently, the suffix of nominals might not be sufficient information for the reader to differentiate whether a word is an adjective or a noun. Further analysis of *GreekLex 2* showed that this can be the case for 21% of unique suffixes of nominals. Analysis of *GreekLex 2* reported in a previous chapter has shown that adjectives do not present the statistical preponderance of stress on the penultimate syllable but

nouns do. Hence, utilising the orthographic information from the end of a string to differentiate grammatical category within nominals that could subsequently interact with each category's stress-regular position does not seem to be a reliable strategy in Greek.

Additionally, it should also be noted that Greek is a language with heavy morphological inflections that are used to indicate, among others, grammatical case (e.g. nominative, genitive etc.). Importantly, formulation of different cases might involve the insertion of an additional vowel that corresponds to an additional syllable resulting in a different position of stress relative to the end (e.g. *εξελίξεις* /ε.ksε.ˈli.ksis/ m. "advances", nominative, plural - *εξελίξεων* /ε.ksε.ˈli.ksε.on/ m. "of the advances", genitive, plural, where stress rises from the penultimate to the antepenultimate), or retaining of the same letter string but with stress falling one syllable further (e.g. *ένορκοι* /ˈε.nor.ci/ m. "jury", nominative, plural - *ενόρκων* /ε.ˈnor.kon/ m. "of the jury", genitive, plural). This is crucial because it is not clear whether grammatical inflections constitute independent entities in the lexicon and how stress position is stored for different variations of the same lemma. So, the fact that this can vary within different inflections might discourage readers of Greek to utilise information on the position that could be considered regular within each grammatical class. For example, a noun or verb that on their lemma forms are stressed on the default position can appear with stress on a non-default position and an adjective that stress position of its lemma form is likely not to be the penultimate can appear with stress on this position.

Overall, it seems that the default pattern might come last in the hierarchy of sources of information regarding position, but when active it presents quite robust contributions to the stress mechanism. Taking into account the issues reported above, it is concluded that to fully explore and investigate the interaction between the default bias towards stress on the penultimate syllable and grammatical category, future research would need to take morphology into account. However, it is difficult to predict whether controlling for the factors discussed above in conjunction with the other psycholinguistic variables that are known to affect reading would allow researchers to generate a

stimulus set that would present sufficient external and internal validity. Additionally, investigations on the reasons underlying the emergence of the default pattern should not only be limited to activation-based strategies but also to Greek's structural properties of linguistic nature that might induce this pattern as a fixed property of the stress assignment mechanism.

3.5 General conclusions

The present experiments aimed to investigate stress assignment in visual word recognition with Greek skilled readers. In Experiment 1, independent orthographic and phonological contributions were observed in the lexical decision task. When the diacritics were not available in uppercase and participants resorted to reading shaped by sublexical processes with low-frequency stimuli, then the default metrical pattern towards stress on the prefinal syllable yielded an advantage for this syllabic position. In contrast, when the diacritics were available, in lowercase, and the orthographic information bolstered the phonological information from the lexicon, then the default pattern appeared too weak to elicit an advantage. This resonates with the view by Protopapas et al. (2007) who concluded that in skilled Greek reading the metrical pattern is only the final source of stress information that the reader is likely to resort to in the absence of other sources, so its contributions are limited compared to lexical retrieval of stress position and decoding of the diacritics. On the other hand, lexical reading of the highly familiar disyllabic items elicited an advantage when stress was marked on the final letter of the word, presenting a processing advantage emerging from this position that has been attributed to parallel reading (Davis, 2010; Whitney, 2007). The second experiment aimed to disentangle positional confounds in interpreting stress effects emerging from syllabic position and results suggested that the absolute syllabic distance from the final syllable in a word is the most important predictor of performance on a lexical decision task. Also, a consistent disadvantage for the antepenultimate position when this was stressed was observed, which was interpreted as indicative that for these items stress assignment is likely to be a characteristic of the final phase of the word recognition process. An alternative reason for this inconsistency between the results of Experiments 1 and 2 was speculated to be the relatively brief presentation of the items that did not allow for naturalistic processing of the stimuli to occur. Results from Experiment 3 showed that this could indeed be the case since, when participants were allowed to view the stimuli until they gave a response, the advantage of stress on the penultimate was elicited once again, but this time with both tri and tetrasyllabic stimuli. Therefore, item-level data regarding these experiments are grouped in appendix tables according to the presentation paradigm (either 500ms or without a time-limit)

Additionally, the effect of the default pattern was observed in Experiment 3 with a grammatical category that does not present a distribution of stress position that favours stress on the penultimate syllable. Nonetheless, these results warrant further investigations before absolute conclusions can be drawn about the mechanisms of stress assignment in Greek reading.

CHAPTER 4

GREEKLEX 2: A LEXICAL DATABASE WITH PART-OF-SPEECH, SYLLABIC, PHONOLOGICAL, AND STRESS INFORMATION

Databases containing lexical properties on any given orthography are crucial for psycholinguistic research as they make possible the experimental manipulation of these properties and investigation of their effects. They also allow researchers to carefully select their experimental stimuli in order to control for extraneous variables that are outside the scope of their theoretical questions of interest yet are known to affect language processing. In the last 10 years, a number of lexical databases have been developed for Greek. However, recent findings from the reading research regarding stress assignment have highlighted the importance of variables such as grammatical class, stress neighbourhood, and predictability of stress position from orthographic information (e.g. Arciuli & Cupples, 2006; Arciuli et al., 2010; Burani & Arduino, 2004) that are absent from current Greek databases. Furthermore, the need for alternative procedures for calculating syllabic measurements and stress information, as well as combination of several metrics to investigate linguistic properties of the Greek language are highlighted. To address these issues, a new extensive lexical database of Modern Greek (GreekLex 2) was developed with part-of-speech information for each word and accurate syllabification and orthographic information predictive of stress, as well as several measurements of word similarity and phonetic information. The addition of detailed statistical information about Greek part-of-speech, syllabification, and stress neighbourhood allowed novel analyses of stress distribution within different grammatical categories and syllabic lengths to be carried out. Results showed that the statistical preponderance of stress position on the prefinal syllable that is reported for Greek language is dependent upon grammatical category. Additionally, analyses showed that a proportion higher than 90% of the tokens in the database would be stressed correctly solely by relying on *stress neighbourhood* information. The efficiency of the algorithms used to obtain this information is also assessed. The database and the scripts for orthographic and phonological syllabification as well as

phonetic transcription are available at http://www.psychology.nottingham.ac.uk/greeklex/ and https://github.com/CypressA/GreekLex-2.

The work that is presented in this chapter has resulted in the following publication:

Kyparissiadis, A., van Heuven, W.J.B., Pitchford, N.J., & Ledgeway, T. (2017). GreekLex 2: A comprehensive lexical database with part-of-speech, syllabic, phonological and stress information. *PLoS ONE*, 12(2), e0172493. doi: 10.1371/journal.pone.0172493

4.1 Overview of psycholinguistic resources in Greek

In Greek, three databases have been developed in the past decade to address the apparent need for statistical information on Greek orthography. Two of them (GreekLex, Ktori et al., 2008; ILSP Psycholinguistic Resource, Protopapas et al., 2012) were developed from written corpora drawn from books and media sources. The third one is a corpus based on subtitle frequencies from films and television programs in Greek (SUBTLEX-GR, Dimitropoulou et al., 2010). Furthermore, a database with word frequencies from online resources such as twitter, blog posts and newspaper web pages has been recently made available (Wordlex, Gimenes & New, 2015). In this section, these databases are presented and subsequently their limitations are discussed.

4.1.1 GreekLex

GreekLex (Ktori et al., 2008) provided the first set of comprehensive orthographic information of a large set of Greek words. It was developed by compiling the entries of an orthographic dictionary (Lexicon of Common Modern Greek, Aristotle University of Thessaloniki, 1998, as cited in Ktori et al., 2008) and retrieving a number of statistical measurements for those entries from the Hellenic National Corpus (HNC, Hatzigeorgiu et al., 2000), a collection of newspapers, books, periodicals and other written texts. The database comprises approximately 35,000 words that were present in both the dictionary and HNC. GreekLex includes only lemmas and not word-forms involving grammatical inflections. However, the database provides both joint lemma frequency and token frequency for each entry, with the latter representing frequency of the particular word-form that orthographically overlaps with the lemma (i.e. the frequency of observing, say, a particular verb in the first person, in singular, active voice and present tense). Ktori et al. (2008) assessed the degree that GreekLex comprises a comparable sample to different versions of the overall HNC corpora (first version: 13 million entries, Hatzigeorgiu, Mikros, & Carayannis, 2001; second version: 43 million entries, Mikros, Hatzigeorgiu, & Carayannis, 2005). They showed that when plotting the summed word frequency in GreekLex as a function of word length, the (Poisson-like) distribution is very similar to those of the different HNC

versions. They also found comparable average word-lengths (number of letters) and similar clustering of approximately 50% of the token frequencies around the four- and five-letter entries.

The lowercase version of GreekLex includes the length, lemma frequency and word (meaning, token) frequency measurements. The uppercase version of the database is stripped from double entries that in lowercase would constitute minimal stress pairs (e.g., *γέρος*, ′old′ - *γερός*, ′strong′ both become *ΓΕΡΟΣ* in uppercase) as stress diacritics are not marked in uppercase Greek. Moreover, the uppercase version of GreekLex provides additional information such as orthographic neighbourhood, defined as the number of entries in the database that can be generated by replacing only one letter in the word of interest, (Coltheart et al., 1977), the number of orthographic neighbours that are of higher frequency, type and token bigram frequencies, and transposition, addition and deletion neighbours – i.e. the number of entries that only differ from the one of interest by i) two adjacent letters, ii) adding a single letter and iii) deleting a single letter, respectively. The database is freely available and the files can be downloaded at http://www.psychology.nottingham.ac.uk/GreekLex/.

4.1.2 ILSP Psycholinguistic Resource

The ILSP Psycholinguistic Resource (IPLR, Protopapas et al., 2012) is a database that was also developed from the HNC corpus at the Institute of Language and Speech Processing (ILSP, Athens, Greece). The database's size is approximately 217,000 entries and comprises all word-forms present in the corpus. IPLR offers abundant information on each entry such as syllabic measurements (number of syllables, stressed syllable, mean syllabic frequency), neighbourhood density (Cotlheart's N measurement (Coltheart et al., 1977), Levenshtein distance (Yarkoni et al., 2008), as well as sum and mean frequencies of the neighbours) and bigram sum and mean frequencies. These measurements are provided both considering types and tokens and both considering the stressed and non-stressed forms of the entries (that is, replacing the stressed vowel of multisyllabic entries with the corresponding one without a stress diacritic). Additionally, these measurements are provided using both the orthographic

and phonological forms of each entry. Orthographic forms in the database were converted to phonetic transcriptions using a text-to-speech synthesis module (Chalamandaris, Raptis, & Tsiakoulis, 2005) with high overall performance (>98%) followed by manual checking and corrections by the authors for ambiguous transcriptions. IPLR is available online (http://speech.ilsp.gr/iplr/) and includes various tools for searching quantitative and text information from the database or computing sublexical measurements for Greek words and nonwords not present in the database.

4.1.3 SUBTLEX-GR

The third database that is available for research in the Greek language is based on counts derived from film and television subtitles. It was developed by Dimitropoulou et al. (2010) and is available at http://www.bcbl.eu/databases/subtlex-gr/ from the Basque Centre on Cognition, Brain and Language (Donostia, Spain). SUBTLEX-GR was derived by compiling a corpus from Greek subtitle files and subsequently calculating frequency measurements from this corpus. It has been demonstrated in several languages (American-English: Brysbaert & New, 2009; British-English: van Heuven et al., 2014; Dutch: Keuleers, Brysbaert, & New, 2010; French: New, Brysbaert, Veronis, & Pallier, 2007; Mandarin Chinese: Cai & Brysbaert, 2010), that subtitled-based frequencies account for a higher proportion of variance than traditional database frequencies in response times obtained from lexical decision and word naming tasks. Dimitropoulou and colleagues confirmed this for Greek as well and concluded that frequency counts and their corresponding relative values derived from a subtitle database seem better measurements and outperform the predictive capability of frequencies acquired from written sources.

SUBTLEX-GR consists of approximately 145,000 word-form entries encountered in the subtitle files. The variables provided involve frequency counts, relative frequencies, length, orthographic neighbourhood (Coltheart's N) and Levenshtein distance. An additional measurement is contextual diversity, which indicates the number of different contexts (films or television series) in which each

entry occurs. This variable has been shown, in some cases, to be a better predictor of reading performance than word frequency in behavioural tasks (e.g. Cai & Brysbaert, 2010).

4.1.4 Wordlex

Gimenes and New (2015) recently made available a database with frequency measurements calculated from online resources, specifically twitter, blog posts and online newspapers. The database provides frequencies for 66 languages including Greek. Word-forms were crosschecked against a spellchecker. Comparisons made using behavioural data from lexical decision megastudies in several languages (not including Greek) showed the new frequency measurements to predict reaction times equally well or sometimes better than the previously existing frequencies (i.e. 'traditional' book-based, and subtitle frequencies). An advantage of this database is that the corpora where frequencies were calculated from are also available, hence allowing for additional calculations. However, at present, the database only provides word-frequency and contextual diversity measurements and no other statistical information about the word or sublexical level.

4.2 Aims of GreekLex 2

Despite the considerable progress and effort in developing the databases reported above, certain psycholinguistic variables that impact language processing are currently absent from these psycholinguistic resources. A prominent variable is Part-of-Speech (PoS) information. In English, PoS category has been shown to affect reading behaviour in several studies. Baayen, Feldman and Schreiber (2006) showed that monosyllabic verbs elicit faster reaction times than monosyllabic nouns in visual word recognition. Also, grammatical category correlates with stress position in English disyllables, with the typical pattern being nouns with prefinal stress and verbs with final stress. Participants have been reported to show sensitivity to this regularity of such words compared to their stress competitors in a variety of tasks (Arciuli & Cupples, 2003; 2006). In a recent study with a similar rationale in Russian, adjectives (which are the only grammatical category that presents a statistical preponderance of stress on the first syllable) were shown to have a processing advantage in word recognition and naming when stressed on the regular position, which was not observed with nouns and verbs (Jouravlev & Lupker, 2014). Hence, for certain designs, researchers might want to match their stimuli for PoS category. Additionally, function words, as opposed to content words, are usually avoided as experimental items in psycholinguistic research, while certain studies focus on specific PoS categories of words (e.g. Yang, Tan, & Li, 2011). These issues illustrate the apparent need of considering PoS information in various experimental designs and make it desirable to have this information readily available in psycholinguistic databases for experimental material selection.

The second point of concern with respect to Greek databases available so far is the syllabification of Greek words. This is relevant because there is evidence suggesting that syllables constitute independent units for reading, with the most typical phenomenon being the inhibitory effect of the initial syllable's frequency in lexical decision (Carreiras et al., 1993; Mathey & Zagar, 2002; Conrad & Jacobs, 2004). Among the Greek databases, only IPLR (Protopapas et al., 2012) provides information about syllabic units of Greek words. These units are based on phonological syllabifications whereas the orthographic syllabified entries provided are phoneme-to-grapheme conversions from the phonological forms. To extract the syllabic units in Greek, one needs to assign

each fully pronounced vowel in the word to a separate syllable. In IPLR, syllabification is performed with the phonetic word-forms according to the principle of maximal onset (Selkirk, 1984), which posits that intervocalic consonants should be preferentially assigned to the subsequent syllable's onset rather than the preceding syllable's coda. Accordingly, syllabification was based on a list of phonologically acceptable initial syllabic consonant clusters based on the language's phonotactics as proposed by Tzakosta and Karra (2011). When a consonant cluster was not in the list, the left part of the cluster was assigned to the coda of the previous syllable up to the letter that the remaining part of the cluster was a unit in the list, consequently assigned to the following syllable's onset. However, this approach results in some syllable-initial consonant clusters of which the phonotactic legality has been challenged by recent behavioural findings (e.g. ά-νθρω-πος ['a-nθro-pos], κα-μβάς [ka-'mvas]). Chaida, Gioulaki, Logotheti and Neocleous (2012) investigated the tonal alignment of the stressed syllable in words with a two-consonant cluster before the stressed vowel. They found that, in word production, whether the first consonant of the cluster was syllabified with the coda of the preceding syllable or the onset of the following one depended on whether the two consonants constituted a legal initial syllable cluster or not. Consonant clusters like [mv] in the above example were split to the previous coda and following onset respectively. We calculated the proportion of such cases, by analysing the approximately 500 consonant clusters in IPLR and GreekLex and found that parsing according to the above approach resulted in 64% (320) syllable-initial clusters that fall within this category. Importantly, such clusters appear in 16% of the GreekLex entries. Therefore, an alternative syllabication method is also provided for such consonant clusters.

A third area that warrants further investigations and necessitates statistical information is stress position and its relationship with lexical and sublexical information. Research involving corpus analyses of several languages including Greek (e.g. Arciuli et al, 2010; Monaghan et al., 2016) has revealed that the orthography provides information about stress position through statistical regularities of the language, even beyond explicitly indicating this position by stress diacritics. Behavioural findings suggest that readers are sensitive to subtle statistical information emerging from language exposure that might emerge only from sub-groups of words in the mental representations. For

example, stress neighbourhood involves the consistency of each specific word ending regarding the syllabic position of stress. Experimental work conducted in Italian (Burani & Arduino, 2004; Colombo, 1992) showed that Italian readers are sensitive to stress neighbourhood when assigning lexical stress. Furthermore, Burani and Arduino (2004) found that words with many stress neighbours (defined in terms of syllabic stress position within the group of words that share the same ending) are named faster than those with many stress competitors. They also argued that stress neighbourhood is a more prominent factor for assigning stress in Italian than stress regularity. The latter refers to the default metrical pattern, a statistical predominance of a specific syllabic position to receive stress more often than the other syllables, which has been shown to affect the stress assignment mechanism in several languages with lexical stress (English: Brown, Lupker, & Colombo, 1994; Italian: Colombo, 1992; Greek: Protopapas et al., 2007; Dutch: Schiller, Fikkert, & Levelt, 2004). Therefore, it was essential to provide such information in GreekLex 2.

The inclusion of the above described variables in GreekLex 2 made it possible to conduct a series of new analyses regarding the predictability of stress position based on different information, such as PoS, as well as the orthographic and phonological endings of words. Furthermore, making available the programmatic implementations of the algorithms for the task of phonetic transcription and orthographic and phonological syllabification will allow other databases lacking these variables to be enhanced with this information. Finally, several important additional variables were also included in GreekLex 2: Zipf values (van Heuven et al., 2014), OLD20 (Yarkoni et al., 2008), which is an improvement of the traditional orthographic similarity measure Coltheart's N (Coltheart at al., 1977), and phonological information on the entries.

An additional issue of concern was that the variables available in GreekLex 1 were based on lemmas. An important question is whether lemmas constitute a representative sample of a given language to calculate sublexical and lexical measures because the frequency of statistical units might be over- or under-estimated (Hofmann, Stenneken, Conrad & Jacobs, 2007). This is particularly important for inflectional languages such as Greek because mainly the suffixes of wordforms present a high level of

variability that signifies changes in several grammatical characteristics of the word (e.g., for verbs: person, number, tense, conjugation, voice etc.; for nouns: case, number). This issue has been addressed in GreekLex 2 because the measurements included in the database have been calculated from the underlying wordforms. Calculations based on the lemma forms only are also provided, allowing future investigations regarding the degree of similarity between the metrics derived from the two sources and whether those calculated from lemma forms are accurate measurements of the language's statistical characteristics. Subsequently, the new information added to GreekLex 2 is described in detail and descriptive statistics about the new variables are provided.

4.3 GreekLex 2

The following sections summarize the new information added to GreekLex 2: part-of-speech information, syllabic information, phonetic transcriptions, stress neighbourhood measurements, Zipf values, and Levenshtein distance-based measurements of orthographic and phonological similarity. As all the new information provided was calculated by considering the stressed and unstressed versions of the entries, the uppercase version of the GreekLex 1 database was deemed redundant and was not further updated.

4.3.1 Part-of-speech (PoS) information

Part-of-speech information is provided for each entry in GreekLex 2. The typical procedure of adding part-of-speech information in a lexical database requires the original texts that the corpus was built from and applying a statistically trained PoS tagger to annotate all the tokens in the corpus (e.g., see Brysbaert, New, & Keuleers, 2012). As the texts of the HNC that GreekLex was generated from are not freely available, it was impossible to follow this procedure to add PoS tags to the entries of the database. However, GreekLex only comprises lemmas, which allowed cross-checking each entry against a dictionary containing such information and acquiring all the possible PoS categories from each lemma. Accordingly, all entries of the database were cross-checked against the Dictionary of Standard Modern Greek (Institute for Modern Greek Studies, 1998) which is available online at http://www.greek-language.gr/greekLang/modern_greek/tools/lexica/triantafyllides/index.html.

The most frequent PoS type in GreekLex 2 was Noun (58.5%), followed by Adjective (25.8%) and Verb (14.2%). Only 1.7% of the entries were Adverbs and the remainder of the categories had frequencies lower than 1% (e.g., Articles, Quantifiers, Prepositions, etc.). Entries that could be characterised as problematic were those that could constitute orthographically identical yet multiple inflections of the same lemma. For example, the form *επάξια* could be the adverb of the adjective *επάξιος*, the feminine adjective in singular and nominative case, or the neutral adjective in plural in

either nominative or accusative case. Although it is clear that such entries were initially included in the lemma database representing the adverbial form which is typically present in dictionaries, the additional, word-form PoS categories could not be ignored and were added as secondary tags. This also helped resolve an issue with the frequencies for such entries, as HNC's search tool does not recognise them as lemmas but rather returns their word-form's frequency in the search results. This means that their word-form frequencies were erroneously recorded as lemma frequencies in the first version of GreekLex, which has now been resolved. There are approximately 140 such instances in the lexicon, which represents a proportion lower than 0.5%. Information about the tag abbreviations used in the database and descriptive statistics of the frequency of each PoS category are provided with the GreekLex 2 supplementary materials.

To evaluate if the automated PoS tagging method returned reliable results, three linguists who had no access to the annotated data were asked to manually annotate a proportion of the database's entries. 1000 items (approximately 3%) were manually annotated by all three linguists. The levels of agreement with the automated method were 98.5%, 97.6% and 98.3%. The inter-rater reliability was 95.8% ($k = 0.958$, $z = 72.2$, $p < .001$, N = 999) based on Fleiss' kappa (Fleiss, 1971) adaptation of the Cohen's kappa statistic for multiple raters and categorical data. Items with inconsistent tags among the linguists or between them and the automated method were mostly nominalised adjectives such as *μασκοφόρος* (m. *masked man*) [noun] *vs* [adj], and *τραχεία* (m. *trachea* but also *rough*-feminine gender) [adj] *vs* [noun].

4.3.2 PoS assignment with a trained tagger

Publication of the Wordlex database (Gimenes & New, 2015) along with its text sources while the present work was being conducted made a large corpus of texts in Greek language available for processing. Although GreekLex frequencies have been calculated from a different corpus, PoS tags for the GreekLex entries were also generated from the text corpora made available with Wordlex. For this

procedure, a PoS tagger was employed that has been developed within the Natural Language Processing Group in the Department of Informatics of Athens University of Economics and Business by Koleli (2011). The tagger uses a Maximum Entropy Classifier and performs with reported accuracy of approximately 92%. The tagger has been trained with journalistic texts and the developers' recommendation is that using the tagger with different genres of texts would ideally need retraining on the specific genre. Hence, the twitter and blog-posts corpora provided in Wordlex were excluded from this procedure. The tagger annotated approximately 10 million tokens (excluding contracted forms, punctuation marks etc.) and 253 thousand types. Only 52% of GreekLex 2 entries were found in the Wordlex corpus. As GreekLex is a lemma-based lexicon, inflected forms of GreekLex entries could be present in the Wordlex corpus but not identified. However, during the development of the original version of GreekLex, word-form entries had also been collected and linked to each lemma. Utilising this information to find matches raised the proportion of tagged entries to 77%.

The automatic tagger's output was compared with the previously acquired PoS information to calculate the level of agreement between the two approaches. To perform this comparison, it was necessary to resolve the issue that the tagger produced more than one PoS categories for a high number of entries in the different contexts that occurred in the texts (27% of the annotated types overall and 46% of the common ones). Manual inspection of such entries revealed that the correct tag is commonly the one that has been most frequently assigned; hence, this was applied as the general rule. However, approximately 5% of the entries did not present a numerical advantage towards any category thus they could not be further processed. After this procedure, of the remaining 25000 words that were both entries in GreekLex and occur in the corpora, 76% had consistent tags between the dictionary information and the tagger's output. Manual inspection of the inconsistent entries revealed that it is the tagger's output that is typically incorrect, whereas there is a high level of consistency between the dictionary information and the manual annotation. Given the relatively poor performance of this procedure, the output of the tagger is not provided in the database files.

4.3.3 Syllabic units

Syllabic information including the syllabic units each entry consists of, the number of syllables, the stressed syllable of polysyllabic entries and the mean syllabic frequency when considering or ignoring the stress marks has been included in GreekLex 2. Type and token syllable frequencies are provided separately because there are indications that the two might have different effects in visual word recognition (Conrad, Carreiras, & Jacobs, 2008). The counts and standardised frequency of occurrence per million for the syllabic units are available in separate files.

Orthographic syllabification was performed according to the rules of Greek grammar (Triantafyllidis, 1941/2000), which is formally taught in school and is applied when writing in order to split the words that reach the end of the line and need to be continued onto the next one. The rules posit that a cluster can constitute the beginning of a syllable if there is a Greek word that starts with such a cluster. Otherwise, the first letter goes with the previous syllable and the remaining consonant(s) are assigned to the beginning of the subsequent syllable. To develop a list with all legal initial consonant clusters, all entries from the three currently available databases in Greek were considered. GreekLex 2 is the first database that provides orthographic syllabic units based on syllabification rules of Greek school grammar. However, whether these units are relevant in Greek reading requires further research.

In terms of parsing the phonological syllables, the maximal onset principle was applied on the basis of phonotactically acceptable consonant combinations. Tzakosta and Karra (2011) proposed a two-dimensional scale involving manner (MoA) and place (PoA) of articulation when the left consonant is a member of a leftmost consonant category compared to the category on the right on at least one of these dimensions (classification of consonant types for MoA and PoA are presented in Figure 4.1). The above procedure was also applied in IPLR but certain entries were re-evaluated in the way consonant clusters are separated between adjacent syllables. Such cases mostly involve clusters with nasal ([m], [n], [ɲ]) and liquid ([l], [r], [ʎ]) consonants, which according to Tzakosta and Karra (2011) are only evaluated on the PoA dimension due to their unclear theoretical status with respect to MoA.

There are two issues related to this. The first is that such clusters seem to be given a ‘free pass’ and considered ‘legal’ without evaluation on the PoA dimension, because otherwise clusters like [rm] (e.g. *άρμα*) and [rp] (e.g. *άρπα*) would still be considered ‘illegal’, in contrast to IPLR’s output (['a-rma], ['a-rpa]). The second issue involves clusters with such consonants that are correctly considered acceptable when only considering PoA, yet word production data (Chaida et al., 2012) reported earlier are inconsistent with this approach. Therefore, to offer an alternative approach, a less liberal methodology was followed in GreekLex 2 and clusters containing the previously-described consonant combinations were still evaluated both in MoA and PoA, in which case entries such as *καμβάς* [ka'mvas] have the consonant cluster split. Additionally, an extra dimension was introduced as a criterion that involves a binary voicing scale (see Tzakosta, 2010) that is adequate on its own to force a cluster split (also presented in Figure 4.1). Furthermore, an additional constraint was set regarding initial liquid or nasal-liquid clusters which were always treated as heterosyllabic. Finally, a small number of clusters retrieved from the set provided by Botinis (2011) which would otherwise be treated as heterosyllabic by the algorithm are added as legal ones. These rules resulted in a novel set of acceptable clusters which is included in the supplementary materials of the database.

Manner of Articulation
STOPS - FRICATIVES/SIBILANTS - AFFRICATES - NASALS - LIQUIDS - GLIDES
Place of Articulation
VELARS - LABIALS – CORONALS
Voicing
VOICELESS – VOICED

Figure 4. 1 Consonant-type classification according to the Manner of Articulation, Place of Articulation, and Voicing scales.

A python script that implements the algorithm based on the rules described above was developed and is provided together with the database. This script is extended to handle multi-consonant clusters by applying similar rules proposed by Tzakosta (2011). However, due to methodological inconsistencies between the two approaches discussed earlier, the resulting acceptable cluster sets are not identical. As mentioned earlier, of the approximately 500 initial consonant clusters considered legal in IPLR and handled as tautosyllabic, 64% (320) were assessed as 'illegal' according to the improved syllabification algorithm. This apparently high proportion was mainly due to clusters with more than two consonants (240 out of 320). These were subsequently parsed with the legal onset criterion that aimed to maximise the number of consonants on the onset to the level they would constitute a legal cluster, but cannot guarantee the legality of codas. Applying this approach had an impact on the phonological syllabification of approximately 16% of types and 5% of tokens in the database. The different approaches followed in the orthographic and phonological syllable parsing mean that the orthographic and phonological syllabic units in GreekLex 2 do not always overlap. The phonological syllables were converted back to the orthographic code as well and are also included in the database. Consequently, there are two forms of orthographic syllabic units; those emerging from traditional grammar rules which were previously unavailable from other psycholinguistic resources, and those emerging from phonology.

An additional issue regarding syllabification are wordforms that contain an ambiguous CVV combination. In these cases, the orthography alone cannot determine whether the middle vowel is fully pronounced or not. When it is pronounced, such letter clusters are parsed into two separate syllables whereas when it is not, they comprise one syllable. The most frequent ambiguous CVV combination is the CiV pattern (see Protopapas & Vlahou, 2009) in which *i* represents different vowels (e.g., *ι, η, υ*) or vowel combinations (e.g., *ει*) that, in isolation, correspond to the [i] sound. In such CiV cases, however, the vowel sound is either fully realised into [i], resulting in two syllables (*κυά*νιο [ci-'a-ni-o]), or not, resulting in one syllable [*γυά*λα ['ja-la]]. Approximately 16% of the entries in GreekLex 2 contained such ambiguities. A simple possible solution that was explored is to consider all words containing each cluster and determine the percentages of such vowel combinations being parsed into

one and two syllables. Then all instances of a given cluster can be parsed according to the majority of cases calculated for this specific cluster. For example, the vowel cluster *ιο* is parsed into separate syllables at a rate higher than 80% of cases hence all instances of this cluster were parsed into two syllables. Despite the fact that this approach guarantees that there will be errors in the instances of ambiguous clusters that are not parsed consistently with the majority of cases, this method resulted in an overall accuracy of 95%. Only 71% of the ambiguous clusters were parsed correctly when applying this approach. Therefore, all entries containing ambiguous entries were cross-checked and the syllabification of erroneous ones was corrected manually. For ambiguous cases, where both pronunciations were acceptable (e.g. *διάφανος* [δi-'a-fa-nos], ['δja-fa-nos]), an orthographic dictionary with syllabic information (Babiniotis, 2008) was consulted for purposes of consistency. A similar approach was also used for IPLR as CiV cases were submitted to manual verification (Protopapas & Vlahou, 2009). However, despite the high accuracy of the automatic approach in conjunction to the manual inspection, errors can naturally not be avoided (e.g. *διαβάτης* GreekLex 2: [δja-'va-tis], IPLR:[δi-a-'va-tis]; *κλεψιά* GreekLex 2: [kle-'psça], IPLR:[kle-psi-'a]). A comparison between the two databases in relation to this issue revealed inconsistent transcriptions with regards to the CiV pattern which are also provided in the supplementary materials of the database. However, it should be noted that very often such discrepancies do not reflect an error in the transcription available in either of the databases but rather alternative transcriptions that are both correct. Nonetheless, GreekLex 2 adheres to the dictionary information to ensure a consistent approach is adopted for all words in the database. Table 4.1 provides descriptive statistics for the distribution of types and tokens by their syllabic length.

Table 4. 1 Counts and proportions (percent) of type and token distribution by syllabic length.

	Types		Tokens	
Syllabic length	Counts	Percentage	Counts per million	Percentage
1	276	0.8	225186	53.5
2	3661	10.4	100472	23.9
3	8391	23.8	43699	10.4
4	10645	30.2	33264	7.9
5	7822	22.2	13783	3.3
6	3270	9.3	4169	1
7	921	2.6	453	0.1
8	252	0.7	128	0
9	54	0.2	50	0
10	11	0	10	0
11	1	0	3	0

4.3.4 Phonetic transcriptions

Phonetic transcriptions of the orthographic strings in GreekLex 2 were generated with an algorithm implemented in Python capitalising on the high level of grapho-phonemic consistency of Greek orthography at least in the feedforward direction, that is, from print to sound (Protopapas & Vlahou, 2009). However, because these are computer generated transcriptions, they can only be an approximation to Greek oral speech. Ambiguous CVV cases were handled by utilising syllabic information and more precisely whether the two vowels were in the same syllabic unit or not. When they are tautosyllabic, the medial vowel is fully pronounced (*αγονιώ* [a-γo-ni-'o]), and when they are heterosyllabic, the vowel is not realised and, in the case of the previous consonant being [n] or [l], it is palatalised and converted to [ɲ] and [ʎ] respectively (*νιώθω* ['ɲo-θo]). However, this approach does not imply or reflect a relationship between orthographic syllabification and the phonetic transcriptions emerging in cases of palatalisation as this is a theoretical issue pertinent to the phonological domain that is not trivial to universally resolve.

To assess how well the algorithm performed in this task, a comparison was carried out of the common entries between GreekLex 2 and IPLR since the latter was phonetically converted using a highly accurate text-to-speech module. This resulted in 24,627 common entries between the two databases. The only changes made before the comparison were: i) The phonetic transcription of some monosyllabic entries in IPLR had the syllable's vowel stressed; this was assessed as redundant and replaced with the unstressed version of the same vowel. ii) Protopapas et al. (2012) indicated that in IPLR all cases of nasal consonants followed by homorganic stops (e.g. [mb],[nd]) were simplified by dropping the nasal, an approach which was also followed in the phonetic conversion algorithm presented here. However, it was observed that in the downloadable version of IPLR that was available at the time of our analyses (21/09/2016, 'all_num_clean_text.txt'), there was variation with respect to whether the nasal was dropped or not (e.g. *ακουμπάω* [aku'mbao], *ακουμπήσαμε* [aku'bisamε]). Consequently, this simplification was applied to all entries in IPLR containing such combinations by

removing the nasal. iii) For the exact same reasons, the labiodental nasal [ɱ] is treated as identical to the bilabial nasal [m].

The level of agreement in phonetic transcriptions of the common entries between the presented algorithm here and the procedure applied in IPLR was 98%. This is notable because it shows the level of transparency of Greek orthography in the feedforward direction, from print to sound. The most substantial inconsistency of Greek orthography involving the CVV pattern was overcome by providing this information to the algorithm. Hence, the set of hand-written rules included in the current algorithm was almost equally efficiently as a rule-based algorithm (Chalamandaris et al., 2005) trained on an excessive amount of data (approximately 900,000 words). A qualitative investigation of the inconsistent transcriptions revealed that the vast majority of them involved entries where the CiV pattern could produce acceptable pronunciations either when [i] was fully pronounced or not (e.g. *διάφανος* [δi'afanos], ['δjafanos]). Remaining inconsistencies mainly involved differences in pronunciation that could be broadly classified as allophones (e.g. *αντένα* [a'dɛna], [a'ntɛna]; *ελέγκτρια* [ɛ'lɛŋgtria], [ɛ'lɛgtria]).

The algorithms for performing the tasks of syllabification and phonetic conversion are implemented in Python. The scripts are useful for processing large databases and are freely available online in contrast to similar software for Greek that have been typically developed for commercial purposes or restricted use (e.g. Chalamandaris et al., 2005; Gakis, Panagiotakopoulos, Sgarbas, & Tsalidis, 2012) and cannot be used for large datasets. At present, the algorithms provided in GreekLex 2 are employed for the syllabification and phonetic transcription of another database including materials from Greek textbooks that are used in primary and secondary education for schools outside Greece (Terzopoulos, Niolaki, Kyparissiadis, Wilson, Duncan, & Masterson, in prep). Further work on these scripts currently being undertaken involves the development of decision trees for ambiguous vowel clusters in order to efficiently handle such cases entirely automatically.

4.3.5 Measurements of stress regularity

Two distinct features have been added in GreekLex 2 regarding the word neighbourhoods that emerge from stress position and word endings. For reasons of disambiguation, one is referred to as *Rime Neighbourhood* and the other as *Stress Neighbourhood*. Rime Neighbourhood refers to the number of entries in the database that match the target entry from the stressed vowel up to the final letter of the word. Stress Neighbourhood (as proposed by Colombo, 1992) involves the orthographic ending of each entry, comprising the nucleus vowel of the prefinal syllable up to the final letter of the word. Stress diacritics are omitted up to this point of processing. Then the metric is generated after calculating the proportion of entries having stress on the same syllabic position as the entry of interest over all entries sharing the same ending with it. For both Rime and Stress Neighbourhood and their corresponding variables, type and token counts as well as calculations on the orthographic and phonological strings are provided separately. The average rime length of the polysyllabic entries in the database was 3.7 letters (*SD* 1.9) and the average final sequence length based on Colombo's criterion was 3.6 letters (*SD* 0.9).

In a comparative study involving corpus analyses in several languages, Monaghan et al. (2016) showed that in Greek, both beginning and ending letters convey cues regarding stress position and depending on the word's number of syllables they can have high predictive value, even though stress position in Greek is explicitly marked with diacritics in lowercase. In a quantitative analysis, each polysyllabic entry in the database was assigned stress at the position that was most frequent among the entries it shared a common orthographic ending or rime with. When considering the orthographic endings according to Colombo's approach, it was computed that 86.9% of the types and 91.3% of tokens in the database would be stressed correctly by following this simple procedure. Repeating the same procedure with the rimes was less straight-forward given that each entry's rime varied in length according to stress position and there were many overlapping endings matching the same entry. The approach of hierarchising endings from longer to shorter ones resulted in 75.5% accuracy for types and 80.0% for tokens.

Hence, it seems that Greek orthography provides sublexical information on stress position that could be utilised by the reader to assign stress. Also, stress neighbourhood seems to offer more straightforward information than rime neighbourhood in terms of stress position. It has been shown that the stress assignment mechanism in Greek is a much more complex process than to simply decode the orthographic diacritics to determine stress position. Rather, it also involves lexical and statistical information (Protopapas et al., 2007). Grimani and Protopapas (2016) used pseudowords and found significantly larger effects of their suffixes on stress assignment when the suffix did not have any stress competitors compared to when it did, thus showing that such effects originate in the distributional properties of the language. Hence, it remains to be further investigated empirically that the measurements presented here constitute sources of stress information that operate in Greek reading.

So far, the focus was on statistical characteristics of stress distribution involving subgroups of the lexicon (e.g. words ending in a given letter string). Now the focus moves on the default metrical pattern. Naturally, the preponderance of words receiving stress on a given syllabic position does not have consistent statistical characteristics across all languages. For example, stress assignment of Italian polysyllabic words with more than two syllables is the only instance of print-to-sound ambiguity in Italian. But approximately 80% of these words are stressed on the prefinal syllable (Thornton et al., 1997) and these words were indeed shown to be read and recognised faster than those stressed on the other positions (Colombo, 1992). Similarly, more than 80% of English disyllabic words in the CELEX database (Baayen et al., 1993) receive stress on the prefinal syllable and this seems to generate similar experimental findings with Italian (Brown et al., 1994; but see Rastle & Coltheart, 2000). In Greek, Protopapas (2006) calculated monosyllables to take up approximately 38% of all words, and polysyllables to present the remaining stress position distribution as follows. Final: 19%, Prefinal: 28%, Antepenultimate: 16%. As illustrated in Table 4.2, the token analysis of the lemmas in GreekLex 2.0 presents a similar distribution.

Table 4. 2 Counts and proportions (percent) of type and token distribution of stress position.

	Types		Tokens	
Stress position	Counts	Percentage	Counts per million	Percentage
Monosyllables	276	0.8	225192	53.2
Final	9951	28.2	61558	14.6
Prefinal	13569	38.4	88817	21
Antepenultimate	11508	32.6	47368	11.2

Note. Monosyllables are presented separately in the analysis as they can only be stressed on their sole syllable.

As illustrated in Table 4.2, the prefinal position only presents a relative dominance, and is higher only when compared to the other positions singularly. It is far from being the most frequent in comparison to its competing positions accumulatively neither in the whole set or even when considering just the polysyllabic entries. Given that the previously-reported research seems to focus on the default pattern specifically on subsets where the dominance is observed (e.g. disyllables in English), the distribution of stress position was calculated separately for each different syllabic length occurring in the database (Figure 4.2).

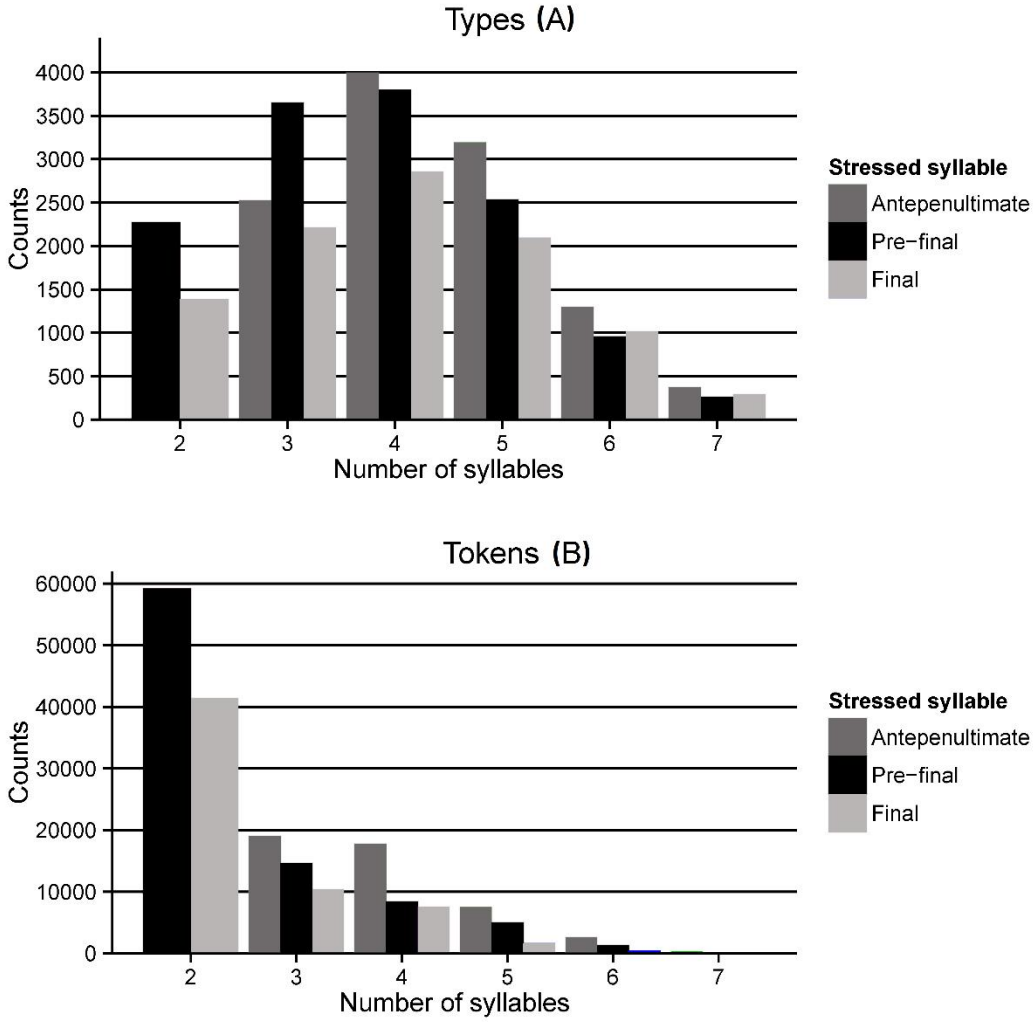


Figure 4. 2 Distribution of stress position by number of syllables for types (A) and tokens (B). Syllabic lengths higher than 7 (up to 11) are not presented in the graph as they accumulatively represent a proportion less than 1% (types) and 0.1% (tokens) of the whole set.

Interestingly, Figure 4.2 illustrates that only disyllabic words consistently show the statistical dominance of the prefinal in both the type and token analysis, and trisyllabic words only in the type analysis. All the other syllabic lengths show a statistical dominance of stress on the antepenultimate syllable. This is important because the default pattern has been shown to be an active source of stress information in behavioural experiments with items larger than disyllabic ones (e.g. Protopapas et al., 2006, used items of 3-5 syllables). Hence, the metrical pattern seems to be active even with sub-groups of words that, when seen in isolation, do not present this statistical dominance of the prefinal syllable. This could perhaps be attributed to the highest overall number of disyllabic token items (see Figure 4.2 B) compared to the other polysyllabic words. A potential concern is that this analysis is based on lemmas and not on wordforms. This is particularly important because in Greek there are several cases in which inflected forms have a different stress position than their lemma (see Protopapas et al., 2006). To verify whether the same patterns would emerge with wordforms as well as from a different source, this analysis was repeated with IPLR's entries. Results showed that the patterns were very similar to the lemma entries of GreekLex 2 (correlation for types: $r = .95$, $p < .001$; for tokens: $r = .98$, $p < .001$; tables are provided in the supplementary materials of the database). Importantly, the crucial observation of non-uniform statistical predominance of stress on the penultimate syllable was found in GreekLex 2 and IPLR.

Finally, the availability of PoS, syllabic, and stress information makes it possible to investigate whether the Greek language has any regularities with respect to grammatical category and stress position. In English, disyllabic nouns typically present a trochaic stress pattern while disyllabic verbs typically present an iambic stress pattern and this has been shown to affect reading behaviour in several psycholinguistic tasks (Arciuli & Cupples, 2003; 2006). Analysis with GreekLex 2 involved the three major PoS categories of nouns, adjectives and verbs that take up 98% of all the entries in the database. As illustrated in Figure 4.3, nouns and verbs are broadly following the overall pattern in all analyses of disyllabic, trisyllabic and polysyllabic stimuli overall, but adjectives do not follow this pattern. In sharp contrast to the default bias towards the prefinal syllable, in the case of adjectives this syllabic position is actually disfavoured. However, it should be noted that this analysis is only based

on lemmas and it remains to be confirmed whether the same pattern would emerge if wordforms were considered. Unfortunately, none of the Greek databases containing wordforms have PoS information, hence this analysis cannot be currently performed. However, the emergence of similar patterns when considering lemmas (Greeklex 2) and wordforms (IPLR) in the analysis of stress position in relation to syllabic length suggests that similar patterns for lemmas and wordforms could also be expected regarding PoS.

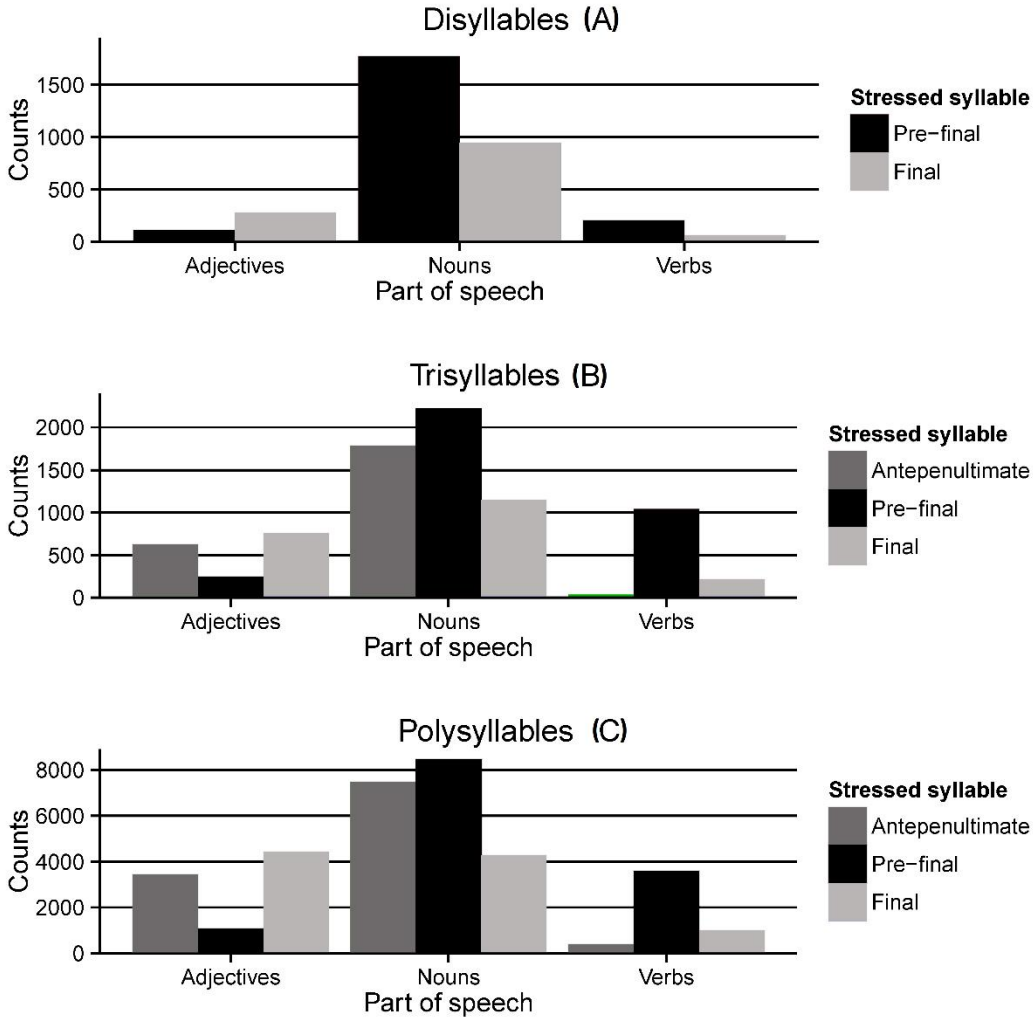


Figure 4. 3 Distribution of stress position by part-of-speech category. Counts are calculated for disyllables (A), trisyllables (B), and all polysyllables (C). Only adjectives, nouns and verbs are considered in this analysis.

4.3.6 Measurements of orthographic similarity

As an alternative to Coltheart's N (i.e. the number of words in a database that have the same length and only differ in one letter from a given entry, Coltheart at al., 1977), Levenshtein distance (Yarkoni et al., 2008) has recently been gaining ground as a more sensitive metric of orthographic similarity because it discerns differences between orthographic strings that would not be captured by Coltheart's definition of neighbourhood. It is defined as the number of insertions, substitutions and deletions required to produce an orthographic string from another string. OLD20 (Yarkoni et al., 2008), which is provided in GreekLex 2, is the mean Levenshtein distance for each word in order to generate its 20 closest orthographic neighbours. While a high N density shows that there are many other words in the database that are only one letter away from a given word, it is a low OLD20 that indicates large orthographic overlap with the 20 closest items in the database. These measurements were calculated both when considering the stressed and the unstressed versions of the entries. Additionally, they were calculated both by considering only the lemmas, which the database currently consists of, but also by processing all the word-forms from the HNC corpus that are assigned to each lemma.

As shown in Figure 4.4, the Coltheart's N density counts that are by far the most frequent in the database are zeros (i.e. no orthographic neighbours). The most frequent OLD20 values cluster around the value of 2 (1.5-2.49). The figure illustrates the counts of both densities (N) and averaged similarity values (OLD20) when considering all word-forms for neighbours rather than just the database's lemmas. As expected and illustrated in Figure 4.5, Coltheart's N density depends upon word length, with shorter words overall presenting higher densities. Similar patterns were observed and reported by Ktori et al. (2008) in an analysis that only considered lemmas as potential neighbours and only those with a frequency higher than 1 per million. A comparable pattern is observed when computing the OLD20 measurement. In this case, higher values indicate lower amount of orthographic overlap with their closest entries, hence the adverse pattern is observed. Again, Figure 4.5 also depicts the patterns emerging after considering all word-forms related to the database's lemmas. Finally, these measurements were also calculated for the phonetic forms of the entries (PLD20, both the stressed and unstressed versions). As expected, due to the high level of grapho-phonemic consistency of the Greek

language, these indices highly correlated with their corresponding orthographic measures. Significant correlations were found between the orthographic and phonological Coltheart's N measurements for stressed ($r = 0.79$) and unstressed forms ($r = 0.79$), as well as between the OLD20 and PLD20 for both stressed ($r = 0.95$) and unstressed ($r = 0.96$) versions of the entries (in all cases, $n = 35283$ and $p < .001$).

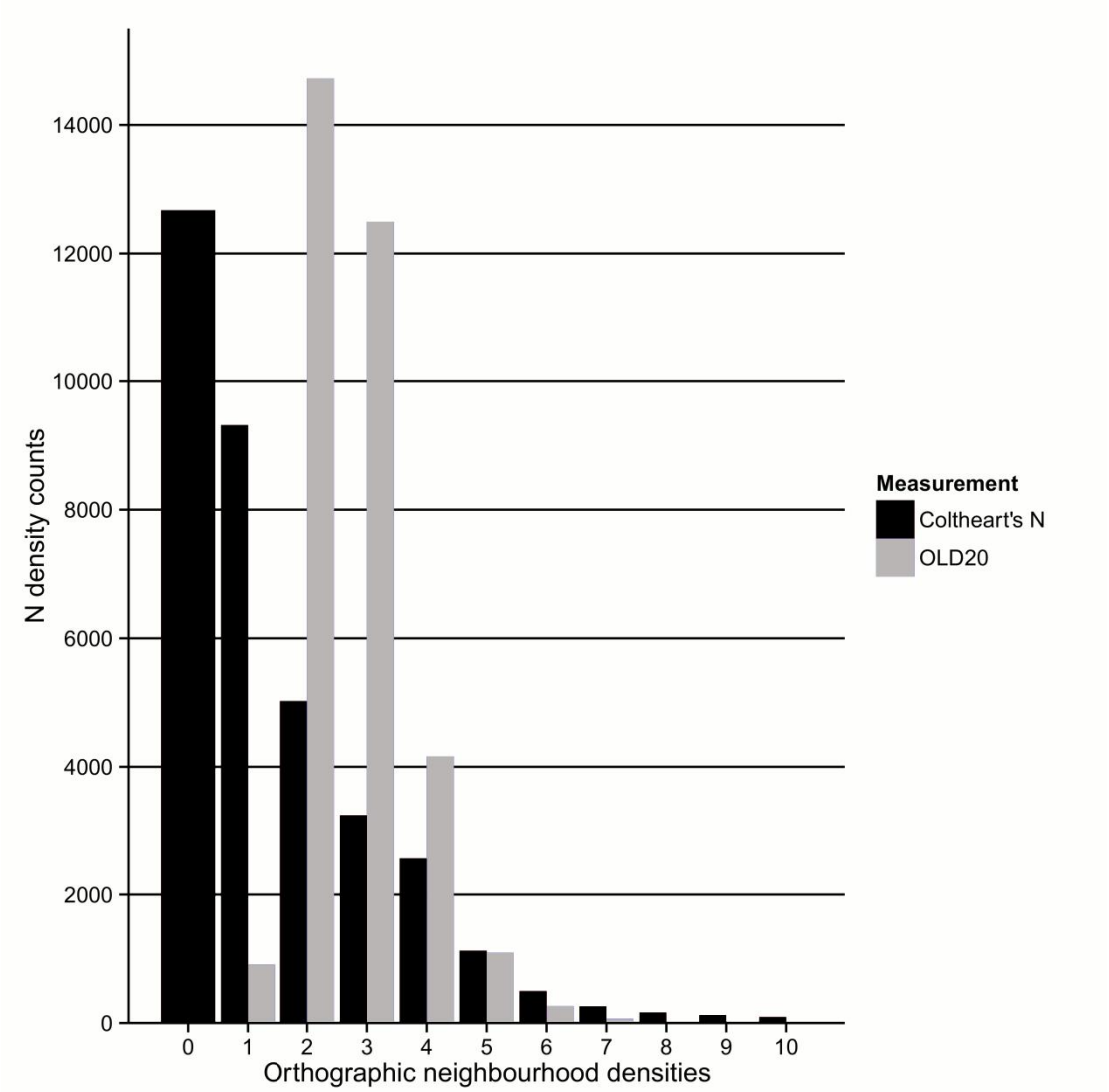


Figure 4. 4 Frequency counts for the clustered OLD20 Levenshtein Distance (based on Yarkoni et al., 2008) values and Coltheart's N orthographic similarity (based on Coltheart at al., 1977) values. OLD20 values are clustered around their closest integer numbers (e.g. a value of 2 represents the counts of all values between 1.5 and 2.49). Coltheart's N values above 10 are not presented in the graph as they accumulatively represent a proportion smaller than 0.5% of the whole set.

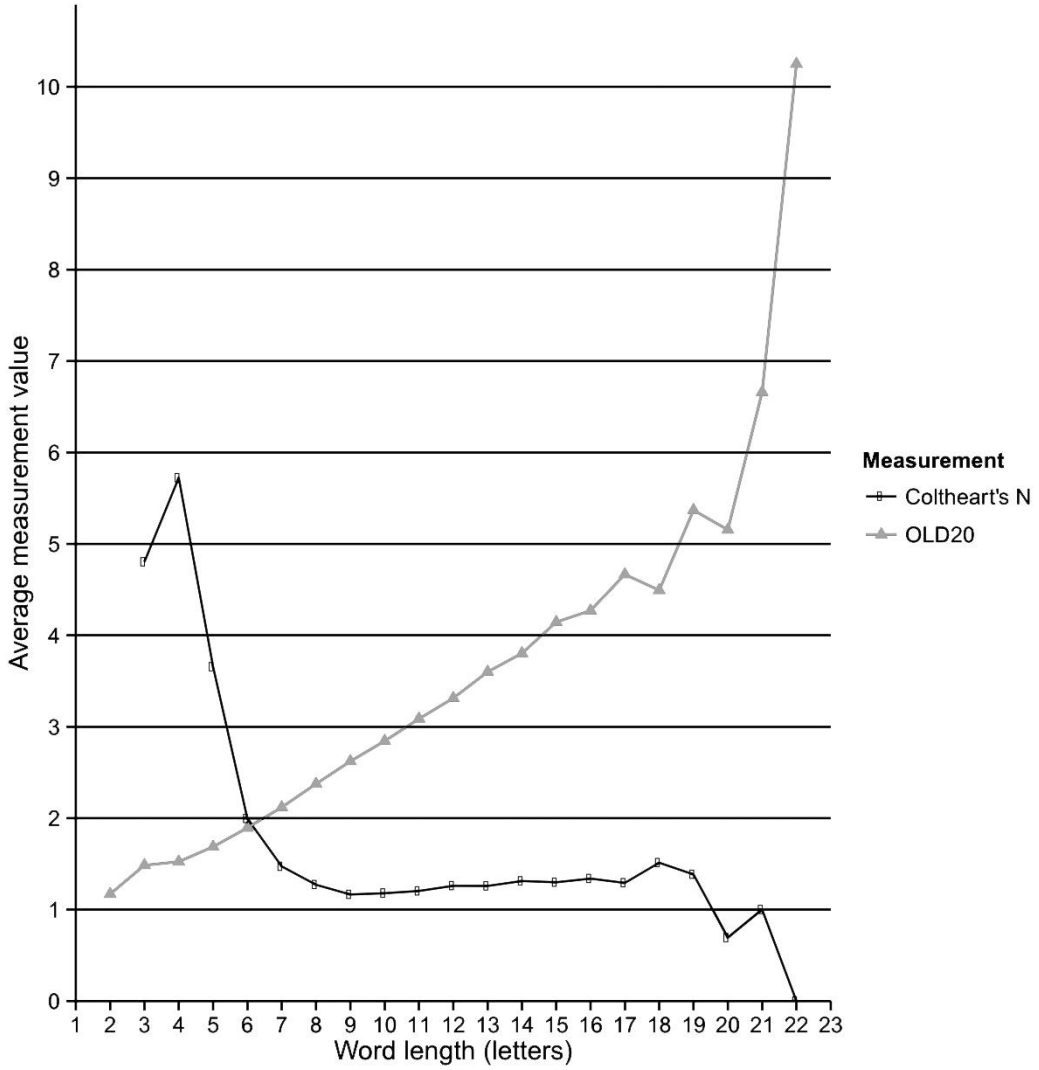


Figure 4. 5 Distributions of mean OLD20 Levenshtein Distance (based on Yarkoni et al., 2008) and Coltheart's N orthographic similarity (based on Coltheart at al., 1977) as a function of word length measured in letters.

4.3.7 Zipf values

Log transformed word frequency values based on the Zipf scale are now provided in conjunction with the traditional measurement of frequency per million (fpmw). As pointed out by van Heuven et al. (2014), there is a relatively large proportion of entries in large corpora that have a frequency lower than 1 fpmw and the word frequency effect is strongest for words below 1 fpmw. The problem with frequencies below 1 fpmw is that these become negative when a logarithmic transformation is applied. Therefore, van Heuven et al. (2014) proposed the Zipf scale of word frequency, which has a number of properties that make it easier to understand. In particular, it is a logarithmic scale with a few points and the middle of the scale separates low from high frequency words. The Zipf values for the entries in GreekLex 2 are calculated using the formula proposed by van Heuven et al. (2014):

$$Zipf = log10\left(\frac{frequency\ count + 1}{46.89 + 0.0353}\right) + 3.0 \qquad (1)$$

where the first number of the denominator represents the corpus size and the second one represents the number of unique word types in the database, both measured in millions.

4.4 Summary and future development

This chapter presented GreekLex 2, an updated version of the GreekLex database (Ktori et al., 2008), reporting information such as part-of-speech category, which is not available in other Greek databases and improved information about syllabic units and orthographic measurements that provide predictability on stress position. Initially, a summary of the first version of GreekLex was presented as well as other databases available in Greek and areas for further development were highlighted. Subsequently, the procedures followed to generate the new information were reported. The database now provides part-of-speech information for each entry; accurate orthographic and phonological syllabification as well as syllabic length and stress position; *stress* and *rime neighbourhood* measurements that indicate the regularity of stress position for each entry based on its ending. Additionally, novel analyses, that the availability of the new features allowed, were carried out and the regularities that Greek language presents were investigated. It was shown that the distribution of stress position does not uniformly adhere to the prefinal syllable bias but is dependent upon grammatical category. Additionally, it was shown that a proportion higher than 85% of the entries in the database would be stressed correctly solely by relying on *stress neighbourhood* information.

In the publication related to the first version of GreekLex, the authors state that future developments would involve "the inclusion of syntactic and phonological information as well as the calculation of syllable frequency counts that would enable further insight into the orthographic processing of Modern Greek." (Ktori et al., 2008, p. 779). These issues have been all addressed in GreekLex 2. Plans for future developments include adding information that is less dependent upon computational and lexicographical tools like phonetic transcription modules or dictionaries, and more reliant on naturally-produced speech (to generate phonetic transcriptions) and intact text corpora (to generate syntactic information directly from such sources).

The database is provided in text files encoded in ASCII and UTF-8 (for users that do not have Greek installed on their system) and as a comma-separated values (csv) file to be opened with spreadsheet software. All files which are related to this chapter, such as the database, the complementary files with

syllabic frequencies, Stress Neighbourhood and PoS information, and the Python scripts for automatic syllabification and phonetic transcription can be found at http://www.psychology.nottingham.ac.uk/greeklex/.

CHAPTER 5

REVIEW OF STRESS IN EUROPEAN ORTHOGRAPHIES AND THE MECHANISMS OF STRESS WITH ENGLISH DISYLLABIC WORDS

To exemplify the variability that the properties of stress are manifested in different languages, this chapter initially presents a brief overview of this linguistic property in several European orthographies with a specific emphasis on the role of stress in these languages as well as the level that it is orthographically marked in each system. The purpose of this review is to highlight the need for behavioural data collected from different linguistic environments before addressing the question of whether a set of universal properties of reading that function beyond the considerable diversity within different writing systems can be developed. Additionally, in light of starting to develop a computational model that will attempt to tackle the challenge of simulating stress assignment in Greek, the first step was to study in depth the behaviour of a leading computational model already available for a different language. Hence, it was deemed essential to acquire data that could be later directly compared to the model's performance. Therefore, this chapter subsequently reports the findings of two behavioural experiments performed with skilled native English speakers that aimed to investigate the mechanisms of assigning stress in skilled English reading and advance on the theoretical knowledge from previous studies of this aspect of reading. In particular, the default pattern mechanism was scrutinised in English because this is an issue that has given rise to conflicting findings reported in the literature. To achieve this, Experiment 1 employed reading aloud of disyllabic words that were either not ambiguous regarding stress position (e.g. *d**O**ctor* and *ins**I**st*) or stress minimal pairs. These are pairs of words with identical orthography yet different stress position that differentiates the meaning between them (e.g. *p**E**rmit* and *perm**I**t*). Participants were asked to name these words when presented in isolation, consequently allowing readers to stress minimal pairs on the position they prefer. Experiment 2 aimed to investigate the dominance of representations of such ambiguous words in the readers' mental lexicon by testing whether a specific metrical pattern would shift the stressing strategies that were adopted in Experiment 1. For this purpose, the same materials

were utilised again but presented in a blocked manner in which minimal pairs appeared with unambiguous items that were consistently stressed either on the first or the second syllable. In this way, a within-blocks priming procedure was induced by either accenting the trochaic (stressed-unstressed) or iambic (unstressed-stressed) metrical frame in each group of items. This way, lexical contributions were directly compared with the effect of the default bias when assigning stress in English (Experiment 1), and the strength of the phonological representations was assessed by contrasting it against different stress position activation (Experiment 2). Additionally, this chapter reports the results of computational simulations performed with these stimuli by using one of the leading computational models of reading polysyllabic words, the Connectionist Dual-Route model (CDP++, Perry et al., 2010; Perry et al., 2013). The purpose of performing these simulations was twofold. Firstly, results of the simulations were used to evaluate how the different information regarding stress position were utilised by CDP++ and draw conclusions on the theoretical assumptions adopted by this model regarding their relative contributions to the way the stress assignment mechanism has been wired and parameterised. Secondly, the patterns that emerged were compared to the results of the behavioural experiments with the aim of assessing the model's performance.

5.1 Stress in different European orthographies

A common point of reference that characterises European alphabetic languages is that each polysyllabic word has at least one syllable that is marked for heavier stress than the others and that its phonological realisation will necessarily include this stress marking[9]. However, the predictability of stress position and the manner that this position is determined varies considerably among different languages. As an example, grammatically assigned stress involves grammatical rules or structural constraints that determine stress position whereas lexical stress is not entirely predictable by grammar hence requires some level of interaction with the phonological lexicon (Apoussidou, 2007). There are languages in which stress is fixed to either an external boundary (first/last) or internal syllable, and others in which it can be freely assigned on any of the word's syllables or a subset of them. Indicatively, in Turkish, stress is always assigned on the final syllabic position (Revithiadou, 1999), whereas, in Greek and Portuguese, it can be freely assigned on any of the three right-most syllables (Coreia, Frota, Butler, & Vigário, 2013). Additionally, the concept of orthographic marks, diacritics, that determine stress position has been extensively discussed throughout this thesis. While it is not a typical characteristic of an alphabetic language to use orthographic diacritics, it is important to mention that this property does not overlap with any of the previously-mentioned ones; while Greek is a language with variant, lexical stress in which orthographic diacritics indicate stress position in lowercase, French, a language with fixed stress, also uses orthographic diacritics marked on several vowels but functioning as accent marks rather than stress position indicators (Tranel, 1987). Finally, it should be highlighted that in certain languages, stress can have a multi-level dimension. In English, secondary stress can appear in conjunction with primary stress (Ashby & Cliffton, 2005). Indicatively, tetrasyllabic words can follow patterns such as secondary_unstressed_primary_unstressed (e.g. *fùndaméntal*) or unstressed_stressed_unstressed_unstressed (e.g. *inténsity*). In contrast, in Greek, a second (or otherwise enclitic) stress only emerges when words appear in context and content words are followed by enclitics hence forming the *phonological word* that also needs to have stress on any of the

[9] Occasional instances of these differences being gradual rather than binary exceed the purpose of the present work. Overall, it does not constitute an oversimplification to consider that each polysyllabic word presents a binary distinction among stressed and unstressed syllables (Protopapas, 2016).

final three syllabic positions (see Chapter 1). In this case, the added stress has similar acoustic properties to the primary stress, whereas the previously dominant stress results with similar acoustic properties to the secondary or subordinate stress type (Arvaniti, 1992).

Table 5.1 presents a two-dimensional classification of European languages similar to the analysis of orthographic complexity in Seymour et al.'s (2003) presented in Chapter 1. Here, the vertical axis represents the continuum of orthographic depth, which is the level of transparency of the grapho-phonemic conversions in the print-to-sound direction. The second dimension here, which in Seymour et al.'s analysis corresponded to syllabic complexity, represents the continuum of stress position predictability, namely the level of opaqueness that characterises stress assignment in each language. This could be alternatively interpreted as the level that the reader needs to resort to the phonological representations in order to retrieve stress or extract this information directly based on abstract knowledge regarding each specific language.

Table 5. 1 Classification of European languages relative to the dimensions of stress predictability (high to low) and orthographic transparency (shallow/transparent to deep).

	Stress Predictability				
	High				*Low*
Shallow	Finnish				
Orthographic Transparency		Greek	Spanish	Italian German	
	Polish French		Portuguese	Dutch	
Deep					English

On one extreme of this continuum, languages such as Finnish and French can be classified as entirely predictable when considering stress assignment because they have a fixed stress position on the first or last syllable of the word respectively (Hannhas, 2007; Karvonen, 2008). It should be noted that fixed stress does not necessarily need to appear on word boundaries. For example, Polish language assigns stress on the penultimate syllabic position (Revithiadou, 1999). Classification criteria for the present analysis comprise stress fixation on a given position, orthographic stress indicators and their consistency of appearance, and existence of linguistic rules that can render stress position unambiguous. Arguably, combinations of the above-mentioned cues typically appear in great variation across languages. For example, while both Finnish and French are characterised as languages with fixed stress, in French, stress can also appear on the penultimate instead of final position when the latter contains a schwa (Hannhas, 2007). This does not lower the level of stress opaqueness in French, as this remains entirely predictable. However, it makes it less straightforward than in Finnish, in which stress invariantly appears on the first syllable (Karvonen, 2008), because in French one additional criterion needs to be applied sporadically. Hence, Finnish is placed higher than French in this classification.

Moving on to languages with variant stress position, the left-most part of the continuum entails those that, albeit variant in position, their stress can be extracted from orthography. In lowercase Greek, stress is always marked orthographically by means of stress diacritics. This means that the reader always has an indication of where stress falls on polysyllabic words without the need to know the specific word or apply any linguistic rules. In comparison to Greek, Spanish is also a language with entirely predictable stress position. There are certain words that take orthographic diacritics as well. However, when the diacritics are not marked, the reader needs to be aware of the rule which posits that stress should be assigned to the prefinal syllable unless the word ends in a consonant other than ‘n’ or ‘s’, in which case the final syllable is stressed (Gutiérrez-Palma & Palma-Reyes, 2008). Hence, despite the absolute predictability of both languages, Greek is classified as less opaque than Spanish.

The final group of languages considered are those with at least a set of words that cannot be stressed correctly without resorting to lexical knowledge. In Italian, stress is generally predictable except for polysyllabic words with three or more syllables for which it cannot be extracted by rule whether they are stressed on the penultimate or the antepenultimate (very few such words are stressed on the final syllable and are marked with stress diacritics in this case). Another indicative example is Dutch disyllabic words that, by rule, are stressed on the prefinal syllable except for when the final syllable is a 'super-heavy' one (of CCV or CVV type) in which case stress falls on the final. The exceptional cases that are stressed on the final syllable without it being a 'super-heavy' one (e.g. *for**E**l*) are presumed to be stored in the phonological representations (Zonneveld, Trommelen, Jessen, Bruce, & Árnason, 1999). An alternative account of addressing this irregularity is that all words with stress on the prefinal syllable are considered default by Dutch speakers whereas any word with stress on the final is considered exceptional and stored in the lexicon (Levelt, Roelofs, & Meyer, 1999). Nonetheless, stored representations need to be involved at some point for the Dutch reader to be able to stress any potential word correctly. Finally, German and English are two languages that stress is not marked and its position cannot be adequately predicted by means of stress rules. Therefore, it has been suggested that in such languages the stress pattern of individual words needs to be lexicalised due to its largely unpredictable nature (Domahs, Wiese, Bornkessel-Schlesewsky, & Schlesewsky, 2008; Wiese 1996).

The classification presented in Table 5.1 and the discussion that succeeds it only constitutes one among several ways of categorising languages with respect to their stress predictability. Hierarchising these criteria in a different manner might result in alternative classifications. If, for example, visually available and consistently present stress marks are considered a more straightforward way of extracting stress position compared to the need of knowing a language's specific standardised position in conjunction to grammatically predictable exceptions, then Greek should be classified as a more transparent language than French in that aspect. While French has fixed stress and Greek variant stress, in French, if the reader does not know the schwa exception described earlier, they will not be able to assign stress correctly in such cases. On the contrary, while the reader of Greek needs to

decode the orthographic diacritic to extract stress position (always, of course, under the assumption that in either language this is not retrieved from the phonological representations), this guarantees that this information is consistently provided as readily available. Hence, under different criteria, Greek might be classified as a less opaque language than French in stress predictability despite the variant stress position of the former. However, the reasons behind selecting this specific hierarchy of criteria lie in the purposes of the present analysis, which was carried out in view of the reading task and the ways this information interacts and shapes this cognitive process, rather than the way they function as purely linguistic properties. For example, as showcased by choices of reading models, attempts to simulate reading behaviour in languages such as French do not entail direct efforts of tackling the stress assignment task due to its fixed property (e.g. Ans et al., 1998; Perry et al., 2014b), in sharp contrast with modelling approaches in other languages even by the same research groups (e.g. Perry et al., 2014a).

It is important to mention that in this analysis, probabilistic cues regarding stress position are not taken into account for the language classification. For example, it is well known that English words contain information regarding stress position in their morphemic affixes (both prefixes and suffixes) as suggested by Fudge (1984) and implemented by Rastle and Coltheart (2000), but also in the more abstract initial and final letter sequences of the word regardless their morphemic status (Arciuli et al., 2010). Additionally, many of the languages with variant stress reviewed here present a statistical preponderance for words stressed on a given syllable, typically the prefinal syllable (e.g. Italian, Greek, German, and English). For some of these languages, such as Italian and Greek, there is clear-cut evidence of a psycholinguistic dimension regarding the most frequent position which is manifested as a processing advantage for words with default stress (Italian: Colombo, 1992; Colombo & Sulpizio, 2015; Greek: Protopapas et al., 2007; Chapter 2 of this thesis). For others, such as English and German, interpretation of behavioural findings is still less clear-cut and whether they have a behavioural dimension is subject to debate (e.g. English: Monsell et al., 1989; Rastle & Coltheart, 2000; German: Levelt et al., 1999; Domahs, Grande, Huber, & Domahs, 2014). But the main issue that renders such cues problematic, hence precluded from the current analysis, is that they are not

adequate to stress correctly a language's word battery in its entirety. In all such languages, exceptional words that take stress in non-default positions can be found. In English, most morphemic or orthographic cues will present cases that stress goes against the cue as well (Arciuli & Cupples, 2006). Consequently, no current model of reading polysyllabic words is able to simulate skilled reading behaviour, which is characterised by at least near to perfect performance on accuracy for known words, if they do not entail access to a lexicon that stores information on stress position. Similarly, underlying linguistic rules can in many cases have high predictive power on stress position. In German, the weight of the final syllable determines whether it is part of a monosyllabic (moraic) or a disyllabic trochee (a prosodic foot consisting of a heavy followed by a light member), which, in turn, affects stress position (Domahs, Knaus, El Shanawany, & Wiese, 2014). However, this requires implicit knowledge of this framework, while experiments investigating the unconscious application of these regularities by readers when stressing nonwords do not yield entirely consistent stressing patterns (Röttger, Domahs, Grande, & Domahs, 2012). Consequently, it cannot be safely inferred from such experiments that sublexical cues are solely relied upon in order to apply stress in languages with opaque stress position.

To conclude, as this analysis illustrates, there are languages with comparable levels of transparency and stress predictability like English (deep orthography, unpredictable stress) and Finnish (shallow orthography, predictable stress), but also languages with contrasting levels of these two characteristics, such as French (deep orthography, predictable stress) and German (shallow orthography, unpredictable stress). An additional feature that is important for orthographic processing is the extent that marked diacritics play a role in each language's stress predictability. Table 5.2 presents a classification of the same languages in a continuum showing the existence of diacritics and their relevance to stress position indication.

Table 5. 2 Classification of European languages according to the existence of diacritical marks and their relevance to stress position.

No diacritics	**Diacritics as accent marks**		**Diacritics as stress indicators**
English	Finnish	**Always**	Greek
	French	Consistency of use	Spanish
	German		Portuguese
	Polish		Italian
		Seldom	Dutch

As illustrated by the table, it is typically the case that the orthographies of European languages contain diacritic marks since among the reviewed languages only English orthography does not involve the use of diacritics. However, in many cases the purpose of such marks is to alter the phonetic realisation of a given letter rather than indicate stress position. Here, the focus is on the languages with diacritics that mark stress. As mentioned before, the only language that consistently marks stress position with diacritics is Greek and that is only in lowercase. Several other languages, such as Spanish and Portuguese, take advantage of the straightforward rules that determine stress position and only use diacritics to mark exceptions. In Italian, stress is only marked on polysyllabic words with more than two syllables when they are stressed on the final and these constitute only a very limited set of the language's vocabulary. Additionally, the conjunction of such orthographic marks with linguistic rules do not adequately cover all cases hence leaving several words to be non-transparent with regards to stress position. Finally, in Dutch, a diacritic might be used occasionally and only in context and indicates stress position but in an indirect manner. The purpose of this diacritic is to emphasise a given word in a sentence and it is marked on this word's stressed syllable. However, this use is neither consistent nor obligatory so it cannot be considered a reliable source of stress information. English is the language that lies at the opposite end of the continuum in comparison to Greek when considering any of these classifications. It does not mark stress orthographically, and it does have overt rules that the reader can follow to apply stress in written words. Therefore, it provides the ideal comparison to the investigation of stress mechanisms in Greek reported in the previous chapters in which stress position is entirely transparent and predictable.

5.2 Stress assignment in skilled reading of English

It has been established from the previous section that stress assignment in English language requires some level of involvement of the mental lexicon where stress is presumed to be stored in the phonological representations. However, statistical analyses in this language as well as behavioural experiments have shown that sublexical cues are available and that they affect the mechanisms of assigning stress by native English speakers. This section serves as a brief summary of this evidence as these studies have been more extensively reviewed in Chapter 1.

In English, there is a statistical predominance of words that receive stress on the prefinal syllable. Approximately 83% of the disyllabic words in the CELEX database (Baayen et al., 1993) are stressed on this syllable (Rastle & Coltheart, 2000). Behavioural data from a word naming experiment by Monsell et al. (1989) have shown that words with stress on the prefinal are named faster than those with stress on the final syllable. This pattern was also reported in an experiment by Brown, Lupker, and Colombo (1994) and the advantage seems to be accentuated in low-frequency words that are expected to encourage sublexical processing strategies. However, because experimental procedures and statistical methods reported in these studies were not deemed entirely transparent, Rastle and Coltheart (2000) attempted but failed to replicate this effect of stress regularity in a word naming experiment that scrutinised this notion of regularity against word frequency. More precisely, while they found an effect of frequency as expected, they did not find a main effect of regularity or an interaction between regularity and frequency. Consequently, evidence from behavioural experiments is not conclusive regarding the behavioural dimension of this statistical characteristic of English language in reading.

Furthermore, we know from statistical analyses (Monaghann et al., 2016), behavioural experiments (Arciuli et al., 2010), and computational simulations (Arciuli et al., 2010; Seva et al., 2009) that initial and final letter sequences bear important information on stress position in English words. This information directs readers on where to assign stress in nonwords and can be used to train computational models to behave in a similar manner to human readers. Additionally, morphemic units

in the beginning and ending of English words, either overlaping with orthographic strings or not, also have predictive value on stress position in English as confirmed behaviourally and computationally (Ktori et al., 2016; Rastle & Coltheart, 2000). Finally, it has been shown by Domahs et al. (2008, 2014) that stress assignment is sensitive to syllabic weight so that the structure of the final and prefinal syllable is influential on how nonwords are stressed. Similarly, Kelly (2004) has shown that disyllabic words with more consonants in the first syllable are more likely to be stressed on this position than when they begin with one consonant (e.g. *blossom* vs. *canal*) and that readers also show the tendency to stress disyllabic nonwords on the prefinal syllable when they begin with two consonants rather than one (e.g. *plonveen* vs. *ponveen*).

Finally, an additional notion of regularity regarding stress position in English language involves grammatical category. Typically stressed disyllabic nouns are considered those with stress on the prefinal syllable and typically stressed verbs are those with stress on the final syllable (Kelly & Bock, 1988). Arciuli and Cupples (2006) have found that readers make fewer errors when naming or recognising regularly compared to irregularly stressed nouns and verbs on this criterion. They have also shown that when seen in written form, regularly stressed such words are easier for native English speakers to classify on grammatical category than irregularly stress ones (Arciuli & Cupples, 2003).

Consequently, it was deemed important that future research additionally focuses on how these different sources of information regarding stress position in English interact or complement each other and whether a hierarchy of contributions from each one could be identified and highlighted. The aim of the experiments reported below was to serve this purpose, particularly in relation to the specific sources of lexical activations and the default metrical bias.

5.3 Experiment 1

5.3.1 Rationale and hypotheses

The first aim of these experiments focusing on stress assignment in English was to investigate the statistical predominance of the prefinal syllable and whether it affects the stressing patterns in this language. Experiments investigating the default bias in English reported in the previous section (Monsell et al., 1989; Brown et al., 1994) used real words as experimental materials but did not reach theoretically consistent conclusions. On the other hand, the typical approach when investigating sublexical cues in relation to the stress mechanism in behavioural research is to ask from readers to perform a reading task with nonwords (Arciuli et al., 2010; Domahs et al., 2014; Kelly, 2004; Ktori et al., 2016; Monaghan et al., 2016; Rastle & Coltheart, 2000; Seva et al., 2009). The purpose of this is to avoid any contributions from lexical retrieval that could hinder contributions from sublexical cues that are expected to emerge (e.g. see Protopapas, 2006). Here, we have chosen to use real words as experimental items but from a subset of the English stress minimal pairs. These are words with the same orthographic form that differ in stress position (e.g. **ò**bject vs. obj**è**ct). Consequently, such items allow the reader to assign stress freely on any of the two syllables without this constituting a naming mistake. Hence, the merits of this approach are expected to emerge from a more naturalistic reading environment involving only real-word stimuli yet still suitable to isolate the reading behaviour under investigation. This approach ensures that any effects arising from orthographic information can be ruled out as potential reasons behind the stressing choices employed by readers, because the exact same orthographic string can be phonetically realised with stress in any of the available positions.

Half of the stress minimal pairs included in the materials are significantly more frequent when stressed on the prefinal syllable and half are more frequent with stress on the final. If the prefinal syllable bias is active in English readers, it would be expected that readers show a tendency to stress items on this syllabic position. Consequently, stress on the final syllable (for the items encouraging this position) would be shifted to the prefinal given the free choice, or those stressed on the prefinal could present a processing advantage. This interpretation would be valid provided that the frequencies of appearance

of these items mirror the strengths of the phonological representations in the mental lexicon. Also, this pattern would be evidence against a strong participation of the mental lexicon in the process of stress assignment (again, under the assumption that calculated frequencies do constitute reliable estimations of the reader's lexicon).

An additional hypothesis that was investigated in this experiment was how participants would perform with minimal pairs in comparison to disyllabic baseline words that can only take stress on one position (e.g. *d**O**ctor* and *ins**I**st).* According to computational models such as the CDP++ (Perry et al, 2010), which is a localist model, in the sublexical route, a two-layer assembly (TLA) network (see chapter 1) creates associations between graphemes and two stress nodes (final – prefinal; note: this model can accommodate input of up to two syllables). Therefore, as far as the sublexical route is concerned, the orthographic form of minimal pairs will be unique, hence the connections between graphemes and the stress nodes can only lead to one stress position. But with respect to the lexical route, a baseline disyllabic word will have one entry in the phonological lexicon and one in the orthographic lexicon, whereas a minimal stress pair will have one entry in the orthographic lexicon but two in the phonological lexicon. This could be expected to introduce a conflict that would emerge from competition in this route and consequently result in worse performance (reaction times or error rates) for the minimal pairs in comparison to the baseline disyllable words.

Finally, in accordance with the approach adopted and justified in Experiment 3 of Chapter 3, presentation of stimuli was not constrained within a specific time limit. Rather, each item remained on screen until a response was given by the participant (or the three-second time-out triggered initiation of the next trial). It is difficult to compare this approach directly to other English stress studies because many such have employed other experimental tasks (e.g. Arciuli & Cupples, 2003; Cooper, Cutler, & Wales, 2002), had atypical readers as partcipants (e.g. Ktori et al., 2016), only involved nonword reading (e.g. Kelly, 2004; Ktori et al., 2016), or did not report presentation duration in their procedure section (e.g. Kelly et al., 1998; Rastle & Coltheart, 2000). Again, this decision was driven by the intention to avoid introducing nondesirable obstacles by inducing potentially rushed responses by the

participants within the 500 ms time window and is consistent with the reading aloud experimental conditions reported in Arciuli and Cupples (2006).

5.3.2 Method

Participants

Thirty native English undergraduate students from the University of Nottingham (*age range* 18-21 years, *mean age* 19.6 years, *SD* 1.1 years) participated in the experiments. Twenty-five were females. All participants had normal or corrected-to-normal vision and none of them reported any diagnosed learning or reading difficulties.

Materials

The stimulus set consisted of 80 monosyllabic and 80 disyllabic English words. The disyllabic set consisted of 40 minimal pairs and 40 words with unambiguous stress position. All words were retrieved from the SUBTLEX-UK database (van Heuven et al., 2014). Twenty minimal pairs had a final-stress dominant entry in the database and 20 had a prefinal-stress dominant entry. Stress dominant position was assessed by means of the ratio of the dominant member's frequency over the total frequency of the orthographic entry in the database (e.g. the frequency of the entry 'compound' occurring with stress on the prefinal syllable over the total frequency of the entry in the database). Only minimal pairs with a ratio higher than 0.8 were considered as candidate items in the stimulus selection process in order to ensure the highest and least ambiguous possible dominance of stress in each syllabic position over the other. Item sets were matched for word frequency (Zipf), orthographic neighbourhood (Coltheart's N, as defined in Coltheart et al., 1977), letter length, and stress position dominance ratio. Additionally, the two minimal pair sets were matched for the level that their orthographic endings encouraged stressed on the final or prefinal syllable, based on the work by Arciuli and Cupples (2006). More specifically, their analysis provides a percentage proportion of

words that present a trochaic or iambic stress pattern within each orthographic ending group (e.g. -ite: 61.9% trochaic, 38.1% iambic). Neither group mean of these indices significantly ($p > .4$) differed from that of the other group or from 50% which is the absolute neutral value (not encouraging stress on any position). The disyllabic words used as baselines were matched on the item level to the minimal pairs on the additional criteria of stress position, and initial letter. Although some words could not be matched exactly, two-tailed matched-paired t-tests indicated that there were no significant differences between the two lists of minimal stress pairs and the two lists of disyllabic baselines, or between each list of minimal stress pairs and each list of disyllabic baselines ($p > .4$). The same procedure was followed for monosyllabic words, which were only used as filler items. The purpose of using these items was to avoid any potential carry-over effects from each trial to the immediately subsequent one. So, the filler items served to 'washout' prior traces of stress from the processing of the new target word given that monosyllabic words are naturally not marked with stress position. All materials used in the experiments are listed in Appendix C.1 and the statistical characteristics of the stimulus sets are presented in Table 5.3.

Table 5. 3 Statistical properties of the disyllabic stimuli used in the experiments

	Minimal pairs		Disyllabic baselines	
	Prefinal dominant	Final dominant	Prefinal stress	Final stress
Log Freq(Zipf)	3.94	3.74	3.86	3.7
Length	6.90	6.90	6.80	6.75
N Density	1.45	1.35	1.65	1.35
Stress dominance Ratio	0.92	0.95	-	-
Trochaic Index	46.8	48.9	-	-
Iambic Index	49.9	45.9	-	-

Notes. Zipf frequency was computed as defined in van Heuven et al. (2014) and Coltheart's N was computed as defined in Coltheart et al. (1977). Stress dominance Ratio mean measures each minimal pair's frequency of occurrence with stress on the given syllable over the total frequency of occurrence of the orthographic form, per group. Trochaic and iambic mean indices are the percentage of words that take stress on the prefinal (trochaic) or final syllable (iambic) for each given ending as reported by Arciuli and Cupples (2006).

Design, apparatus and procedure

A repeated-measures design was employed in which the independent variables were word type (stress minimal pair, disyllabic baseline word), and stress position (first syllable – prefinal, second syllable - final). Accuracy of responses and naming latencies, from the point the stimulus appeared on screen until the onset of the participant's vocal response, were recorded. In addition, position of stress assignment per item was recorded by listening to all the responses of each participant after the experimental session was over.

Stimuli were presented on a 19-inch CRT screen (1024x768 pixels, 85 Hz) connected to a PC running Windows XP. Stimulus presentation and response recording was controlled with DMDX (Forster & Forster, 2003, version 4). Participants were seated approximately 40 cm away from the computer screen. Responses were recorded with a head-mounted microphone and participants were instructed to be as fast and accurate as possible. The accuracy of the onset of the vocal responses was checked, and adjusted where appropriate, with CheckVocal (Protopapas, 2007). This software was also used to mark the stress position per item.

Stimuli were presented in 14-point Courier New, a non-proportional font in which all letters occupy the same amount of space. Each disyllabic item, be it minimal pair or baseline word, was followed by a monosyllabic item so there was a fixed order of monosyllabic, disyllabic, monosyllabic, disyllabic etc. but the item order within each category was randomised. Each trial started with the presentation of a fixation cross (+) for 500 ms, followed by a blank screen for 250 ms and presentation of the stimulus which remained on the screen for three seconds if a verbal response had not been initiated. A naming response (or the three-second time out) triggered onset of the next trial. The inter-trial interval was 1000 ms.

A practice session preceeded commencement of the experimental trials. In each case, the proportion of practice items matched the proportion of experimental stimuli resulting from the variable manipulations. Specifically, four minimal pair items (two with dominant stress on the prefinal and two on the final), four baseline disyllabic items (two stressed on the prefinal and two on the final) and

eight monosyllabic items were presented to participants before the lower or uppercase blocks, resulting in 16 items in total.

5.3.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies greater than 3.5 SDs away from the mean were excluded from the analysis. No responses were below the low cut-off point of 300 msec, so exclusion of low latencies was not needed. Mean reaction times for correct responses, error rates, and consistency with the dominant stress position were calculated and submitted for analysis across participants and across items. For minimal pairs, correct naming was taken as correct pronunciation of the constituent letters, independent of the position where stress was applied. Consistency with the dominant stress position was assessed on the criterion of whether the stress applied to each critical item by each participant was the most frequent (dominant) between the two in the database frequencies. Descriptive statistics for response times and accuracy rates are reported in Table 5.4 and item-level data of these measurements are provided in Appendix C.2.

Table 5. 4 Experiment 1: Mean reaction times (milliseconds), accuracy rates (percentage correct), and consistency with dominant stress position (percentage consistent) in the disyllabic stress minimal pairs and baselines. Standard deviation given in parenthesis.

Response latencies (ms)		
	Dominant prefinal	Dominant final
Minimal Pair	524 (66)	515 (67)
Baseline	533 (66)	515 (62)
Accuracy (% correct)		
	Dominant prefinal	Dominant final
Minimal Pair	97.7 (4.3)	97.9 (3.7)
Baseline	95.6 (5.1)	98.1 (2.9)
Consistency (% consistent)		
	Dominant prefinal	Dominant final
Minimal Pair	67.7 (15.4)	73.0 (14.9)

Note. Dominant prefinal: Minimal pairs that appear more frequently with stress on the prefinal syllable. Dominant final: Minimal pairs that appear more frequently with stress on the final syllable.

For reaction times, there was no main effect of word type (F_1(1, 29) = 2.88, p = .10, η_p^2 = .01, F_2(1, 76) = 0.74, p = .39, η_p^2 = .01). There was a significant main effect of stress position for the subject analysis (F_1(1, 29) = 20.1, p < .001, η_p^2 = .41), with words stressed on the final being named faster than words stressed on the prefinal, but this difference was not significant for the item analysis (F_2(1, 76) = 0.37, p = .54, η_p^2 = .05). The interaction between word type and stress position was not significant (F_1(1, 29) = 2.85, p = .10, η_p^2 = .09, F_2(1, 76) = 0.37, p = .54, η_p^2 = .01).

For accuracy, there was no significant main effect of word type (F_1(1, 29) = 1.79, p = .19, η_p^2 = .06, F_2(1, 76) = 0.66, p = .42, η_p^2 = .01), or stress position (F_1(1, 29) = 3.77, p = .06, η_p^2 = .12, F_2(1, 76) = 1.32, p = .26, η_p^2 = .02), and the interaction was also not significant (F_1(1, 29) = 4.13, p = .051, η_p^2 = .13, F_2(1, 76) = 0.86, p = .36, η_p^2 = .01).

For consistency with the database's dominant stress position, a t-test showed that there was no significant effect of stress position (t(58) = 1.38, p = .17, d = 0.35). One-sample t-tests were also conducted in order to see whether the consistency of minimal stress pairs with the database frequencies was above chance (50%). These tests showed that consistency with the database was significantly above chance for both minimal stress pairs dominantly stressed on the left (t(29) = 6.20, p < .001, d = 2.30) and minimal stress pairs dominantly stressed on the right (t(29) = 8.35, p < .001, d = 3.10).

5.3.4 Discussion

Experiment 1 was conducted to investigate whether the default metrical bias towards the prefinal syllable that is observed in statistical analyses of the language is active when readers assign stress to real words either simply disyllabic or minimal stress pairs. The results were quite straightforward. There was no advantage of the prefinal syllable that emerged from the present data. There was no advantage for the unambiguous disyllabic words stressed on the left and no advantage for the minimal pairs that were classified as dominant on the prefinal over those that were final-dominant, neither in the naming times nor in the error rate analysis. In contrast to this sublexical stress mechanism that did not appear to be active in this task, lexical contributions were confirmed to be a source of stress

information for the minimal pairs. That is because the level of consistency between the stress position of preference of the readers and the one emerging from the database frequencies showed that they agreed beyond the chance level. Hence, participants seemed to rely predominantly on the phonological representations to assign stress from the lexical route to these items and the strength of these representations seemed to reflect the frequencies of each of the two phonological entries corresponding to the unique orthographic one. Finally, the prediction regarding the hypothesised conflict expected to emerge from these competing phonological forms as lexical candidate target entries did not seem to slow reaction times for these items. Overall, minimal pair stimuli did not present longer response latencies or higher error rates compared to the unambiguous baselines. A potential interpretation of this result might be that the non-dominant phonological entry of each pair is not strong enough to introduce competition. Alternatively, Cutler (1986) has hypothesised that English readers might be 'deaf' in hearing differences between stress minimal pairs such as ***f****O**rbear* and *forb**E**ar* which could be treated as homophones. This would mean that such words would only be represented by one entry in the phonological lexicon, similarly to the orthographic lexicon. Cutler reached this conclusion because in a cross-modal associate priming study that utilised stress minimal pairs, each such item activated associates of both members of the pair. To investigate these possibilities, simulations were performed with the CDP++ model, seemingly the leading computational model of reading at present, in order to further explore these hypotheses. The results of these simulations are reported in the next section.

5.4 Computational simulations using the Connectionist Dual-Route Model

The Connectionist Dual-Route model of reading (Perry et al., 2010; Perry et al., 2013) is developed according to the theory that reading can be performed through two pathways, lexical and sublexical. While the lexical route involves direct retrieval of orthographic and phonological entries from the lexicon, the sublexical route involves the process of mapping sounds to graphemes through a learned associative network that is trained by creating connections between graphemes and their corresponding sounds as well as letter combinations and stress position (for a more detailed review of the model's architecture, see Chapter 1). This model was chosen to perform these simulations because it has successfully integrated a stress algorithm to a fully working implementation of a theoretical approach in reading and can accommodate disyllabic input. Hence, it was preferred over other models that are either monosyllabic, or only limit their focus on stress assignment rather than integrate it as a sub-process to a computationally implemented reading theory. Additionally, this model can adequately simulate many behavioural effects in English (Perry et al., 2010), has been adapted for other languages (Perry et al, 2014a; Perry et al., 2014b) and can also simulate seemingly contradictory results (Colombo & Sulpizio, 2015; Perry et al., 2014a).

5.4.1 Simulation 1

The purpose of the first simulation was to establish how the different sources of information for stress assignment interact according to the model's architecture. To investigate this, all the minimal pair items that were available in the model's lexicon were initially collected. 125 items were identified and they comprised base forms but also different wordforms belonging to the same lemma (e.g. *protest, protests*). The output of this simulation is presented in Appendix D.1. Indicatively, the program produced pronunciations of 85 of these items with stress on the prefinal syllable. However, this calculation is not particularly informative because it might depend on several factors such as each member's dominant stress position (based on the split frequencies of each member) and the output of the TLA network associations with orthographic patterns.

To further explore this, all entries that were congruent between i) the TLA network output and ii) the stress position assigned to the word's output phonology were excluded from further analysis. This resulted in 21 remaining entries that encouraged different stress position between i) the trained associations of orthographic patterns and stress in the lexicon, and ii) the final output stress position that was applied to the produced phonology. To explore where this inconsistency emerged from, the output stress position was considered in relation to the relative frequencies of the two members of each pair. Of the 21 entries, 18 had the TLA output stress on the position that pointed to the member with the lowest frequency among the two, yet the member with the highest relative frequency was produced. Consequently, it is concluded that lexical information arising from the phonological representations of the lexical route have higher weight than the TLA output regarding the stress nodes in the way that the model's architecture is currently wired.

5.4.2 Simulation 2

The purpose of the second simulation was to see whether the model would replicate the patterns that emerged from the behavioural investigations with the human participants. Because the model's lexicon did not include all the minimal pair items from the experimental materials, and using a subset of each experimental group would change the statistical characteristics of their matching variables, comparisons were made on the item level. Ten items were found in the model's lexicon from the minimal pairs with the dominant member stressed on the prefinal, and eight items from those with a dominant final.

Importantly, it was observed that approximately half of these items did not have their dominant member consistent between the SUBTLEX-UK database and the CDP++ model's lexicon. For example, while the entry *contest* belonged to the group with dominant stress on the prefinal according to the database frequencies, the frequencies in the model's lexicon were *prefinal*: 36, *final*: 164. Similarly, the entry *construct* belonged to the group with dominant stress on the final syllable but the model's lexicon frequencies were *prefinal*: 148, *final*: 25. Consequently, these items were compared irrespective of the initial groups they belonged to in the behavioural experiment. To make it

comparable to the model's output, each item was classified as stressed on the prefinal or final position by participants depending on the ratio of times it was stressed on either of the syllables. For example, a ratio of 75% prefinal classified the item as stressed on the prefinal whereas a ratio of 35% prefinal classified the item as stressed on the final (the whole set of common items along with their characteristics is provided in Appendix D.2).

Of the common items in total, 56% were stressed by the model at the same position as the human readers and 44% were stressed on the other position. Consequently, performance of the model on this aspect was not optimal. It should be noted, however, that neither should the database frequencies be taken as the gold standard because the sporadic existence of low ratios of accordance between the stress dominance emerging from the database and the stress position applied by the majority of readers illustrates that the stressing attitudes did not always mirror the expectation arising from the database split frequencies between the two members. Alternatively, for some items, different factors might have been at play when naming them and assigning stress, which have not been controlled for or taken into account when selecting the materials. Nonetheless, irrespective of the assumptions arising from the database frequencies, sub-optimal performance of the model with such items when directly compared to human responses warrants further investigations. The inconsistency of the split frequencies of each pair's members between the database and the lexicon might be one reason behind this result but it would be extremely difficult to assess which source has more representative frequencies per each case. Importantly, this model is able to successfully simulate several behavioural patterns, which suggests that the lexicon's frequencies that have been extracted from the CELEX database (Baayen et al., 1993) are not problematic overall. Additionally, it should be kept in mind that minimal pairs constitute an extremely limited set of English language and that their split frequencies between their member pairs is a very fine issue that requires looking at the procedures that they have been collected for the two databases in order to be assessed. This goes beyond the scope of the present work. But, unfortunately, it limits evaluation of the model's performance because it cannot be currently established whether the relatively poor performance in the simulation should be attributed to problematic frequencies of the critical items or inherent problems of the model's architecture or parameterisation.

5.5 Experiment 2

5.5.1 Rationale and hypotheses

In Experiment 1, lexical contributions to the stress assignment mechanism were compared against the default metrical pattern in English naming. Results showed that the default bias was not active and that in the absence of orthographic information as cues to stress position (which was excluded by means of the identical orthography of minimal stress pairs), frequency of the phonological representations was the primary source of information for assigning stress. In this experiment, to explore the stability of this mechanism, lexical information is compared against a sublexical metrical frame that is induced by presenting minimal pairs with disyllabic words that are consistently stressed in the final or the prefinal syllable. This was expected to introduce a within-block activated trochaic (stressed – unstressed) or iambic (unstressed – stressed) metrical frame.

Protopapas et al. (2007) have attempted to introduce such a metrical frame in a more explicit manner by asking participants to remember a specific word while they were carrying out a nonword naming task. In that case, this frame was put against the default metrical pattern that has been shown to be active in Greek reading. However, activating a different stress position in working memory failed to induce a shift from the default prefinal syllable since participants were still more likely to assign stress there. In English, it has been shown that stress position can be primed and used as a cue that facilitates lexical access (Cooper et al., 2002). When target words were visually presented at the offset of a sentence that ended with a prime with congruent stress position to the target, then the target was recognised faster in comparison to a control condition. However, minimal pairs have been shown to be inefficient in inducing a stress position priming themselves (Cutler, 1986). That might be the case because the difference of the acoustical properties could be less salient for such items compared to unambiguous disyllabic words that clearly indicate their stress position. So, for stress minimal pairs, the segmental phonological information itself prior to any suprasegmental features might be adequate to activate both entries and consequently both stress positions. In the present experiment, minimal stress pairs are used as targets rather than primes.

In this experiment, the relative contributions of lexical information and sublexical suprasegmental phonological cues are compared and quantified. If stress is assigned purely lexically, based on the strength of the most frequent phonological representations between the two minimal pair members, then it is expected that the same pattern with Experiment 1 should emerge. That is, minimal pairs should be stressed on their dominant stress position, be it final or prefinal, regardless of whether the position that is being primed is consistent or inconsistent to the strong phonological representation. If metrical information can be primed, an effect that has been successfully elicited by Cooper et al. (2002), then the trochaic or iambic metrical frame is expected to increase the activation of the entries with a congruent stress pattern in the lexicon. Consequently, the member with congruent stress position with the primes can reach the activation threshold first despite the stronger phonological representation of the other member resulting from higher frequency of occurrence. This could be reflected in the stress assignment of participants that can be shifted from the more dominant phonological representation to the one that agrees in stress position with the prime, resulting in slower reaction times for responses to items with the dominant member incongruent to the prime's stress, and/or lower performance on accuracy with these items. This will allow to further investigate whether any effects emerging from the default pattern in English that have been previously reported (Brown et al., 1994; Monsell et al., 1989) might be yielded due to higher activation of given syllabic positions within specific lexical neighbourhoods or due to an overall higher activation in the default position that is constantly active with speakers of this language due to more general properties of the language's word battery.

5.5.2 Method

Participants

Participants of Experiments 2 were the same with Experiment 1.

Materials

Materials for this experiment were also the same in Experiment 1 but items were split into two blocks of 80 items each. Each block included the 20 unambiguous disyllabic baselines that were consistently stressed on either the left or the right syllable. These disyllabic baselines acted as within-block primes for the minimal stress pairs, and within each block 20 minimal stress pairs were included; 10 had the dominant stress position on the left syllable, and 10 had the dominant stress on the right syllable. The 80 monosyllabic words were split between the two blocks, so each block contained 40 monosyllabic filler words.

Design and procedure

A between groups design was employed in which the independent variable was stress position (prefinal, final) of the critical items which were the stress minimal pairs. Comparisons were performed separately for each block (i.e. when either the prefinal or the final syllable was primed). In addition to accuracy of responses, naming latencies, and position of stress assignment per item, similar to Experiment 1, consistency with the prime was also recorded with the criterion of whether the position of the assigned stress agreed with the stress position of the particular block's unambiguous disyllabic baselines (or primes, for the purpose of this experiment).

The experimental procedure was identical to Experiment 1 except for the split of materials in two blocks, each consisting 20 disyllabic primes (either consistently stressed on the prefinal or the final syllable), 20 minimal pairs (10 with prefinal dominant and 10 with final dominant), and 40 monosyllabic filler items. The order of appearance of the word types was also kept the same as in Experiment 1.

Between carrying out Experiment 1 and 2, participants were given instructions for a digit search task. This was a filler task that was implemented in order to deter participants from focusing on the purpose of the study, and to reduce any possible repetition effects when completing the second experiment, as the same experimental materials were used (Scarborough, Gerard, & Cortese, 1979). In the digit

search task, participants had to decide whether a single digit was present within a six-digit string. There were no practice trials, and there were 40 real trials which lasted approximately seven minutes.

5.5.3 Results

In accordance with Ulrich and Miller (1994), 1% of response latencies greater than 3.5 SDs away from the mean were excluded from the analysis. Mean reaction times for correct responses, error rates, and consistency with the dominant stress position were calculated and submitted for analysis across participants and across items. Additionally, consistency with each block's primed syllabic position was assessed on the criterion of whether the stress applied to each critical item by each participant corresponded to the primed position of the block the item appeared in. Descriptive statistics for response times and accuracy rates are reported in Table 5.5.

Table 5. 5 Experiment 2: Mean reaction times (milliseconds), accuracy rates (percentage correct), consistency with dominant stress position (percentage consistent), and consistency with the within-block primed stress position (percentage consistent) in the stress minimal pairs. Standard deviation given in parenthesis.

Response latencies (ms)				
	Prefinal syllable primed		Final syllable primed	
	Dominant prefinal	Dominant final	Dominant prefinal	Dominant final
Minimal Pair	498 (62)	495 (61)	500 (81)	485 (77)
Baseline	502 (64)	-	-	486 (64)
Accuracy (% correct)				
	Prefinal syllable primed		Final syllable primed	
	Dominant prefinal	Dominant final	Dominant prefinal	Dominant final
Minimal Pair	94.5 (9.7)	97.9 (5.1)	98.9 (3.4)	98.3 (3.7)
Baseline	96.5 (4.8)	-	-	98.7 (2.9)
Consistency with database (% consistent)				
	Prefinal syllable primed		Final syllable primed	
	Dominant prefinal	Dominant final	Dominant prefinal	Dominant final
Minimal Pair	72.3 (19.1)	54.1 (18.9)	63.8 (17.1)	80.5 (12.3)
Consistency with the primes (% consistent)				
	Prefinal syllable primed		Final syllable primed	
	Dominant prefinal	Dominant final	Dominant prefinal	Dominant final
Minimal Pair	72.3 (19.1)	45.9 (18.9)	36.2 (17.1)	80.5 (12.3)

Note. Dominant prefinal: Minimal pairs that appear more frequently with stress on the prefinal syllable in the database. Dominant final: Minimal pairs that appear more frequently with stress on the final syllable in the database.

For reaction times, there was no difference between the minimal pairs emerging from dominant stress position in the block that the prefinal stress position was primed ($t_1(29) = 0.55$, $p = .59$, $d = 0.041$, $t_2(18) = 0.25$, $p = .81$, $d = 0.11$). In the block that the final syllable was primed, the difference between groups with dominant prefinal vs. final syllable in the database was significant in the by-subject analysis ($t_1(29) = 2.10$, $p = .04$, $d = 0.18$) that showed minimal pairs with dominant final syllable to be read faster than those with prefinal dominant, but not in the by-item analysis ($t_2(18) = 1.61$, $p = .13$, $d = 0.72$).

For accuracy, there was no significant difference between minimal pairs with dominant prefinal or final syllable, neither when the prefinal ($t_1(29) = -1.74$, $p = .09$, $d = 0.44$, $t_2(18) = -1.51$, $p = .15$, $d = 0.68$) nor when the final ($t_1(29) = 0.65$, $p = .52$, $d = 0.151$, $t_2(18) = 0.69$, $p = .50$, $d = 0.31$) was primed.

Regarding the consistency of minimal stress pairs with the prime, rates of agreement were calculated between the dominant stress position emerging from the database and the actual stress preference of the readers. Comparisons were performed between minimal pairs that their database-dominant stress position was the same with the primed position and those with their dominant position being inconsistent with the primed one. Paired-samples t-tests showed that both when the prefinal stress position was primed ($t_1(29) = 5.45$, $p < .001$, $d = 1.37$, $t_2(18) = 2.33$, $p = .032$, $d = 1.04$) and when the final stress position was primed ($t_1(29) = 3.36$, $p = .002$, $d = 1.03$, $t_2(18) = 2.19$, $p = .042$, $d = 0.98$), the minimal pairs with the same dominant stress position as the prime were stressed by the readers on that position with a higher rate of consistency when compared to the minimal pairs who did not have their dominant stress on the same position as the prime. Statistical analysis of the consistency with the database frequencies is not reported because this information replicates the consistency with the prime in an inverse manner (see Table 5.5).

5.5.4 Discussion

Experiment 2 was conducted to investigate whether inducing a metrical pattern would have an impact on the performance of the readers depending on whether the critical items (minimal pairs) had their dominant member's stress congruent with the prime. When considering response latencies and error rates, no such pattern emerged. When considering the stress assignment of readers, however, their stressing strategies shifted from conformance to the database-dominant stress position, given that they could freely assign stress on any of the two positions without this producing a naming error. It was observed that the minimal pairs with the dominant member having stress on the different position from the prime showed a statistically significant tendency to be stressed in accordance with the prime rather than their dominant phonological representation when compared to those whose dominant stress position was the same as the prime. This can be interpreted as evidence that the metrical pattern induced became active and influenced the stress assignment mechanism of the participants.

Seemingly, this priming effect can be attributed to participants extracting the phonological information and effectively priming themselves when naming disyllabic unambiguous words during Experiment 2, as no explicit phonological output was provided to give information about stress assignment. Within the context of the CDP++ model, this could be the result of an initial higher activation on either of the two stress nodes, depending on the prime, which would subsequently interact with the phonological lexicon. However, despite the apparent contributions of this sublexical cue to the stress mechanism, this information did not outperform the one emerging from the lexicon and the strength of the dominant member's phonological representation. That is because for minimal pairs whose dominant member is incongruent with the prime's stress, the stress assignment preference of the readers is still more consistent with the lexical factor compared to the priming factor (54.1 vs. 45.9 when priming the prefinal, 63.8 vs. 36.2 when priming the final). Therefore, lexical contributions to stress assignment appear to be the primal source of stress position information in the absence of orthographic information emerging from the initial and final letter sequences of the orthographic forms. This is a theoretical assumption that seems to have been adopted and implemented by the CDP++ model as well, as shown from the output of the simulations reported in a previous section. It remains to be

investigated whether a metrical frame would exemplify stronger contributions if it is induced in a more explicit manner, as, for example, that attempted by Protopapas et al. (2007).

However, current results do not preclude the possibility that stress position extraction might be a process that does not entirely rely in lexical retrieval but it can also be partly computed. Based on the literature in English stress assignment discussed earlier, this process might be modulated by frequency. The englsih language battery of minimal pairs, as captured by SUBTLEX-UK (van Heuven et al., 2014) that materials were retrieved from, did not allow for this variable to manipulated in the present study but was rather kept constant. The effort to match the critical, minimal-pair groups for several other factors, such as length, orthographic similarity, adequately high dominance of either final or prefinal stress within the item-specific frequency of each minimal pair's orthographic entry, and orthographic cues that do not encourage stress on either syllabic position, made it impossible to manipulate frequency as well. The reason why controlling these variables was hierarchised higher than manipulating frequency was based on the expectation that the free stressing patterns that minimal pairs allow might function beyond the overall frequency of each orthographic entry, solely in relation to the relative frequencies of the two phonological versions of each item. It could be hypothesised that items of higher overall frequency might encourage heavier reliance on the phonological representations that encode stress, whereas minimal-pair items of low overall frequency could be more susceptible to experimental manipulations such as priming the stress position. It should be mentioned though that the Zipf values of the items used in the present study indicate that their traditional frequency counts lie between one and 10 occurrences per million words (see van Heuven et al., 2014), i.e. they are not high-frequency words. Hence, the predominance of reliance on lexical sources shown in the present data was elicited with stimuli on the lower side of the frequency continuum. But whether the strategies elicited in these results would be shifted as a function of frequency in a deliberate frequency manipulation is an issue for a future study to investigate.

5.6 General discussion

In this chapter, a review of the linguistic characteristics of stress in several European orthographies aimed to showcase why studying the stress assignment mechanism in different linguistic environments is essential in reading research. English language was evaluated as a suitable plateau for these investigations, due to the inconclusiveness of the theoretical knowledge drawn from previous research, the identified variety of sources baring information on stress position, in similarity with Greek, and the availability of computational models that behavioural results could be directly compared against. Subsequently, results from two experiments were reported that aimed to investigate the relative contributions of different sources of stress position to the stress assignment mechanism. It was shown that the statistical preponderance of English disyllabic words stressed on the prefinal syllable was not an active source of information regarding stress position, thus corroborating the results acquired by Rastle and Coltheart (2000). In contrast, explicitly inducing a metrical frame to the participants' working memory effectively shifted their stressing strategies to conform to this metrical pattern, but only partly. Compared to the hypothesised dominant position emerging from the statistics of English language or an explicitly activated metrical frame in the working memory by experimental manipulations, lexical contributions regarding stress position are still stronger. Consequently, lexical stress assignment appears to be the first point of reference as a source of information regarding stress assignment in English. This resonates with findings reported earlier in this thesis regarding Greek, in which lexical information is also dominant; the metrical bias was weaker than other cues and was found to function mainly in their absence. Further investigations in English need to put lexical retrieval against the orthographic information emerging from beginning and final letter sequences to assess the relevant contributions of these two sources to the stress mechanism of English readers. That is because it has not been yet established how these two factors work in conjunction to each other and whether they contribute independently to the stress assignment mechanism. Utilisation of disyllabic minimal stress could also shed light to this question by orthogonally manipulating database-dominant stress position and the position associated with each word's orthography. With respect to this issue, results from computational simulations reported in this chapter indicate that in the context of a dual-

route theory as implemented in CDP++, lexical information is weighted higher than any other cue regarding stress position. This could be seen as mirroring the linguistic characteristics of English language as stress position is considered not to be fully predictable from orthography. Hence it encourages access to the phonological representations where this information is stored to perform the task of stress assignment in reading. Finally, sub-optimal performance of the CDP++ model in simulations involving stress minimal pairs compared to human data showed a potential area that the model might need further development. Analyses with the particular stimuli could not shed light on whether the inherent architecture of the model or the lexicon and the frequencies that it has been trained with were the locus of problematic performance. Future simulations and behavioural data collection should aim to address this issue.

CHAPTER 6

GENERAL CONCLUSIONS AND OUTCOMES OF COMPUTATIONAL SIMULATIONS

6.1 General conclusions

With the recent shift of focus from investigating monosyllabic words towards the polysyllabic domain in the field of reading research (e.g. Ktori et al., 2016; Yap & Balota, 2009) and computational modelling of reading (Perry et al., 2010; 2013), new challenges have emerged in understanding the cognitive mechanisms that underlie the reading task. Of central position among these new challenges is understanding how readers perform the task of stress assignment, that is, how they decide to accent certain syllables within polysyllabic words and pronounce them with greater prominence in comparison to the other syllables of the word. Since, until recently, the leading computational models of reading focused on explaining how monosyllabic input is processed (e.g. Coltheart et al., 2001; Harm & Seidenberg, 2004), this question had not been adequately addressed neither has it received the attention it deserved in the attempt to understand the complex reading process. With the shift to the polysyllabic domain, several explanations have been proposed regarding how this challenge is tackled by the reader, such as retrieving this information from memory or extracting it from the information that is available in each language's orthography, in either an explicit (e.g. diacritics marking stress position) or covert manner (e.g. statistical regularities between orthographic patterns and stress position). Since the availability of this information largely varies among languages, it is imperative that research is conducted in each specific linguistic environment to investigate how readers of each language utilise the information available to them and how this process affects the mechanisms of reading.

The aim of this thesis was to perform behavioural investigations in two languages, namely Greek and English, with the purpose of advancing theoretical knowledge on how the stressing mechanisms function in these languages. Additionally, it aimed to investigate through quantitative analyses the

statistical characteristics of Greek, in an attempt to identify additional sources of information on stress position that emerge from the orthography in Greek language. Finally, it aimed to assess the behaviour of an already established computational model by directly comparing it with behavioural data that would enhance understanding of how this model functions in specific circumstances related to the stress assignment task. Results of these comparisons in conjunction with the theoretical implications emerging from the behavioural experiments would then inform the efforts to develop an initial model in reading polysyllabic words in Greek language, which has not been documented in previous computational reading research. The outcome of this attempt is described and assessed by means of computational simulations in a subsequent section of this chapter. The following section summarises the results of the behavioural and quantitative investigations that were carried out and have been previously presented in this thesis.

6.1.1 Summary of results and theoretical implications

Previous research on stress assignment in Greek has been conducted by Protopapas and colleagues (Protopapas, 2006; Protopapas et al., 2006; 2007; Protopapas & Gerakaki, 2009) and has identified three major sources of stress information in this language that are utilised by readers. These sources are lexical contributions that allow the reader to assign stress by knowing the word, decoding of the orthographic diacritics that indicate stress position in lowercase Greek, and reliance on the strategy to assign stress on the default, prefinal syllabic position due to the higher proportion of words stressed there in comparison to each of the other possible positions (final, and antepenultimate - m. third syllable from the end). It has been argued by these researchers that all three sources are active and engage in a complex interplay that ends up informing the reader on where to assign stress. The relative contributions of these sources have been argued to depend on the factor of reading maturity since skilled readers show a higher tendency to decode the orthographic marks, potentially due to the fact that they have automatized the reading process to the level that they can afford to allocate part of their cognitive resources in the additional task of decoding the diacritical stress marks. This thesis focused

on skilled reading and attempted to identify which are the factors that encourage the relative contributions of each of the three factors and under which circumstances these contributions might shift by resorting to any of the three over the other sources. As an example, we know that in uppercase reading of Greek, stress is not marked orthographically so its correct assignment should rely on lexical knowledge or sublexical cues that do not emerge from the direct indication of stress position by the diacritics. So the aim was to scrutinise the process that leads to correct assignment of stress in reading Greek words. Additionally, of central focus regarding the aims of this thesis was identifying the locus/i that stress is represented by Greek readers. In regard to computational models of reading such as the CDP++ (Perry et al., 2010) or the DRC (Coltheart et al., 2001), these levels of representations could be the phonological output lexicon, the orthographic input lexicon, and/or the letter-unit level (figurative representations of these models' architecture are presented in Chapter 1).

The first experimental chapter of this thesis (Chapter 2) reports the results of two reading aloud experiments with native-Greek skilled readers who were asked to read Greek disyllabic low- and high-frequency words and nonwords that were either stressed on the prefinal or final syllable and were presented in either lowercase (i.e. with diacritics) or in uppercase (i.e. without diacritics). Activation of the default metrical pattern was showcased by the fact that nonwords in uppercase presented a statistically significant preference to be stressed on the prefinal, default syllabic position and by the fact that low-frequency word stressed on the final showed a significant tendency to be erroneously stressed on the prefinal syllable. Hence, even real word items, when lexical activations were not very strong due to their low frequency, seemed to be read in a serial manner with the subsequent application of stress to the default position despite this constituting a reading mistake. However, postulations by previous research that this strategy is of limited use when the other sources of information are present were also confirmed. When the diacritics were available (lowercase, both frequency groups) or when lexical activations prevailed (uppercase, high-frequency group) words were stressed correctly despite the absence of the diacritics and regardless of whether the correct stress position was the default one or not.

This experiment also yielded an overall effect of case type that was observed in the analysis of response latencies but not durations of production. This led to the interpretation that it was an effect involving only the earlier stages of processing as reflected by the response time measurements whereas it subsequently faded in later processing phases as reflected in the duration analysis. Nonetheless, it gave rise to the hypothesis that this case type effect could be originating on the additional difference between lower and uppercase that characterises Greek language, namely the absence of explicit orthographic information indicating stress position. This hypothesis was investigated by conducting Experiment 2 in which the reading times of monosyllabic words and nonwords were compared between lower and uppercase in Greek skilled reading. For this hypothesis to be supported, the case type effects observed in disyllabic stimuli of Experiment 1 should not be yielded by monosyllabic materials. Because the effect of case type prevailed in reading of monosyllabic stimuli in Experiment 2, it was concluded that it was a true effect of the case type of presentation rather than the result of the absence of one source of information indicating stress position.

Subsequently, behavioural investigations on stress assignment in Greek focused on distinguishing between the phonological and orthographic contributions of stress information and the different levels that stress is being represented in the Greek reading system. Experiment 1 of Chapter 3 utilised identical variable manipulations as Experiment 1 of Chapter 2 but in this case participants were asked to carry out a lexical decision task. Hence, this experiment isolated the production phase of reading and focused on the early processes of visual word recognition. Results highlighted both phonological and orthographic contributions of stress assignment in Greek reading. In the absence of diacritics (uppercase), participants showed faster reaction times when recognising low-frequency words stressed on the prefinal compared to the final syllable. This pattern again directs to the activation of the default bias in the absence of explicit orthographic indicators of stress position as well as strong lexical activations (of the high-frequency words that did not allow this advantage to emerge; this is attributed to direct lexical retrieval).

In lowercase, where the diacritics were present, two effects were observed. Firstly, lowercase nonwords stressed on the prefinal syllable elicited faster response times than those stressed on the final. Because these otherwise well-matched items are not fully represented in the orthographic (nor the phonological) lexicon the effect that emerged was attributed to the decoding of the diacritics and it was concluded that these marks function and are processed as independent units with independent contributions to the reading mechanism.

Additionally, a not a-priori predicted effect was that high-frequency words stressed on the final syllable were recognised faster than those stressed on the prefinal syllable only in lowercase but not in uppercase. To further investigate this effect, a post-hoc analysis of high-frequency stimuli in lower and uppercase showed that specifically words that bare the diacritic and are stressed on the final present a processing advantage over the other three categories. This was attributed to the syllabic structure of Greek that posits that in a stressed syllable, the (vowel) letter that is marked with the diacritic is typically the final one and in the case of final stress (but not prefinal stress), this overlaps with the final letter of the word. This pattern corroborates findings in Italian that showed words receiving a stress mark in the final letter to benefit from a processing advantage due to the salient position of the diacritic that accelerates the lexical search in the orthographic representations by confining the group of potential word candidates (Cubelli & Beschin, 2005). In the context of letter position encoding literature, the exterior letter position advantage has been implemented by leading computational models (Davis, 2010; Whitney, 2001; 2007) that posit simultaneous activations of all letter positions, an implementation in accordance with the properties of direct lexical access that is expected to take place with high-frequency stimuli. This possibility is further explored and discussed in the modelling approach adopted and presented in the subsequent section of this chapter.

Nonetheless, the emergence of a positional effect of stress diacritics with real-word stimuli constitutes evidence for the potential encoding of the stress diacritic in the orthographic lexicon. Hence, although the diacritic seems to be processed as an independent unit, its gradual embedding in the orthographic representations of the mental lexicon that comes with reading maturity and continuous encounters of

the visual form of real words cannot be precluded. To summarise, Experiment 1 (Chapter 3) in lexical decision showed evidence of stress functioning on the phonological and orthographic level and being represented in both the phonological lexicon, the orthographic lexicon, and the letter level.

Subsequently, a lexical decision experiment with tri and tetrasyllabic words (Experiment 2, Chapter 3) was conducted that aimed to disentangle any advantage emerging with the prefinal syllable of disyllabic words, either as a result of the default pattern or because this syllable simply occurs prior to the final one within the context of serial processing. The unexpected pattern of a positional disadvantage of the antepenultimate syllable rather than the hypothesised advantage of the prefinal led to further investigations regarding the default bias in Experiment 3, with better controlled trisyllabic stimuli. Additionally, the experimental procedure employed in Experiment 3 did not apply the 500 ms presentation duration of each item on screen. This choice was made because it was postulated that the unexpected pattern in Experiment 2 of the same chapter could be due to the utilisation of longer stimuli (three or four syllables) the processing of which could not be naturally completed by participants within this time window. In Experiment 3, the metrical pattern advantage was indeed elicited over the other two positions in this experiment but, importantly, it was not only observed with the grammatical category of nouns that internally present the statistical dominance of words stressed on the prefinal, but also with adjectives that do not present this preponderance. This raises questions regarding the origin of the default pattern in Greek which, unlike English, does not seem to emerge from neighbourhood activations of specific grammatical categories. Rather, either the relative dominance of this position when compared to each of the other positions on the entire language battery establishes a positional advantage for any lexical unit, or, alternatively, it arises from some structural property of the language that has not been identified so far by research.

Manipulation of the grammatical category in the latter experiment was made possible after the work carried out for the development of GreekLex 2 which is described in Chapter 4. More specifically, the within-grammatical groups statistical dominance of different syllabic positions in other languages such as English (Arciuli & Cupples, 2006) led to the investigation of this possibility for Greek. So far,

statistical calculations regarding the syllabic position of stress in Greek had solely elicited the relative dominance of prefinal syllable when specifically compared to the other possible ones rather than the entirety of the remaining battery of lexical units (Protopapas, 2006; Protopapas & Vlahou, 2009). The calculation of grammatical class and syllabic information for GreekLex 2 allowed novel analyses showing that also in Greek the prefinal dominance is not uniformal but rather depends upon grammatical category. Additionally, calculations of stress and rime neighbourhood showed that, in accordance with other languages, final letter strings in Greek words also bare information that has predictive value on stress position. It remains to be confirmed behaviourally whether this information is utilised by Greek readers when assigning stress, although initial investigations seem to point towards this direction (Grimani & Protopapas; 2016). The scripts used to perform the tasks of syllabic parsing and orthography-to-phonology conversions have been made freely available in hope of assisting the enhancement of other databases in development with this information.

Finally, the subsequent chapter started with a comparison of the linguistic properties of stress in several European orthographies, with a specific emphasis on the level that it is orthographically marked in each system as well as the way stress information interacts with and shapes the reading process. The great variety of characteristics across languages in this aspect mandates independent investigations and data collection before a set of universal properties can be de developed that functions beyond the considerable diversity of different writing systems. English is a language that presents many differences in comparison to Greek when considering stress; it is not explicitly marked orthographically with diacritics but orthographic cues of written words carry information regarding its position. Part of the stress research in English has investigated the function of the default bias but with inconclusive results on whether it also has a behavioural dimension (Brown, Lupker, & Colombo, 1994; Monsell, Doyle, & Haggard, 1989; Rastle & Coltheart, 2000). In an attempt to shed light on this issue, a naming experiment was carried out in which orthographic contributions were ruled out by the use of disyllabic minimal stress pairs (e.g. **ò**bject vs. obj**è**ct). This way, the strength of lexical activations either favouring the prefinal or final syllable of each critical item were directly compared against the default bias. Results showed that participants stressed these items in agreement to the

dominant representation, that is, the entry with the highest frequency between the two in an English psycholinguistic database, but no tendency to stress the prefinal syllable more often than the final. Hence, it was concluded that the default bias, if existent in English, has much weaker contributions in stress assignment than directly retrieving stress position from the phonological representations. In a follow-up experiment utilising the same critical items, it was shown that participants were prone to shift their stressing strategies against the lexically dominant stress position when they were primed to stress the competing position. This was taken as evidence that stress assignment in English does not entirely rely on lexical retrieval but might be partly computed. However, even in this experiment lexical retrieval was the most consistent and reliable strategy of the readers. In future research, it remains to be established what the preferred strategy of the readers is when lexical contributions are directly compared against orthographic cues.

The chapter on English stress assignment also reported the results of computational simulations with the CDP++ model that can shed some light to the latter question. When using minimal pairs whose orthographic patterns indicated a stress position opposite to the position of the dominant entry of each minimal pair (based on the frequencies of the two in the training lexicon), in 85% of cases the produced output from the model was the entry with the highest frequency. Hence, the way this model is currently wired seems to place lexical activations higher than orthographic cues on the hierarchy of importance among the sources of information on stress position. However, an item-level analysis of a subset of the minimal pairs used in the behavioural experiments that was present in the model's lexicon showed a poor level of agreement (50%) between the preferred position by humans and the output of the simulation. But, in fairness to the model, that has been proven able to successfully simulate a wide range of behavioural patterns, the reasons behind these inconsistencies might lie in the word frequencies of the minimal pairs in the training lexicon rather than its architecture or parameterisation.

In conclusion, a brief comparison between two languages with variant stress that have been studied in this thesis shows significant differences in their mechanisms of assigning stress to polysyllabic words.

While in Greek stress seems to be encoded on various levels of representation involving both phonology and orthography, in English it is only represented on the phonological level. However, contributions of orthography on stress assignment in English are also apparent through the development of associations between orthographic patterns and stressed syllabic positions. Therefore, orthography is indirectly affecting the phonological output on this aspect although there is no overt and straightforward rule that can be extracted from these associations that could be expressed in a confined set of linguistic rules. In Greek, on the other hand, the contributions of orthography to stress assignment are more straightforward by the presence of orthographic diacritics. This justifies the evidence that stress is encoded in the orthographic lexicon as an embedded part of the orthographic representation and also directly decoded on the letter level by functioning as an independent unit. But phonology also has an integral role in this process and interacts with the orthographic information when available. In the absence of strong lexical activations, conformance to the default pattern is also a strategy that, despite being imperfect, was shown to remain active in skilled Greek reading. This contrasts the evidence we acquired in the English experiments in which the elsewhere observed and reported in the literature default pattern did not manifest itself in any aspect of the present data. The following section summarises an initial attempt to incorporate the theoretical implications that have been concluded in this thesis in a preliminary computational model and the results from simulations to evaluate the architecture of this implementation.

6.2 Computational simulations

This chapter describes results of simulations performed with an Interactive Activation model (IA, McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). The aim was to simulate patterns of results acquired in the behavioural data in word recognition that were discussed in the previous sections. This model was implemented in a python version of the IA model developed by van Heuven (available at: http://www.psychology.nottingham.ac.uk/staff/wvh/). A very brief introduction of the main characteristics of the model is followed by preliminary results from simulations.

6.2.1 Model overview

The Interactive Activation model is a connectionist model that intends to capture general properties of neuronal populations and forms the basis of many currently state-of-the-art computational models (DRC, Coltheart et al., 2001; CDP++, Perry et al., 2010) that are hand-wired, in the sense that they do not rely on statistical learning methods such as back-propagation but rather have all their parameters explicitly set by the experimenter. Hence, it belongs to the family of localist models, which include representational units at the word level, as opposed to distributed models emerging from back-propagation. Its interactive architecture allows activations to flow in both directions between adjacent levels and occurs in a parallel manner; all letter positions fire simultaneously from the first cycle. Importantly, it only represents language on the level of orthography while phonology and semantics are not considered. The version used here has two levels of representation, letters and words. For purposes of simplicity, the feature level, that IA model originally used as an additional level before letters, has been deactivated. However, the current version is designed by van Heuven to simulate exactly the same output to the corresponding model that includes the feature level.

6.2.2 Preliminary results

Attempts to simulate behavioural findings focused on the word recognition data with the bisyllabic lowercase words. Because nonwords are handled on the basis of a fixed ‘time-out’, differences within

this stimulus category cannot be considered with the current version of the model. As a benchmark, the aim was to initially simulate the frequency effect and, subsequently, effects emerging from the position of stress. As a reminder, an advantage on words stressed on the final syllable has been observed in high-frequency items when stress was marked (lowercase). Simulations were performed with a subset of the stimuli used in that experiment including only 4-letter words. As shown in Figure 6.1, the basic version of the model efficiently simulates the frequency effect but expectedly not any stress effect (in the figure, the output of the simulation is indicatively compared to the effect elicited by the high-frequency words). In an independent measures 2x2 by-item analysis with frequency and stress position, there was a main effect of frequency ($F_2(1, 64) = 42.3$, $p < .001$, $\eta_p^2 = .04$) with a lower number of cycles ($M = 24.1$, $SD = 0.70$) for the high- compared to the low-frequency items ($M = 26.6$, $SD = 2.03$), no main effect of stress position ($p > 0.5$) and no interaction ($p > 0.5$).

However, in computational modelling, letters are regarded as abstract units once they get past the feature level. Theoretical implications of the results from the lexical decision experiment with the disyllabic stimuli suggest that stress should have an orthographic dimension on the representations of the input lexicon. The representation of stressed letters as different units seems to produce some interesting patterns. As seen in Figure 6.2, the presence of the diacritics appears to constrain activations to fewer candidates. In the uppercase version of the model, the second closer word in the lexicon to the input ΑΓΟΡΑ is seemingly ΑΓΟΡΙ. However, when using the lowercase, stressed versions of the words in the training lexicon, the different position of stress between the two items leads to the competing candidate not surpassing the activation threshold (αγορά – αγόρι). Weaker competition is also reflected in recognition time that is faster in lowercase.

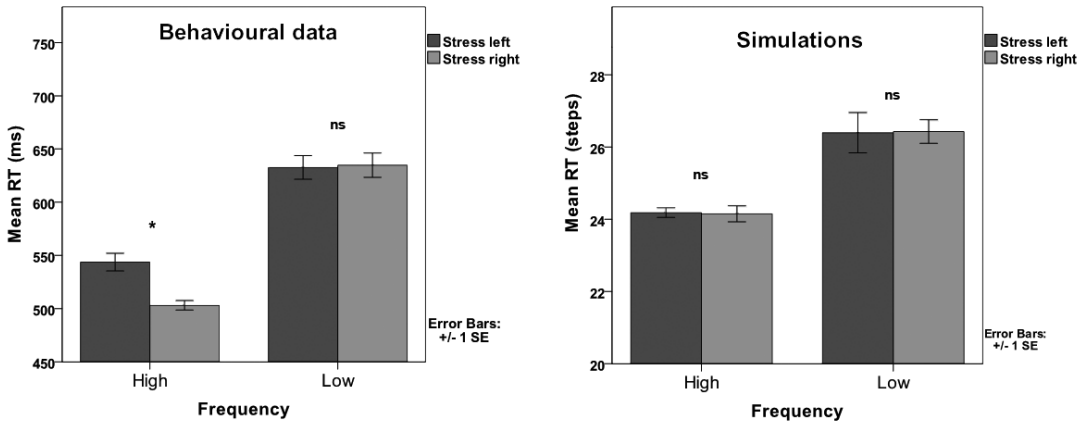


Figure 6. 1 Comparison of results between Experiment 1 of Chapter 3 and computational simulations with disyllabic Greek words.

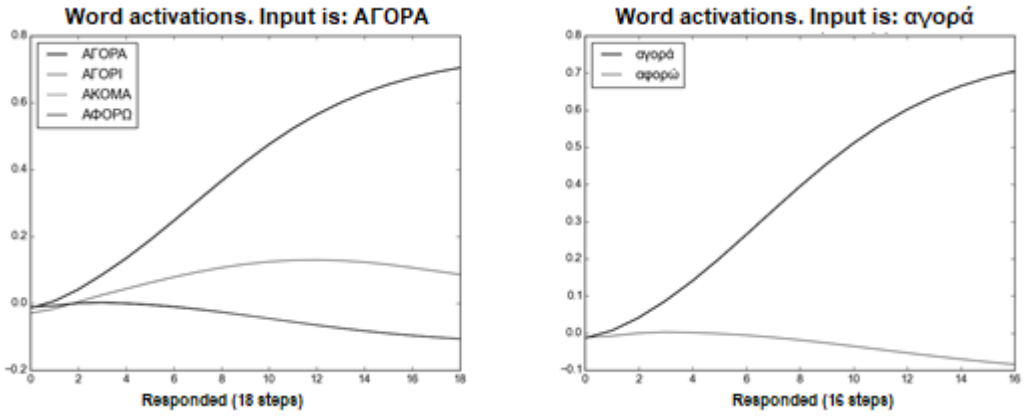


Figure 6. 2 Comparison of the activations of a Greek interactive activation model between the same input word in upper and lowercase.

6.2.3 Theoretical assumptions and model enhancements

Beyond using the lowercase version of words, the major advancement to the basic IA model was to represent stress position at a separate level. To achieve this, stress positions of the disyllabic entries in the input lexicon were retrieved from GreekLex 2 (see Chapter 4) and separately encoded as 1 (final) or 2 (prefinal). This distinction was used for the two nodes of the additional stress layer. Then associations were not calculated only between letters and words in the input lexicon, but also between each of these two levels and the intermittent stress layer. However, the connections between the letter level and the stress level were only of excitatory but not inhibitory nature. The parameter set with all the connections between the levels is presented in Table 6.1 and a schematic representation of the emerging model's architecture is presented in Figure 6.3. Finally, an additional enhancement to the model was to extend it to receive output of different word lengths, between four and eight letters. To achieve this, a template of eight positions was used and the empty slots were represented by dots. Hence, lexical entries of different lengths to the input word are inhibited by the missing letters in the template. For example, as illustrated in Figure 6.4, the entry *κάνει* will receive inhibition from the input word *κάνω* from the fourth (ω) and fifth (.) slot.

Table 6. 1 Parameter set of the excitatory and inhibitory connections between the different layers of the model used in the lexical decision simulations.

Parameter	Value
Letter-word excitation	0.03
Letter-word inhibition	0.06
Word-word inhibition	0.21
Word-letter excitation	0.3
Letter-stress excitation	0.07
Stress-word excitation	0.1
Stress-word inhibition	0.05

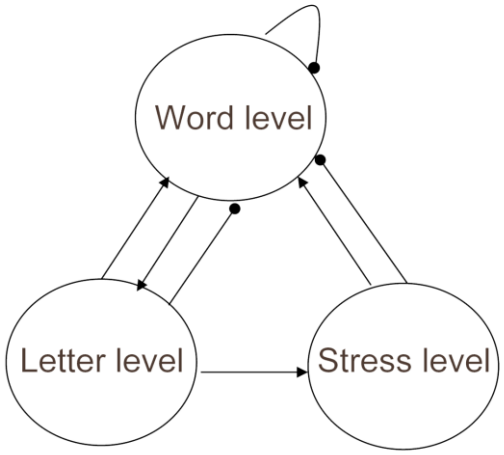


Figure 6. 3 Schematic representation of the enhanced interactive activation model with the additional layer of stress and the nature of the connections between different levels of representation.

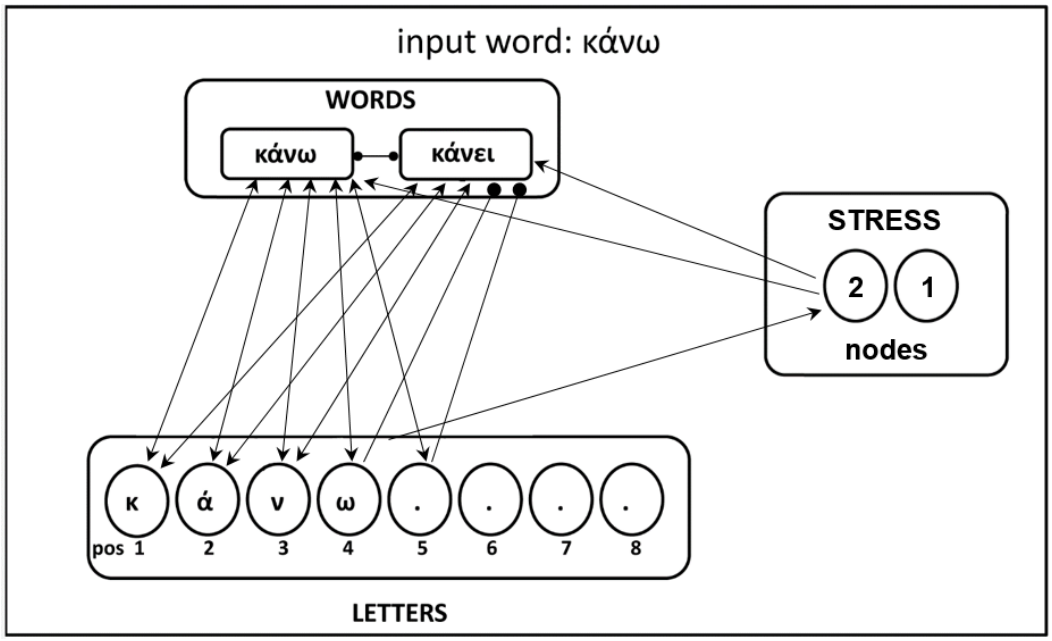


Figure 6. 4 Example of the implementation of the template approach in the interactive activation model to accommodate input that varies in length, and the resulting excitatory and inhibitory activations.

A behavioural pattern that was attempted to be simulated was the faster reaction times in recognising lowercase, high-frequency words that were stressed on the final compared to the prefinal syllable. This was attributed to the fact that stress on the final syllable typically occurs on the final letter of the word and exterior positions have been argued to benefit from a processing advantage over interior positions in several models of letter position encoding. Indicatively, Whitney, (2008) describes the architecture of the SERIOL model as different between the lexical and sublexical routes because only in the former one, additional excitation is induced to the word level from the final letter, which is not the case in the sublexical route. This resonates with the fact that the final-letter advantage was only observed in high-frequency items in which the lexical route should be more dominant, but not low-frequency items, in which the sublexical route is expected to be the predominant one. To simulate this implementation in the present model, both excitatory and inhibitory connections between the exterior letters and the other two layers were consistently accented by a constant factor. Input words are parsed by the model into a letter position template, but also parsed in the two comprising syllables (utilising the syllabifying software described in Chapter 4), and subsequently the stressed position is identified. No other use of the syllabic information is employed by the model. However, this process suffices for the letter level to be able to feed information to the stress level regarding stress position.

The implementations described above were shown to be adequate to simulate the positional effect observed with high-frequency items. A simulation that was performed with the high-frequency words that were used in the behavioural experiment showed that those stressed on the final elicited responses in significantly ($t(39) = 2.66$, $p = .011$, $d = 1.6$) fewer cycles ($M = 15.8$, $SD = 1.17$) than those stressed on the prefinal syllable ($M = 16.7$, $SD = 0.90$). However, a model that would be able to simulate the results of this study in their entirety has not yet been developed. For example, such an effect should not be elicited in simulations with low-frequency stimuli because the effects of serial processing should not allow exterior positional advantages to emerge. It would be easy to implement a cut-off point to prohibit emergence of the external positions accentuation based on the input word's initial activation resulting from the frequency of occurrence, but this would be far too artificial and not informative on the 'horse race' between the lexical and sublexical process. The purpose of this

simulation was merely to investigate whether the behavioural results could be replicated computationally by implementing specific theoretical postulations, which was shown to be the case. To simulate the interaction between lexical and sublexical processes, a dual-route architecture would be imperative.

6.3 Outlook

This thesis was conducted with the aim of investigating the stress assignment mechanisms in two languages, Greek and English. Experimental work in Greek highlighted that the process of stress assignment in this language receives contributions from both the phonological and orthographic domain. It also produced evidence that stress information is encoded on different levels of representations in the native-Greek speaker's reading system; the phonological output representations, the orthographic input lexicon, and the letter level where orthographic stress diacritics are functioning as independent processing units. Qualitative analyses have highlighted another potential source of information, the orthographic and phonological word endings that present a high level of predictability regarding stress position. Future research needs to directly investigate this factor in experimental designs aiming to study stress assignment in Greek. Finally, qualitative and behavioural investigations in regard to the metrical bias have shown that this is an active source of information but its effect diminishes in the presence of other cues indicating stress position. However, it was shown that despite the relative statistical dominance of this pattern in the language's battery, its contributions to stress assignment, when in effect, appear uniformal and do not solely emerge in stressing words coming from the lexical neighbourhoods that the pattern originates from.

In contrast, the experiments in English did not yield any evidence supporting the debated in the literature effect of the default metrical pattern which was not manifested in the presence of lexical activations. However, by eliciting positional effects in stress assignment it was shown that stress in English reading might still be partly computed and partly lexically retrieved. Future investigations regarding this issue in English should focus on directly exploring the relative contributions of these two sources of stress position information in the English reading system. While several computational approaches regarding polysyllabic reading in English address the problem of stress assignment by means of calculating its position from orthography, utilisation of identical orthographic patterns with multiple alternative stress positions that result in different lexical entries highlighted why this approach cannot be adequate on each own to tackle the stress assignment problem. Comparisons of the

behavioural results to the output of a leading computational model, CDP++, showed suboptimal performance which suggests that further work might be necessary to accommodate such results.

Finally, comprehensive analyses of the characteristics of Greek orthography resulted in the publication of a lexical database, GreekLex 2, which offers new information (e.g. part-of-speech), alternatively calculated variables in comparison to previous sources (e.g. syllabic units), and results of qualitative analyses that might be informing future experimentations in this language. Freely available software tools that were created in the development of this database are provided in hope that they will be used for the development of future databases with corresponding information.

Part of this software has been also used for the development of a primitive model in Greek visual word recognition in an attempt to provide some theoretical justification for the assumptions adopted in the discussion of the experimental results reported in the thesis. As no other results of computational simulations have been reported so far in the reading literature regarding Greek, it is aspired that these attempts might be the initial step to develop a fully working computational model of reading Greek polysyllabic input by the author of this thesis.

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APPENDICES

Appendix A - Experimental materials used in Chapter 2

Table A. 1 List of the disyllabic stimuli used in Experiment 1 of Chapter 2 (and Experiment 1 of Chapter 3).

Words				Nonwords			
High Frequency		Low Frequency		Prefinal		Final	
Prefinal	Final	Prefinal	Final				
αίμα	αργά	βάφω	βαφή	άρτε	μέλδον	αιρά	ορπή
γύρω	αρχή	βίος	γοργός	βάος	μέμα	αρζί	παζώ
δέκα	κακό	βόας	θωρώ	βίλω	μπέγος	βαπί	πηρί
ζώνη	καλά	βόλι	κερί	βόνω	μύμη	βοκή	πηρώ
θέλω	καρδιά	γίδα	κιλό	γόκη	νέμα	γιλή	πιρά
θέμα	κατά	γνάθος	κινώ	γόπι	νήρα	γναρός	ποξή
θέση	μαζί	γόβα	κοπή	γύτα	ξέση	γορτής	ποτή
κάθε	μετά	γόμα	λιτή	θέχη	όρτι	δελύ	ρολί
κάτι	νερό	έλκω	μαμή	θώβα	πάκα	ζανώ	στιπός
λέξη	νησί	ζάρι	μπερές	κάμη	πέμα	ζωρά	σχεγμή
μάχη	ξανά	θήκη	ορδή	κάρπει	πρέλον	θελά	τορί
μέλλον	πηγή	μύδι	ορθό	κάσω	σίχη	θενή	τροδιά
ξέρω	πολύ	ξύνω	παπί	κέδη	τάλο	θηζή	τωρώ
πίσω	σιγά	πήζω	πατώ	κίθο	τάνη	καγά	φαλά
πρέπει	στιγμή	πόκα	πεζή	κόδι	τίκα	καμή	φοπή
τάξη	σχεδόν	τάζω	ροπή	κόνα	χάκω	κιζώ	φορρίς
τρόπος	τιμή	τόπι	φακή	λέτα	χλώτος	μαρώ	φωξή
τώρα	φωνή	φόλα	χαλώ	λίδα	χώθε	νορί	χατί
χέρι	χαρά	φόρτος	χλωρός	μάλω	ψάλθος	ξαρά	χερό
χώρα	ψυχή	ψάλτης	ψιλή	μάφη	ψύσι	ξυτώ	ψιφώ

Note: Prefinal and Final refer to the syllabic position of stress

Table A. 2 Translations of real-word stimuli used in Experiment 1 of Chapter 2 (and Experiment 1 of Chapter 3).

High Frequency				Low Frequency			
Prefinal		Final		Prefinal		Final	
αίμα	blood	αργά	late	βάφω	(I) paint	βαφή	paint
γύρω	around	αρχή	start	βίος	life	γοργός	fast
δέκα	ten	κακό	bad	βόας	boa	θωρώ	(I) look
ζώνη	belt	καλά	well	βόλι	shot	κερί	candle
θέλω	(I) want	καρδιά	heart	γίδα	goat	κιλό	kilo
θέμα	subject	κατά	against	γνάθος	jaw	κινώ	(I) move
θέση	position	μαζί	together	γόβα	pump	κοπή	cut
κάθε	every	μετά	after	γόμα	rubber	λιτή	lean
κάτι	something	νερό	water	έλκω	(I) pull	μαμή	midwife
λέξη	word	νησί	island	ζάρι	dice	μπερές	beret
μάχη	battle	ξανά	again	θήκη	case	ορδή	horde
μέλλον	future	πηγή	source	μύδι	mussel	ορθό	correct
ξέρω	(I) know	πολύ	much	ξύνω	(I) scratch	παπί	duck
πίσω	back	σιγά	slowly	πήζω	(I) congeal	πατώ	(I) step
πρέπει	must	στιγμή	moment	πόκα	(card game)	πεζή	on foot
τάξη	class	σχεδόν	almost	τάζω	(I) promise	ροπή	inclination
τρόπος	way	τιμή	price	τόπι	ball	φακή	lentil
τώρα	now	φωνή	voice	φόλα	poisoned bait	χαλώ	(I) damage
χέρι	hand	χαρά	happiness	φόρτος	burden	χλωρός	verdant
χώρα	country	ψυχή	soul	ψάλτης	chanter	ψιλή	thin

Note: Prefinal and Final refer to the syllabic position of stress

Table A. 3 List of the monosyllabic stimuli used in Experiment 2 of Chapter 2, and the root words that the nonwords were generated from.

Words		Nonwords			
High Frequency	Low Frequency	Root word	Nonword	Root word	Nonword
βγει	βγες	μυς	λυς	βρω	γρω
βρει	βρες	δες	δας	συν	δυν
γεια	γαρ	πας	πης	πυρ	παρ
γης	δρας	μπω	πρη	θες	θος
γιος	δρυς	τρως	τρες	στου	στει
ζει	δρω	μπας	φρας	ζεις	φους
ζουν	καις	στης	σπης	μεις	θοις
λες	κυρ	πουν	γαιν	καιν	κειν
ματς	λουξ	δουν	δοιν	παις	ρεις
μπαρ	μπες	φευ	φει	στων	κλων
μπει	πλους	σεις	σοις	τρις	κλις
πλην	ρουζ	χεις	κεις	δεις	βαις
πριν	ρους	φλου	φλει	πεις	πλες
προς	σκαν	μπλε	ντρε	νους	ντις
σκορ	σκας	σταρ	στερ	γκρι	γκρε
στους	σνακ	κλιπ	κλεπ	τζιν	τραν
τεστ	τρων	γκολ	γρολ	μπολ	κρολ
τρεις	τσεκ	στυλ	σταλ	τρακ	τροκ
φως	φταις	ρθεις	θροις	κλαις	γραις
χθες	ψες	μπρος	ντρος	μπεις	γλεις

Table A. 4 Translations of the real-word monosyllabic stimuli used in Experiment 2 of Chapter 2, and of the root words that the nonwords were generated from.

Words				Nonwords			
High Frequency		Low Frequency		Root word		Root word	
βγει	(she' ll) exit	βγες	(you) exit (imper.)	μυς	muscle	βρω	(I' ll) find
βρει	(she' ll) find	βρες	(you) find (imper.)	δες	(you) see (imper.)	συν	plus
γεια	hi	γαρ	because	πας	(you) go	πυρ	arm
γης	earth	δρας	(you) act	μπω	(I' ll) enter	θες	(you) want
γιος	son	δρυς	oak	τρως	(you) eat	στου	(article, sing., masc., genitive)
ζει	(she) lives	δρω	(I) act	μπας	in case	ζεις	(you) live
ζουν	(they) live	καις	(you) burn	στης	(article, sing., fem., genitive)	μεις	we
λες	(you) say	κυρ	mister	πουν	(they' ll) say	καιν	(they) burn
ματς	game	λουξ	luxurious	δουν	(they' ll) see	παις	child
μπαρ	bar	μπες	(you) enter (imper.)	φευ	alas	στων	(article, plural., masc., genitive)
μπει	(she' ll) enter	πλους	sail	σεις	you	τρις	three times
πλην	minus	ρουζ	blush	χεις	(you've) got	δεις	(you' ll) see
πριν	before	ρους	course	φλου	vague	πεις	(you' ll) say
προς	toward	σκαν	(they) explode	μπλε	blue	νους	mind
σκορ	score	σκας	(you) explode	σταρ	star	γκρι	grey
στους	(article, plural, masc. dative)	σνακ	snack	κλιπ	clip	τζιν	jean
τεστ	test	τρων	(they) eat	γκολ	goal	μπολ	bowl
τρεις	three	τσεκ	check	στυλ	style	τρακ	nervoussness
φως	light	φταις	(you) are at fault	ρθεις	(you'll) come	κλαις	(you) cry
χθες	yesterday	ψες	yesterday	μπρος	forward	μπεις	(you' ll) enter

Note. masc: masculine gender, fem.: feminine gender, sing.: singular number, imper.: imperative.

Table A. 5 Item-level measurements regarding response time and accuracy of all word stimuli used in the reading aloud experiments (involving monosyllabic and disyllabic items) in Chapter 2.

Item	Stress	Frequency	Syllables	Response Time (ms)	Accuracy (%)	Uppercase	Response Time (ms)	Accuracy (%)
αίμα	prefinal	high	2	479	100	ΑΙΜΑ	512	100
αργά	final	high	2	462	100	ΑΡΓΑ	537	93.8
αρχή	final	high	2	442	100	ΑΡΧΗ	457	100
βαφή	final	low	2	501	93.8	ΒΑΦΗ	525	96.8
βάφω	prefinal	low	2	472	100	ΒΑΦΩ	540	100
βγει	-	high	1	439	100	ΒΓΕΙ	448	100
βγες	-	low	1	428	100	ΒΓΕΣ	452	95.8
βίος	prefinal	low	2	481	100	ΒΙΟΣ	515	100
βόας	prefinal	low	2	480	100	ΒΟΑΣ	523	100
βόλι	prefinal	low	2	477	100	ΒΟΛΙ	547	84.4
βρει	-	high	1	438	95.8	ΒΡΕΙ	448	75
βρες	-	low	1	453	91.7	ΒΡΕΣ	460	83.3
γαρ	-	low	1	437	95.8	ΓΑΡ	462	100
γεια	-	high	1	412	100	ΓΕΙΑ	484	100
γης	-	high	1	429	100	ΓΗΣ	452	100
γίδα	prefinal	low	2	463	100	ΓΙΔΑ	505	100
γιος	-	high	1	425	100	ΓΙΟΣ	485	100
γνάθος	prefinal	low	2	481	96.9	ΓΝΑΘΟΣ	526	100
γόβα	prefinal	low	2	475	100	ΓΟΒΑ	514	100
γόμα	prefinal	low	2	476	100	ΓΟΜΑ	505	100
γοργός	final	low	2	499	100	ΓΟΡΓΟΣ	583	68.8
γύρω	prefinal	high	2	474	100	ΓΥΡΩ	515	96.9
δέκα	prefinal	high	2	463	100	ΔΕΚΑ	504	100
δρας	-	low	1	440	100	ΔΡΑΣ	451	95.8
δρυς	-	low	1	440	100	ΔΡΥΣ	457	100
δρω	-	low	1	427	100	ΔΡΩ	454	100
έλκω	prefinal	low	2	473	100	ΕΛΚΩ	519	96.9
ζάρι	prefinal	low	2	464	100	ΖΑΡΙ	504	100
ζει	-	high	1	431	100	ΖΕΙ	432	100
ζουν	-	high	1	427	100	ΖΟΥΝ	425	100
ζώνη	prefinal	high	2	444	100	ΖΩΝΗ	490	100
θέλω	prefinal	high	2	452	100	ΘΕΛΩ	461	100
θέμα	prefinal	high	2	440	100	ΘΕΜΑ	473	100
θέση	prefinal	high	2	439	100	ΘΕΣΗ	467	100
θήκη	prefinal	low	2	475	100	ΘΗΚΗ	540	100
θωρώ	final	low	2	433	93.8	ΘΩΡΩ	494	96.9
κάθε	prefinal	high	2	480	100	ΚΑΘΕ	533	100
καις	-	low	1	515	100	ΚΑΙΣ	539	75
κακό	final	high	2	426	96.9	ΚΑΚΟ	481	100
καλά	final	high	2	491	100	ΚΑΛΑ	560	93.8
καρδιά	final	high	2	479	100	ΚΑΡΔΙΑ	490	100
κατά	final	high	2	488	100	ΚΑΤΑ	551	93.8

κάτι	prefinal	high	2	507	100	ΚΑΤΙ	531	100
κερί	final	low	2	483	100	ΚΕΡΙ	516	81.2
κιλό	final	low	2	466	100	ΚΙΛΟ	515	96.9
κινώ	final	low	2	475	100	ΚΙΝΩ	535	90.6
κοπή	final	low	2	479	100	ΚΟΠΗ	530	87.5
κυρ	-	low	1	464	100	ΚΥΡ	478	100
λέξη	prefinal	high	2	467	96.9	ΛΕΞΗ	501	100
λες	-	high	1	432	100	ΛΕΣ	438	100
λιτή	final	low	2	466	100	ΛΙΤΗ	533	87.1
λουξ	-	low	1	484	100	ΛΟΥΞ	504	100
μαζί	final	high	2	449	96.9	ΜΑΖΙ	486	100
μαμή	final	low	2	467	100	ΜΑΜΗ	566	75
ματς	-	high	1	450	100	ΜΑΤΣ	480	100
μάχη	prefinal	high	2	463	100	ΜΑΧΗ	527	93.3
μέλλον	prefinal	high	2	451	100	ΜΕΛΛΟΝ	498	96.9
μετά	final	high	2	463	100	ΜΕΤΑ	498	93.8
μπαρ	-	high	1	441	95.8	ΜΠΑΡ	437	100
μπει	-	high	1	430	100	ΜΠΕΙ	435	95.8
μπερές	final	low	2	510	96.9	ΜΠΕΡΕΣ	548	87.5
μπες	-	low	1	420	100	ΜΠΕΣ	424	100
μύδι	prefinal	low	2	475	100	ΜΥΔΙ	511	100
νερό	final	high	2	452	100	ΝΕΡΟ	483	96.8
νησί	final	high	2	451	100	ΝΗΣΙ	488	100
ξανά	final	high	2	439	100	ΞΑΝΑ	493	100
ξέρω	prefinal	high	2	478	100	ΞΕΡΩ	498	100
ξύνω	prefinal	low	2	493	100	ΞΥΝΩ	543	100
ορδή	final	low	2	465	93.8	ΟΡΔΗ	530	96.8
ορθό	final	low	2	471	96.8	ΟΡΘΟ	522	90.6
παπί	final	low	2	497	100	ΠΑΠΙ	541	93.8
πατώ	final	low	2	486	100	ΠΑΤΩ	551	77.4
πεζή	final	low	2	487	100	ΠΕΖΗ	571	90.6
πηγή	final	high	2	474	100	ΠΗΓΗ	557	96.9
πήζω	prefinal	low	2	507	100	ΠΗΖΩ	540	100
πίσω	prefinal	high	2	473	100	ΠΙΣΩ	505	100
πλην	-	high	1	449	100	ΠΛΗΝ	463	100
πλους	-	low	1	473	100	ΠΛΟΥΣ	473	100
πόκα	prefinal	low	2	500	100	ΠΟΚΑ	563	100
πολύ	final	high	2	486	100	ΠΟΛΥ	530	96.9
πρέπει	prefinal	high	2	483	100	ΠΡΕΠΕΙ	548	100
πριν	-	high	1	466	95.8	ΠΡΙΝ	465	100
προς	-	high	1	445	100	ΠΡΟΣ	468	100
ροπή	final	low	2	460	100	ΡΟΠΗ	513	93.8
ρουζ	-	low	1	450	95.8	ΡΟΥΖ	476	100
ρους	-	low	1	442	100	ΡΟΥΣ	451	100
σιγά	final	high	2	416	100	ΣΙΓΑ	476	100
σκαν	-	low	1	431	100	ΣΚΑΝ	429	100

σκας	-	low	1	408	95.8	ΣΚΑΣ	434	100
σκορ	-	high	1	413	95.8	ΣΚΟΡ	422	100
σνακ	-	low	1	399	95.8	ΣΝΑΚ	409	100
στιγμή	final	high	2	462	100	ΣΤΙΓΜΗ	492	96.9
στους	-	high	1	410	100	ΣΤΟΥΣ	416	95.7
σχεδόν	final	high	2	419	100	ΣΧΕΔΟΝ	454	100
τάζω	prefinal	low	2	494	100	ΤΑΖΩ	535	100
τάξη	prefinal	high	2	462	100	ΤΑΞΗ	514	96.9
τεστ	-	high	1	475	100	ΤΕΣΤ	498	100
τιμή	final	high	2	478	100	ΤΙΜΗ	517	100
τόπι	prefinal	low	2	506	100	ΤΟΠΙ	563	100
τρεις	-	high	1	471	100	ΤΡΕΙΣ	495	95.7
τρόπος	prefinal	high	2	477	100	ΤΡΟΠΟΣ	545	100
τρων	-	low	1	460	100	ΤΡΩΝ	498	100
τσεκ	-	low	1	474	100	ΤΣΕΚ	495	100
τώρα	prefinal	high	2	478	100	ΤΩΡΑ	523	100
φακή	final	low	2	434	96.8	ΦΑΚΗ	471	96.9
φόλα	prefinal	low	2	427	100	ΦΟΛΑ	497	90.3
φόρτος	prefinal	low	2	456	100	ΦΟΡΤΟΣ	495	96.9
φταις	-	low	1	412	95.8	ΦΤΑΙΣ	464	100
φωνή	final	high	2	414	96.9	ΦΩΝΗ	454	100
φως	-	high	1	398	100	ΦΩΣ	397	100
χαλώ	final	low	2	431	100	ΧΑΛΩ	465	78.1
χαρά	final	high	2	444	96.9	ΧΑΡΑ	469	100
χέρι	prefinal	high	2	493	100	ΧΕΡΙ	513	100
χθες	-	high	1	414	100	ΧΘΕΣ	416	100
χλωρός	final	low	2	433	96.9	ΧΛΩΡΟΣ	468	90.6
χώρα	prefinal	high	2	416	100	ΧΩΡΑ	450	100
ψάλτης	prefinal	low	2	500	100	ΨΑΛΤΗΣ	500	100
ψες	-	low	1	404	100	ΨΕΣ	408	95.8
ψιλή	final	low	2	453	100	ΨΙΛΗ	527	90.6
ψυχή	final	high	2	456	100	ΨΥΧΗ	463	100

Notes. The first Response Time (ms) and Accuracy (%) measurements presented in the table correspond to the lowercase items and the subsequent columns to the uppercase items. In the experimental sessions, all items in this table were presented for 500 ms and then disappeared from screen regardless of whether participants had input a response by the end of this period or not.

Table A. 6 Item-level measurements regarding response time and accuracy of all nonword stimuli used in the reading aloud experiments (involving monosyllabic and disyllabic items) in Chapter 2.

Item	Stress	Syllables	Response Time (ms)	Accuracy (%)	Uppercase	Response Time (ms)	Accuracy (%)
αιρά	final	2	562	100	ΑΙΡΑ	614	86.2
αρζί	final	2	490	96.9	ΑΡΖΙ	567	87.1
άρτε	prefinal	2	495	100	ΑΡΤΕ	557	96.9
βαις	-	1	473	73.9	ΒΑΙΣ	540	72.7
βάος	prefinal	2	496	100	ΒΑΟΣ	571	100
βαπί	final	2	481	100	ΒΑΠΙ	572	100
βίλω	prefinal	2	475	100	ΒΙΛΩ	570	93.5
βοκή	final	2	486	93.8	ΒΟΚΗ	591	100
βόνω	prefinal	2	470	100	ΒΟΝΩ	542	100
γαιν	-	1	521	76.2	ΓΑΙΝ	543	84.2
γιλή	final	2	483	100	ΓΙΛΗ	543	96.9
γκρε	-	1	493	100	ΓΚΡΕ	503	95.5
γλεις	-	1	504	91.3	ΓΛΕΙΣ	514	91.7
γναρός	final	2	493	93.8	ΓΝΑΡΟΣ	545	100
γόκη	prefinal	2	485	93.8	ΓΟΚΗ	545	100
γόπι	prefinal	2	481	96.8	ΓΟΠΙ	562	100
γορτής	final	2	547	74.2	ΓΟΡΤΗΣ	618	93.5
γραις	-	1	484	83.3	ΓΡΑΙΣ	539	86.4
γρολ	-	1	476	91.3	ΓΡΟΛ	481	95.5
γρω	-	1	440	91.3	ΓΡΩ	450	87.5
γύτα	prefinal	2	480	100	ΓΥΤΑ	553	96.9
δας	-	1	442	100	ΔΑΣ	447	100
δελύ	final	2	484	96.9	ΔΕΛΥ	541	93.8
δοιν	-	1	473	91.7	ΔΟΙΝ	467	90.5
δυν	-	1	432	100	ΔΥΝ	437	100
ζανώ	final	2	488	100	ΖΑΝΩ	558	96.9
ζωρά	final	2	605	73.3	ΖΩΡΑ	593	96.9
θελά	final	2	467	100	ΘΕΛΑ	513	100
θενή	final	2	463	100	ΘΕΝΗ	563	100
θέχη	prefinal	2	487	90.6	ΘΕΧΗ	538	84.4
θηζή	final	2	439	96.9	ΘΗΖΗ	497	93.8
θοις	-	1	455	95.8	ΘΟΙΣ	455	91.7
θος	-	1	411	100	ΘΟΣ	428	100
θροις	-	1	444	100	ΘΡΟΙΣ	468	91.3
θώβα	prefinal	2	524	100	ΘΩΒΑ	648	100
καγά	final	2	522	100	ΚΑΓΑ	567	100
καμή	final	2	477	96.9	ΚΑΜΗ	601	96.6
κάμη	prefinal	2	506	100	ΚΑΜΗ	587	100
κάρπει	prefinal	2	555	96.9	ΚΑΡΠΕΙ	630	90.3
κάσω	prefinal	2	497	100	ΚΑΣΩ	580	100
κέδη	prefinal	2	499	100	ΚΕΔΗ	598	100
κειν	-	1	494	87.5	ΚΕΙΝ	565	91.7

κεις	-	1	505	100	ΚΕΙΣ	543	95.8
κιζώ	final	2	499	100	ΚΙΖΩ	552	96.8
κίθο	prefinal	2	484	100	ΚΙΘΟ	550	100
κλεπ	-	1	499	91.7	ΚΛΕΠ	519	100
κλις	-	1	485	100	ΚΛΙΣ	497	100
κλων	-	1	476	100	ΚΛΩΝ	481	100
κόδι	prefinal	2	479	100	ΚΟΔΙ	551	100
κόνα	prefinal	2	468	100	ΚΟΝΑ	565	100
κρολ	-	1	480	100	ΚΡΟΛ	507	95.8
λέτα	prefinal	2	481	100	ΛΕΤΑ	558	90.6
λίδα	prefinal	2	461	100	ΛΙΔΑ	537	100
λυς	-	1	440	100	ΛΥΣ	450	100
μάλω	prefinal	2	483	100	ΜΑΛΩ	548	96.9
μαρώ	final	2	463	100	ΜΑΡΩ	557	100
μάφη	prefinal	2	485	100	ΜΑΦΗ	567	96.7
μέλδον	prefinal	2	517	100	ΜΕΛΔΟΝ	615	71
μέμα	prefinal	2	479	96.9	ΜΕΜΑ	549	100
μπέγος	prefinal	2	512	100	ΜΠΕΓΟΣ	596	100
μύμη	prefinal	2	480	93.8	ΜΥΜΗ	595	96.8
νέμα	prefinal	2	535	93.8	ΝΕΜΑ	610	100
νήρα	prefinal	2	507	93.8	ΝΗΡΑ	571	96.8
νορί	final	2	486	96.9	ΝΟΡΙ	527	100
ντις	-	1	446	95.8	ΝΤΙΣ	464	100
ντρε	-	1	469	100	ΝΤΡΕ	467	100
ντρος	-	1	456	100	ΝΤΡΟΣ	473	95.8
ξαρά	final	2	520	100	ΞΑΡΑ	614	96.9
ξέση	prefinal	2	524	100	ΞΕΣΗ	574	93.5
ξυτώ	final	2	489	100	ΞΥΤΩ	582	100
ορπή	final	2	475	100	ΟΡΠΗ	514	96.8
όρτι	prefinal	2	531	100	ΟΡΤΙ	611	100
παζώ	final	2	534	93.8	ΠΑΖΩ	616	96.9
πάκα	prefinal	2	521	96.9	ΠΑΚΑ	611	96.9
παρ	-	1	473	100	ΠΑΡ	507	100
πέμα	prefinal	2	529	100	ΠΕΜΑ	606	100
πηρί	final	2	573	93.3	ΠΗΡΙ	687	87.5
πηρώ	final	2	497	100	ΠΗΡΩ	629	90.6
πης	-	1	466	95.8	ΠΗΣ	487	100
πιρά	final	2	498	100	ΠΙΡΑ	605	100
πλες	-	1	488	95.8	ΠΛΕΣ	487	100
ποξή	final	2	530	100	ΠΟΞΗ	621	100
ποτή	final	2	485	100	ΠΟΤΗ	581	96.6
πρέλον	prefinal	2	571	96.9	ΠΡΕΛΟΝ	671	96.6
πρη	-	1	473	100	ΠΡΗ	507	100
ρεις	-	1	496	100	ΡΕΙΣ	506	83.3
ρολί	final	2	483	100	ΡΟΛΙ	555	93.3
σίχη	prefinal	2	454	93.8	ΣΙΧΗ	515	96.9

σοις	-	1	466	87.5	ΣΟΙΣ	461	77.3
σπης	-	1	452	100	ΣΠΗΣ	429	100
σταλ	-	1	402	100	ΣΤΑΛ	422	100
στει	-	1	408	83.3	ΣΤΕΙ	426	79.2
στερ	-	1	400	91.7	ΣΤΕΡ	437	91.7
στιπός	final	2	501	96.9	ΣΤΙΠΟΣ	528	90.3
σχεγμή	final	2	532	100	ΣΧΕΓΜΗ	570	100
τάλο	prefinal	2	519	100	ΤΑΛΟ	608	100
τάνη	prefinal	2	519	100	ΤΑΝΗ	612	100
τίκα	prefinal	2	544	100	ΤΙΚΑ	590	100
τορί	final	2	437	100	ΤΟΡΙ	633	96.8
τραν	-	1	477	100	ΤΡΑΝ	508	100
τρες	-	1	482	95.8	ΤΡΕΣ	491	91.7
τροδιά	final	2	526	100	ΤΡΟΔΙΑ	606	100
τροκ	-	1	486	95.8	ΤΡΟΚ	491	95.8
τωρώ	final	2	508	100	ΤΩΡΩ	547	100
φαλά	final	2	480	96.9	ΦΑΛΑ	539	96.8
φει	-	1	446	100	ΦΕΙ	483	95.8
φλει	-	1	439	95.7	ΦΛΕΙ	448	95.8
φοπή	final	2	470	90.6	ΦΟΠΗ	516	100
φορρίς	final	2	461	96.9	ΦΟΡΡΙΣ	509	100
φους	-	1	413	100	ΦΟΥΣ	424	100
φρας	-	1	428	95.8	ΦΡΑΣ	452	95.8
φωξή	final	2	464	96.7	ΦΩΞΗ	553	90.3
χάκω	prefinal	2	464	96.9	ΧΑΚΩ	502	96.7
χατί	final	2	446	87.5	ΧΑΤΙ	504	100
χερό	final	2	469	90.6	ΧΕΡΟ	544	86.2
χλώτος	prefinal	2	450	93.8	ΧΛΩΤΟΣ	501	84.4
χώθε	prefinal	2	493	93.8	ΧΩΘΕ	527	100
ψάλθος	prefinal	2	535	100	ΨΑΛΘΟΣ	571	100
ψιφώ	final	2	495	96.9	ΨΙΦΩ	543	96.6
ψύσι	prefinal	2	520	100	ΨΥΣΙ	645	100

Notes. The first Response Time (ms) and Accuracy (%) measurements presented in the table correspond to the lowercase items and the subsequent columns to the uppercase items. In the experimental sessions, all items in this table were presented for 500 ms and then disappeared from screen regardless of whether participants had input a response by the end of this period or not.

Appendix B - Experimental materials used in Chapter 3

Table B. 1 List of the real word stimuli used in Experiment 2 of Chapter 3.

High frequency						Low frequency					
Trisyllabic			Tetrasyllabic			Trisyllabic			Tetrasyllabic		
APU	PU	U	APU	PU	U	APU	PU	U	APU	PU	U
έστειλε	παιδείας	κεντρικής	νωρίτερα	γεωργίας	αναφορά	άτολμους	βαμμένοι	ηθικοί	φιλόζωο	ιδεώδη	εξαπατώ
πρόκειται	ζητήσει	βουλευτές	διάλογο	ηλικίας	αριστερά	μέτοικοι	εκβάλλει	εραστής	διέπονται	ιερέας	επιτελώ
βρίσκονται	ανάγκες	πληθυσμού	ξεκίνησε	ιστορίας	εισαγωγή	βύσσινο	εκθέτω	εκτενώς	εξώδικο	καλοήθη	εφηβικό
είκοσι	κινήσεις	τακτική	κατάφερε	προϊόντα	επιλογή	είδησης	εκλάμψεις	χτεσινή	εξώφυλλα	θορυβώδη	υπακοής
αίτημα	χιλιάδες	αφορούν	εισόδημα	περασμένη	επιστολή	έμμετρος	εργάτης	μισητές	επέλεξα	εκλογέας	παραβολή
πάντοτε	προτάσεις	υπουργού	τουλάχιστον	ορισμένες	επιτροπή	έμπειροι	εφέσεις	ερυθρός	επίκτητη	πινακίδα	επιδρομή
άνθρωπος	σχολεία	αρχηγός	παράδειγμα	εργασίες	εφαρμογή	έναστρος	ηγείται	συνετές	επίπληξη	ταραξίες	επιφανής
τμήματος	μπορούσαν	καθεστώς	δημόσιο	γεγονότα	καθηγητής	ένστολοι	πλακώσει	δυσφορεί	θυμώνατε	τιμωρίες	πολυτελή
πλαίσιο	παιχνίδια	μεταξύ	λιγότερο	ομιλία	κοινωνική	κοίταγμα	ιδρώνει	προπονεί	ισόποσα	υπηρέτες	επιρροών
σύμβαση	ανθρώπους	αριθμός	εξέλιξη	εβδομάδα	κυπριακό	κύλινδρος	ιμάντες	πονηρούς	κατάστρωμα	σημασίες	υποτιμώ
γίνονται	γνωρίζουν	λειτουργούν	απόγευμα	ηγεσία	μεταφορά	πρόσθετοι	καινούριων	ελλιπείς	νεότητα	δομημένα	συζυγικά
ρύθμιση	συμβαίνει	μουσικής	παράδοση	επιπλέον	μοναδική	πρότεινα	οικείος	συναφείς	παγίωση	νικημένη	ερημική
θέατρο	προβλέπει	προφανώς	ζητήματα	εξαιτίας	παραγωγή	πρότυπες	ομπρέλες	αιχμηροί	παράσιτο	γεωπόνος	εξοχικές
έννοια	απόψεις	προκαλεί	διάστημα	τελευταίο	παρασκευή	πρώιμοι	ποικίλους	κατακτούν	πολύμηνη	ιδρωμένη	μοναχική
πρόγραμμα	μιλώντας	αρχικά	σενάριο	χαρακτήρα	περιοχή	πώρωση	προκρίνει	ευπρεπώς	προαύλιο	κωνοφόρα	φυλετικών
αίσθηση	εκείνος	προσφορά	επίσκεψη	παραπάνω	πολιτικό	στάσιμα	προσμένει	δυστυχείς	προσέλθουμε	προηγμένη	παροδικοί
έρχονται	πιστεύουν	ασφαλώς	περίοδο	επομένως	προοπτική	στέλνουμε	σπουργίτι	τριμελούς	υπέφεραν	ξυρισμένα	θρηνητικό
πράγματι	ακόμα	προσπαθεί	επίθεση	αποφάσεις	προσωπικό	στρέφομαι	συστήνω	σφαιρικοί	φυγόπονη	οικονόμος	υδραυλικά
πρόσφατα	κερδίσει	γυναικών	οφείλεται	εναντίον	σημερινή	σύνεση	ταυτίζουν	σκοτεινής	χιτώνιο	επιβάτης	κυματιστή
τέσσερις	δηλώσεις	δυστυχώς	διάταξη	δεδομένα	συνολικά	χείριστος	τυχαίνουν	συγκρουσθεί	χωμάτινο	αποδράσεις	μονομερής

Note. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress.

Table B. 2 Translations of the high-frequency stimuli used in Experiment 2 of Chapter 3.

Trisyllabic						Tetrasyllabic					
APU		PU		U		APU		PU		U	
έστειλε	she sent	παιδείας	education (gen.)	κεντρικής	central (gen.)	νωρίτερα	earlier	γεωργίας	agriculture (genit.)	αναφορά	reference
πρόκειται	it's about	ζητήσει	(she'll) ask	βουλευτές	congressmen	διάλογο	dialogue	ηλικίας	age (genit.)	αριστερά	left
βρίσκονται	they are located	ανάγκες	needs	πληθυσμού	population (gen.)	ξεκίνησε	(she) started	ιστορίας	history (genit.)	εισαγωγή	introduction
είκοσι	twenty	κινήσεις	movements	τακτική	tactic	κατάφερε	(she) managed	προϊόντα	products	επιλογή	choice
αίτημα	request	χιλιάδες	thousands	αφορούν	(they) concern	εισόδημα	income	περασμένη	passed (femin.)	επιστολή	epistle
πάντοτε	always	προτάσεις	proposals	υπουργού	minister (gen.)	τουλάχιστον	at least	ορισμένες	certain (femin.)	επιτροπή	committee
άνθρωπος	human	σχολεία	schools	αρχηγός	leader	παράδειγμα	example	εργασίες	works	εφαρμογή	application
τμήματος	section (gen.)	μπορούσαν	(they) could	καθεστώς	regime	δημόσιο	public	γεγονότα	events	καθηγητής	professor
πλαίσιο	framework	παιχνίδια	games	μεταξύ	between	λιγότερο	less	ομιλία	speech	κοινωνική	social (femin.)
σύμβαση	convention	ανθρώπους	humans	αριθμός	number	εξέλιξη	evolution	εβδομάδα	week	κυπριακό	cypriot
γίνονται	(they) become	γνωρίζουν	(they) know	λειτουργούν	(they) function	απόγευμα	afternoon	ηγεσία	leadership	μεταφορά	transfer
ρύθμιση	configuration	συμβαίνει	(it) happens	μουσικής	music	παράδοση	tradition	επιπλέον	furthemore	μοναδική	unique (femin.)
θέατρο	thatre	προβλέπει	(it) predicts	προφανώς	obviously	ζητήματα	issues	εξαιτίας	due to	παραγωγή	production
έννοια	meaning	απόψεις	opinions	προκαλεί	(she) provokes	διάστημα	space	τελευταίο	last (neutral)	παρασκευή	preparation
πρόγραμμα	programme	μιλώντας	(while) talking	αρχικά	initially	σενάριο	scenario	χαρακτήρα	character (accus.)	περιοχή	region
αίσθηση	sense	εκείνος	he/him	προσφορά	offer	επίσκεψη	visit	παραπάνω	additional	πολιτικό	political
έρχονται	(they're) coming	πιστεύουν	(they) believe	ασφαλώς	surely	περίοδο	period (accus.)	επομένως	therefore	προοπτική	prospect

πράγματι	indeed	ακόμα	yet	προσπαθεί	(she) tries	επίθεση	attack	αποφάσεις	decisions	προσωπικό	personnel
πρόσφατα	recently	κερδίσει	(he'll) win	γυναικών	women (gen.)	οφείλεται	(I'm) due to	εναντίον	against	σημερινή	present-day's
τέσσερις	four	δηλώσεις	statements	δυστυχώς	unfortunately	διάταξη	layout	δεδομένα	data	συνολικά	in total

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. gen: genitive (possessive) case. accus.: accusative case. femin.: feminine gender. neutral: neutral gender.

Table B. 3 Translations of the low-frequency stimuli used in Experiment 2 of Chapter 3.

Trisyllabic						Tetrasyllabic					
APU		PU		U		APU		PU		U	
άτολμους	timorous	βαμμένοι	painted (pl.)	ηθικοί	ethical (pl.)	φιλόζωο	animal-loving	ιδεώδη	ideal beliefs	εξαπατώ	(I) deceive
μέτοικοι	immigrants	εκβάλλει	(she) emits	εραστής	lover	διέπονται	(they're) governed	ιερέας	priest	επιτελώ	(I) perform
βύσσινο	sour cherry	εκθέτω	(I) expose	εκτενώς	extensively	εξώδικο	extrajudicial	καλοήθη	benign	εφηβικό	adolescent
είδησης	news (gen.)	εκλάμψεις	flares	χτεσινή	yesterday's	εξώφυλλα	book covers	θορυβώδη	noisy (pl. neutral)	υπακοής	obedience (fem., gen.)
έμμετρος	rhyming	εργάτης	worker	μισητές	hateful (fem.)	επέλεξα	(I) chose	εκλογέας	elector	παραβολή	parable
έμπειροι	experienced	εφέσεις	appeals	ερυθρός	red	επίκτητη	acquired	πινακίδα	plate/sign	επιδρομή	raid
έναστρος	starry	ηγείται	(he) leads	συνετές	prudent (fem.)	επίπληξη	scolding	ταραξίες	troubemakers	επιφανής	prominent
ένστολοι	uniformed	πλακώσει	(he'll) cover	δυσφορεί	(she) grudges	θυμώνατε	(you) got mad	τιμωρίες	punishments	πολυτελή	luxurious (pl., neutral)
κοίταγμα	glance	ιδρώνει	(she) sweats	προπονεί	(she) trains	ισόποσα	commensurate	υπηρέτες	servants	επιρροών	influences (gen)
κύλινδρος	cylinder	ιμάντες	straps	πονηρούς	sneaky (pl., accus.)	κατάστρωμα	ship deck	σημασίες	meanings	υποτιμώ	underestimate
πρόσθετοι	additional (pl.)	καινούριων	new (gen.)	ελλιπείς	incomplete (pl.)	νεότητα	youth	δομημένα	structured	συζυγικά	spousal (pl.)
πρότεινα	(I) suggested	οικείος	familiar	συναφείς	relevant (pl.)	παγίωση	consolidation	νικημένη	beaten (fem.)	ερημική	deserted
πρότυπες	standard	ομπρέλες	umbrellas	αιχμηροί	sharp (pl.)	παράσιτο	parasite	γεωπόνος	agriculturist	εξοχικές	rural
πρώιμοι	premature	ποικίλους	various	κατακτούν	(they) conquer	πολύμηνη	of many months (fem.)	ιδρωμένη	sweaty (fem.)	μοναχική	lonesome (fem.)
πώρωση	zealotry	προκρίνει	(she) qualifies	ευπρεπώς	decently	προαύλιο	forecourt	κωνοφόρα	coniferous	φυλετικών	racial (pl., gen.)
στάσιμα	statically	προσμένει	(she) awaits	δυστυχείς	unfortunate (pl.)	προσέλθουμε	(we'll) attend	προηγμένη	advanced (fem.)	παροδικοί	temporary (pl.)

στέλνουμε	(we) send	σπουργίτι	sparrow	τριμελούς	three-part (gen.)	υπέφεραν	(they) suffered	ξυρισμένα	shaved (pl., neutral)	θρηνητικό	mournful (neutral)
στρέφομαι	(I) turn to	συστήνω	(I) introduce	σφαιρικοί	spherical	φυγόπονη	shirker	οικονόμος	housekeeper	υδραυλικά	hydraulics
σύνεση	prudence	ταυτίζουν	(they) identify	σκοτεινής	dark (fem., gen.)	χιτώνιο	tunic	επιβάτης	passenger	κυματιστή	wavy (fem.)
χείριστος	worst	τυχαίνουν	(they) happen to	συγκρουσθεί	(she'll) collide	χωμάτινο	clay-made	αποδράσεις	escapes	μονομερής	monomer

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. gen: genitive (possessive) case. femin.: feminine gender. neutral: neutral gender, pl.: plural number.

Table B. 4 List of the nonword stimuli used in Experiment 2 of Chapter 3.

Stress consistent						Stress inconsistent					
Trisyllabic			Tetrasyllabic			Trisyllabic			Tetrasyllabic		
APU	PU	U	APU	PU	U	APU	PU	U	APU	PU	U
βγαίραμε	ατροίκου	αγγιχθούς	αξίζακε	απαρείψω	αγγεδικά	άλμυνος	αδράπει	ασκιστρί	ανάκροφη	εγκυμόρει	ακυνωσώ
πίγραμμες	αρπαίου	ακριλό	απίρανη	απογράξει	βοηρηθεί	άστριπο	αροίφες	αφραιού	εδάφιπος	εκτοβώθω	γυδαικειάς
δύσμοιχων	ασπρίφεις	αντληθούς	ατύβησα	αλοθήκης	δικτυωμή	δύκατης	αρνήχω	αντερούν	εξώτιθων	εξωγέδη	ενωμετής
έκπτωλοι	γλιστρήκεις	ασαρή	βισώθηκε	ερωπένη	ενοζική	θαύχασμου	ζημεύτους	ασκειές	επόχινο	ερηβίκη	εκαρμοζώ
έρχοναι	εγκλήμεις	βανιστώ	βοτέψετε	ενωμέτοι	εξεπιχθώ	θρύτικες	εγκλείσπει	θολωζεί	ερήμιτα	ητιμάθης	λεωφοχοί
κρέασα	ηπείνους	επιτού	θανάσιγη	επιβλέζω	ηζιθανή	μπρόστικου	εκπέλεις	ικρυσεί	ηλέδαπα	ησωίκο	οξυγολά
δρίσιμοι	κεζάτη	κωμιφές	ενώπηκα	επιβύσει	ιταλιπός	τρώινος	βαιρίκης	μπουσωνούν	ιχάγενων	θαναφίκες	ποξεμενό
θέγιστος	κουμπάμοι	οψαλών	ισμύουσες	ιμεώδες	μηχανιφό	στίφουργους	γαπνίστο	πεσμεχής	καθόψικου	θυζατρίκες	υπορηκή
μπλέκεναι	λαντζούρι	παιδιτού	ευνόηχο	υψωμέση	μοναχιρό	σύμβουρη	παλούτσης	σκριμμενή	νομάξικης	μονογώλω	υποφεχώ
κλείτομαι	βεσίτης	πληξωθείς	λιγόψερος	κοσονάκι	μυσοποιούν	ρόξικες	χαφίκοι	τυνθετώ	πασχάμινου	παραθίλω	χακαρωνώ
κλοίαρχο	γετρούσε	κροκληθούν	οφοίωμα	κοσμηκένο	νοητιλό	άπλωσκε	ανίτοι	βρατησή	αλάπανε	ανεφάσε	αροκιμό
χλήττουμε	ξυχίζει	κροσιτές	μανεύτηκε	μαζεθένα	οθογενή	βένναιος	διδάγρα	γριαμβοί	απάλλαβω	εξεψέσε	ανυπορτοί
κρόσθεση	οιτείους	γεισμικοί	μετάδηψη	μεζενάκι	ομονογώ	είστραττω	δροσίμε	δρισιμούς	βοήρανε	ετιπόνο	γοναξισμά
σκίρανε	πυτζάσες	σταθπιστούν	ξημέρωλε	νευριάχω	ορβανωθώ	έκλεμπεις	ευχραύστες	δρωφενά	επίσαλλω	ευστανείας	εξυψωχής
σπάτιμο	ρεντόνι	συπαντώ	πανίσχυφη	ξεδυτίσω	ορμηγικά	σάφεδες	μπρεκέσαι	ευμαιρός	μαζέμελων	εγευρέση	ημιζεοί
σφήλαια	συγκρίξουν	συντηβούν	παρέδιχε	οξυμέφος	συμμαξικός	μάρευουν	σειθούμε	κανασπρός	ορέξαγος	ζοριβόμαι	κωμοποσή
στένεσθε	θυνάξεις	σχολιμός	ταυτόρημοι	σημαψάκι	σαρωτιψή	μέτρουναν	πραστούμε	πατηκά	παράζαω	ζωνταδεύε	ομοηκό
φείξονται	θηρήσουν	ταζαχθούν	παρέκευση	υπογάλω	υπερχομές	πύθμεδας	σκρωχνούμε	μαθαιοί	πελάφειας	ξηπωσούμε	παζαβασής
φλύατες	υμνούρε	φυτιδοί	υλάκουσα	φιλενάσα	χαφογελώ	στάλωσει	σπρωσίμο	παιστριά	τσαρίσμενα	εβημώσε	σαμηνειάς
φρούψηση	ρωνίζουν	θωριστού	υξώσουμε	φριζαλέος	φυκετικό	γράμπενοι	χλιβέται	παμπλουρής	υφόστουμε	ψηφιζέραι	φιλοτιλή

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. Stress consistent: Nonword is stressed on the same position as the real word it was generated from. Stress inconsistent: Nonword is stressed on a different position than the real word it was generated from.

Table B. 5 List of the stimuli used in Experiment 3 of Chapter 3.

Words						Nonwords					
Verbs			Adjectives								
APU	PU	U	APU	PU	U	APU		PU		U	
ακόνισε	αθροίζει	ανησυχώ	άγνωστοι	αγχώδης	αιχμηρού	βγαίραμε	μετάδηψη	ατροίκου	αφραίου	αγγιχθούς	αντερούν
βάδισε	αποβλέπεις	αποστατούν	άπαιχτος	ακμαίος	ελλιπείς	πίγραμμες	φινότιμη	αρπαίου	ασκείες	ακριλό	αροιφές
βάπτιζε	βασίζεις	απωθεί	άσπλαχνη	ακραίους	εξοχικές	δύσμοιχων	αρόκιμο	ασπρίφεις	θολώζει	αγγεδικά	ζημευτούς
διέρχεται	εκβάλλει	βοηθούν	έντεχνες	αυθάδης	ερημική	έκπτωλοι	γρίαμβοι	γλιστρήκεις	μπουσώνουν	βοηρηθεί	εγκρειστεί
έκατσες	εκθέτω	διοικείς	γύφτικα	αφρώδεις	ευσεβών	απίρανη	δρίσιμους	εγκλήμεις	πεσμέχης	βανιστώ	βαιρικής
έπονται	εκλύουν	δυστυχεί	δύσβατος	γαλάζιους	μαλλιαρός	βισώθηκε	δρώφενα	επικλέπω	σκριμμένη	ενοζική	ητιμαθής
εργάζεστε	επιβάλλω	εκτελείς	έμμετρος	γατίσιες	μισητές	δρίσιμοι	εύμαιρος	επιβύσει	τυνθέτω	εξεπιχθώ	παλουτσής
έρχεστε	επισύρει	εκτελεστεί	έμπειροι	γελοίους	μουλωχτοί	θέγιστος	κάνασπρος	κουμπάμοι	χαρατώνω	οψαλών	χαφικοί
ευθύνεσαι	ζεσταίνεις	ενδημούν	έμπιστοι	θαρραλέο	ορεινούς	μπλάκεσαι	πάμπλουρης	λαντζούρι	εκαρμόζω	παιδιρού	μονογωλώ
ευχόμασταν	ηγείται	εξαντληθεί	έναστρος	θορυβώδη	παροδικοί	κλείτομαι	ανέφασε	ξεδυτίσω	υπονέρω	πληξωθείς	αλμυνός
κρέμασε	ιδρώνει	εξαπατώ	ένστολοι	καημένος	πονηρούς	κολοίαρχο	ζορίβομαι	γετρούσε	αλαπάνε	κροκληθούν	αστριπό
ντρέπεστε	καθαρίζω	εξασκεί	επίκτητη	καινοτόμο	σκεπαστό	χλήττουμε	εύχραυστες	ξυχίζει	απρώστε	κροσιτές	δυκατής
γεύομαι	ξεριζώνει	εξοφλούν	έυχρηστο	καινούριων	συζυγικά	κρόσθεση	μπρέκεσαι	οιτείους	βενναίος	γεισμικοί	θαυχασμού
προσέλθουμε	πηγάζουν	ευλογούν	ισόποσα	λαθραίος	συναφείς	ξημέσωσε	σείθουμε	πυτζάσες	ειστράττω	σταθπιστούν	βοηράνε
πρότεινα	πλακώσει	κατακτούν	κρίσιμους	μοντέρνες	σφαιρικοί	σπάτιμο	πράστουμε	υπογάλω	εκλέμπεις	συπαντώ	τρωινός
σέβονται	προκρίνει	προπονεί	μονόπλευρη	οικείος	τολμηροί	σπάλαια	σκρώχνουμε	συγκρίξουν	υσοστούμε	συντηβούν	στιφουργούς
σκέφτηκες	προσμένει	προωθεί	πρώιμοι	οικονόμος	τριμελούς	στένεσθε	σπρώσιμο	θυνάξεις	παρεύουν	σχολιμός	συμβουρή
στέλνουμε	συστήνω	συγκινείς	σίγουρους	ορεξάτος	φουντωτή	φείξονται	χλίβεται	θηρήσουν	μιτρούσαν	ταζαχθούν	παραθινώ
στρέφομαι	ταυτίζουν	συγκρουσθεί	φιλότεχνοι	ποικίλους	φυλετικών	υξώσουμε	ψηφίρεσαι	μεζενάκι	πυθμόνας	οθογενή	εκπελείς
σύνελθε	τυχαίνουν	συναντάς	χωμάτινο	τεμπέλης	χτεσινή	φρούψηση	άχρυνοι	ρωνίζουν	σταλώσει	θωριστού	παραζάς

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. Materials are presented in lowercase in this table so that the orthographic stress diacritics position can be apparent, but they were always presented to participants in uppercase in the experimental session.

Table B. 6 Translations of the real-word stimuli used in Experiment 3 of Chapter 3.

Verbs						Adjectives					
Antepenultimate		Penultimate		Ultimate		Antepenultimate		Penultimate		Ultimate	
ακόνισε	(she) sharpened	αθροίζει	(she) gathers	ανησυχώ	(I am) worried	άγνωστοι	strangers	αγχώδης	stressful	αιχμηρού	sharp (gen.)
βάδισε	(she) walked	αποβλέπεις	(you) aspire	αποστατούν	(they) defect	άπαιχτος	unbeaten	ακμαίος	blooming	ελλιπείς	incomplete (pl.)
βάπτιζε	(she was) baptising	βασίζεις	(you) base	απωθεί	(she) pushes away	άσπλαχνη	heartless (fem.)	ακραίους	extreme (pl., accus.)	εξοχικές	rural (pl., fem.)
διέρχεται	(she) goes through	εκβάλλει	she (emits)	βοηθούν	(they) help	έντεχνες	artistic (fem., pl.)	αυθάδης	insolent	ερημική	deserted (fem.)
έκατσες	(you) sat	εκθέτω	(I) expose	διοικείς	(you) command	γύφτικα	of gypsy origin (pl.)	αφρώδεις	foamy (pl.)	ευσεβών	pious (pl., gen.)
έπονται	(they) follow	εκλύουν	(they) release	δυστυχεί	(she) is miserable	δύσβατος	rutty	γαλάζιους	azure (pl., accus.)	μαλλιαρός	hairy
εργάζεστε	you (work) (pl.)	επιβάλλω	(I) force	εκτελείς	(you) perform	έμμετρος	rhyming	γατίσιες	catlike	μισητές	despised (pl., fem.)
έρχεστε	(you) come (pl.)	επισύρει	(it) entails	εκτελεστεί	(she will be) executed	έμπειροι	skilled (pl.)	γελοίους	ridiculous (pl., accus.)	μουλωχτοί	conniving (pl.)
ευθύνεσαι	(you) are responsible	ζεσταίνεις	(you) warm	ενδημούν	(I) reside	έμπιστοι	trustworthy (pl.)	θαρραλέο	brave (neutral)	ορεινούς	mountainous (pl., accus.)
ευχόμασταν	(we used to) wish	ηγείται	(she) leads	εξαντληθεί	(she will get) exhausted	έναστρος	starry	θορυβώδη	noisy (pl., neutral)	παροδικοί	temporary (pl.)
κρέμασε	(she) hang	ιδρώνει	(she) sweats	εξαπατώ	(I) deceive	ένστολοι	wearing uniform (pl.)	καημένος	lamented	πονηρούς	sneaky (pl., accus.)
ντρέπεστε	(you) are ashamed (pl.)	καθαρίζω	(I) clean	εξασκεί	(she) practices	επίκτητη	acquired (fem.)	καινοτόμο	pioneering (neutral)	σκεπαστό	covered (neutral)
γεύομαι	(I am) tasting	ξεριζώνει	(she) eradicates	εξοφλούν	(they) pay off	έυχρηστο	handy (neutral)	καινούριων	new (pl., fem., gen.)	συζυγικά	spousal (pl., neutral)
προσέλθουμε	(we will) attend	πηγάζουν	(they) originate	ευλογούν	(they) bless	ισόποσα	of same quantity (neutal, pl.)	λαθραίος	smuggled	συναφείς	relevant (pl.)

πρότεινα	(I) suggested	πλακώσει	(she will) cover	κατακτούν	(they) conquer	κρίσιμους	crucial (pl., accus.)	μοντέρνες	modern (pl., fem.)	σφαιρικοί	spherical (pl.)
σέβονται	(they) respect	προκρίνει	(she) qualifies	προπονεί	(she) coaches	μονόπλευρη	one-sided (fem.)	οικείος	familiar	τολμηροί	courageous (pl.)
σκέφτηκες	(you) thought)	προσμένει	(she) anticipates	προωθεί	(she) propels	πρώιμοι	premature (pl.)	οικονόμος	thrifty	τριμελούς	tripartite (gen.)
στέλνουμε	(we) send	συστήνω	(I) introduce	συγκινείς	(you) affect	σίγουρους	certain (pl., accus)	ορεξάτος	hearty	φουντωτή	bushy (fem.)
στρέφομαι	(I) turn	ταυτίζουν	(they) identify	συγκρουσθεί	(she will) class	φιλότεχνοι	dilettante (pl.)	ποικίλους	various (pl., accus.)	φυλετικών	racial (pl. gen.)
σύνελθε	(you) recover (imper.)	τυχαίνουν	(they) happen (to)	συναντάς	(you) encounter	χωμάτινο	consisting of clay (neutral)	τεμπέλης	lazy	χτεσινή	yesterday's (fem.)

Note. pl.: plural number, fem.: feminine gender, neutral: neutral gender, accus.: accusative case, gen.: genitive (possessive) case, imper.: imperative

Table B. 7 Item-level measurements regarding response time and accuracy of all word stimuli used in the lexical decision Experiments 1 and 2 (involving polysyllabic items) in Chapter 3.

Item	Stress	Frequency	Syllables	Response Time (ms)	Accuracy (%)	Uppercase	Response Time (ms)	Accuracy (%)
αίμα	PU	high	2	523	100	ΑΙΜΑ	513	94
αίσθηση	APU	high	3	550	100	ΑΙΣΘΗΣΗ	588	93.8
αίτημα	APU	high	3	519	96.9	ΑΙΤΗΜΑ	609	96.9
αιχμηροί	U	low	3	621	93.8	ΑΙΧΜΗΡΟΙ	671	87.5
ακόμα	PU	high	3	517	100	ΑΚΟΜΑ	495	100
ανάγκες	PU	high	3	513	96.9	ΑΝΑΓΚΕΣ	574	93.8
αναφορά	U	high	4	499	100	ΑΝΑΦΟΡΑ	569	100
άνθρωπος	APU	high	3	518	93.8	ΑΝΘΡΩΠΟΣ	587	100
ανθρώπους	PU	high	3	523	100	ΑΝΘΡΩΠΟΥΣ	540	90.6
απόγευμα	APU	high	4	557	100	ΑΠΟΓΕΥΜΑ	515	96.9
αποδράσεις	PU	low	4	580	100	ΑΠΟΔΡΑΣΕΙΣ	615	100
αποφάσεις	PU	high	4	557	100	ΑΠΟΦΑΣΕΙΣ	611	100
απόψεις	PU	high	3	503	96.9	ΑΠΟΨΕΙΣ	548	100
αργά	U	high	2	511	100	ΑΡΓΑ	568	100
αριθμός	U	high	3	501	96.9	ΑΡΙΘΜΟΣ	528	100
αριστερά	U	high	4	523	100	ΑΡΙΣΤΕΡΑ	602	100
αρχή	U	high	2	480	100	ΑΡΧΗ	495	100
αρχηγός	U	high	3	524	96.9	ΑΡΧΗΓΟΣ	585	100
αρχικά	U	high	3	493	100	ΑΡΧΙΚΑ	543	93.8
ασφαλώς	U	high	3	506	100	ΑΣΦΑΛΩΣ	560	100
άτολμους	APU	low	3	907	51.6	ΑΤΟΛΜΟΥΣ	839	84.4
αφορούν	U	high	3	572	93.8	ΑΦΟΡΟΥΝ	592	100

βαμμένοι	PU	low	3	594	100	ΒΑΜΜΕΝΟΙ	716	93.8
βαφή	U	low	2	590	80	ΒΑΦΗ	597	93.3
βάφω	PU	low	2	563	90.6	ΒΑΦΩ	567	100
βίος	PU	low	2	655	96.9	ΒΙΟΣ	571	100
βόας	PU	low	2	656	81.2	ΒΟΑΣ	709	81.2
βόλι	PU	low	2	702	90.3	ΒΟΛΙ	606	96.8
βουλευτές	U	high	3	528	100	ΒΟΥΛΕΥΤΕΣ	666	96.9
βρίσκονται	APU	high	3	540	96.9	ΒΡΙΣΚΟΝΤΑΙ	572	100
βύσσινο	APU	low	3	680	96.9	ΒΥΣΣΙΝΟ	689	81.2
γεγονότα	PU	high	4	508	100	ΓΕΓΟΝΟΤΑ	608	96.9
γεωπόνος	PU	low	4	605	96.9	ΓΕΩΠΟΝΟΣ	649	100
γεωργίας	PU	high	4	552	100	ΓΕΩΡΓΙΑΣ	734	96.9
γίδα	PU	low	2	638	100	ΓΙΔΑ	618	93.5
γίνονται	APU	high	3	596	96.9	ΓΙΝΟΝΤΑΙ	651	87.1
γνάθος	PU	low	2	616	96.9	ΓΝΑΘΟΣ	617	100
γνωρίζουν	PU	high	3	618	100	ΓΝΩΡΙΖΟΥΝ	576	96.9
γόβα	PU	low	2	601	90.3	ΓΟΒΑ	579	100
γόμα	PU	low	2	590	87.1	ΓΟΜΑ	604	90
γοργός	U	low	2	608	90.6	ΓΟΡΓΟΣ	647	75
γυναικών	U	high	3	550	100	ΓΥΝΑΙΚΩΝ	573	96.9
γύρω	PU	high	2	650	93.8	ΓΥΡΩ	641	90
δεδομένα	PU	high	4	524	100	ΔΕΔΟΜΕΝΑ	541	96.9
δέκα	PU	high	2	547	96.9	ΔΕΚΑ	508	100
δηλώσεις	PU	high	3	528	100	ΔΗΛΩΣΕΙΣ	572	96.9
δημόσιο	APU	high	4	498	100	ΔΗΜΟΣΙΟ	541	100
διάλογο	APU	high	4	561	100	ΔΙΑΛΟΓΟ	594	96.9
διάστημα	APU	high	4	545	100	ΔΙΑΣΤΗΜΑ	613	93.8

διάταξη	APU	high	4	603	96.9	ΔΙΑΤΑΞΗ	641	96.9
διέπονται	APU	low	4	772	87.5	ΔΙΕΠΟΝΤΑΙ	902	65.6
δομημένα	PU	low	4	740	84.4	ΔΟΜΗΜΕΝΑ	738	90.6
δυστυχείς	U	low	3	624	96.9	ΔΥΣΤΥΧΕΙΣ	677	93.8
δυστυχώς	U	high	3	496	96.9	ΔΥΣΤΥΧΩΣ	531	100
δυσφορεί	U	low	3	612	87.5	ΔΥΣΦΟΡΕΙ	715	100
εβδομάδα	PU	high	4	519	100	ΕΒΔΟΜΑΔΑ	565	100
είδησης	APU	low	3	627	90.6	ΕΙΔΗΣΗΣ	701	93.5
είκοσι	APU	high	3	570	100	ΕΙΚΟΣΙ	652	87.5
εισαγωγή	U	high	4	550	100	ΕΙΣΑΓΩΓΗ	599	93.8
εισόδημα	APU	high	4	519	100	ΕΙΣΟΔΗΜΑ	574	100
εκβάλλει	PU	low	3	667	96.9	ΕΚΒΑΛΛΕΙ	623	87.5
εκείνος	PU	high	3	513	100	ΕΚΕΙΝΟΣ	591	100
εκθέτω	PU	low	3	533	100	ΕΚΘΕΤΩ	577	96.8
εκλάμψεις	PU	low	3	616	90.6	ΕΚΛΑΜΨΕΙΣ	671	90.6
εκλογέας	PU	low	4	616	78.1	ΕΚΛΟΓΕΑΣ	721	90.6
εκτενώς	U	low	3	555	100	ΕΚΤΕΝΩΣ	661	96.9
έλκω	PU	low	2	617	87.5	ΕΛΚΩ	642	100
ελλιπείς	U	low	3	624	96.9	ΕΛΛΙΠΕΙΣ	792	84.4
έμμετρος	APU	low	3	720	75	ΕΜΜΕΤΡΟΣ	776	71.9
έμπειροι	APU	low	3	612	90.6	ΕΜΠΕΙΡΟΙ	581	100
εναντίον	PU	high	4	563	100	ΕΝΑΝΤΙΟΝ	671	84.4
έναστρος	APU	low	3	687	87.5	ΕΝΑΣΤΡΟΣ	752	81.2
έννοια	APU	high	3	574	96.9	ΕΝΝΟΙΑ	637	93.8
ένστολοι	APU	low	3	606	90.6	ΕΝΣΤΟΛΟΙ	624	87.5
εξαιτίας	PU	high	4	531	100	ΕΞΑΙΤΙΑΣ	658	83.9
εξαπατώ	U	low	4	614	100	ΕΞΑΠΑΤΩ	808	83.9

εξέλιξη	APU	high	4	534	100	ΕΞΕΛΙΞΗ	653	93.5
εξοχικές	U	low	4	560	100	ΕΞΟΧΙΚΕΣ	668	78.1
εξώδικο	APU	low	4	673	90.6	ΕΞΩΔΙΚΟ	677	90.6
εξώφυλλα	APU	low	4	636	96.9	ΕΞΩΦΥΛΛΑ	649	100
επέλεξα	APU	low	4	649	100	ΕΠΕΛΕΞΑ	789	77.4
επιβάτης	PU	low	4	527	100	ΕΠΙΒΑΤΗΣ	609	100
επιδρομή	U	low	4	538	100	ΕΠΙΔΡΟΜΗ	586	100
επίθεση	APU	high	4	535	96.9	ΕΠΙΘΕΣΗ	574	96.9
επίκτητη	APU	low	4	766	93.5	ΕΠΙΚΤΗΤΗ	810	77.4
επιλογή	U	high	4	537	100	ΕΠΙΛΟΓΗ	524	96.9
επιπλέον	PU	high	4	507	100	ΕΠΙΠΛΕΟΝ	572	100
επίπληξη	APU	low	4	730	90.6	ΕΠΙΠΛΗΞΗ	771	96.9
επιρροών	U	low	4	777	75	ΕΠΙΡΡΟΩΝ	877	84.4
επίσκεψη	APU	high	4	539	96.9	ΕΠΙΣΚΕΨΗ	523	100
επιστολή	U	high	4	511	96.9	ΕΠΙΣΤΟΛΗ	560	100
επιτελώ	U	low	4	622	100	ΕΠΙΤΕΛΩ	666	96.9
επιτροπή	U	high	4	508	100	ΕΠΙΤΡΟΠΗ	577	96.9
επιφανής	U	low	4	532	96.9	ΕΠΙΦΑΝΗΣ	613	96.9
επομένως	PU	high	4	527	100	ΕΠΟΜΕΝΩΣ	585	100
εραστής	U	low	3	570	100	ΕΡΑΣΤΗΣ	632	100
εργασίες	PU	high	4	523	100	ΕΡΓΑΣΙΕΣ	636	96.9
εργάτης	PU	low	3	495	100	ΕΡΓΑΤΗΣ	625	96.9
ερημική	U	low	4	545	96.9	ΕΡΗΜΙΚΗ	624	96.9
ερυθρός	U	low	3	606	100	ΕΡΥΘΡΟΣ	711	96.9
έρχονται	APU	high	3	542	96.9	ΕΡΧΟΝΤΑΙ	555	96.9
έστειλε	APU	high	3	651	100	ΕΣΤΕΙΛΕ	657	100
ευπρεπώς	U	low	3	611	93.8	ΕΥΠΡΕΠΩΣ	708	93.8

εφαρμογή	U	high	4	514	100	ΕΦΑΡΜΟΓΗ	578	100
εφέσεις	PU	low	3	693	90.3	ΕΦΕΣΕΙΣ	803	84.4
εφηβικό	U	low	4	528	96.9	ΕΦΗΒΙΚΟ	574	100
ζάρι	PU	low	2	594	96.8	ΖΑΡΙ	623	100
ζητήματα	APU	high	4	566	90.6	ΖΗΤΗΜΑΤΑ	607	100
ζητήσει	PU	high	3	579	100	ΖΗΤΗΣΕΙ	638	96.9
ζώνη	PU	high	2	559	100	ΖΩΝΗ	535	100
ηγείται	PU	low	3	610	96.9	ΗΓΕΙΤΑΙ	715	90.6
ηγεσία	PU	high	4	527	100	ΗΓΕΣΙΑ	591	96.9
ηθικοί	U	low	3	515	100	ΗΘΙΚΟΙ	578	96.9
ηλικίας	PU	high	4	542	100	ΗΛΙΚΙΑΣ	577	96.9
θέατρο	APU	high	3	500	100	ΘΕΑΤΡΟ	581	100
θέλω	PU	high	2	502	100	ΘΕΛΩ	475	100
θέμα	PU	high	2	490	100	ΘΕΜΑ	544	100
θέση	PU	high	2	534	100	ΘΕΣΗ	495	100
θήκη	PU	low	2	742	84.4	ΘΗΚΗ	783	87.5
θορυβώδη	PU	low	4	609	100	ΘΟΡΥΒΩΔΗ	737	93.8
θρηνητικό	U	low	4	764	71.9	ΘΡΗΝΗΤΙΚΟ	806	64.5
θυμώνατε	APU	low	4	816	62.5	ΘΥΜΩΝΑΤΕ	830	62.5
θωρώ	U	low	2	653	90.6	ΘΩΡΩ	649	80.6
ιδεώδη	PU	low	4	664	96.9	ΙΔΕΩΔΗ	664	96.9
ιδρωμένη	PU	low	4	593	96.9	ΙΔΡΩΜΕΝΗ	652	93.8
ιδρώνει	PU	low	3	538	100	ΙΔΡΩΝΕΙ	605	90.6
ιερέας	PU	low	4	570	100	ΙΕΡΕΑΣ	659	93.8
ιμάντες	PU	low	3	732	93.8	ΙΜΑΝΤΕΣ	769	84.4
ισόποσα	APU	low	4	761	71.9	ΙΣΟΠΟΣΑ	821	78.1
ιστορίας	PU	high	4	574	100	ΙΣΤΟΡΙΑΣ	616	96.9

κάθε	PU	high	2	572	96.9	ΚΑΘΕ	511	97
καθεστώς	U	high	3	544	96.9	ΚΑΘΕΣΤΩΣ	644	100
καθηγητής	U	high	4	567	100	ΚΑΘΗΓΗΤΗΣ	613	96.9
καινούριων	PU	low	3	696	86.7	ΚΑΙΝΟΥΡΙΩΝ	752	80.6
κακό	U	high	2	509	100	ΚΑΚΟ	584	96.9
καλά	U	high	2	507	100	ΚΑΛΑ	534	93.8
καλοήθη	PU	low	4	732	96.8	ΚΑΛΟΗΘΗ	738	96.9
καρδιά	U	high	2	516	100	ΚΑΡΔΙΑ	502	100
κατά	U	high	2	527	100	ΚΑΤΑ	616	81.2
κατακτούν	U	low	3	607	96.8	ΚΑΤΑΚΤΟΥΝ	749	84.4
κατάστρωμα	APU	low	4	561	96.9	ΚΑΤΑΣΤΡΩΜΑ	606	96.8
κατάφερε	APU	high	4	581	96.9	ΚΑΤΑΦΕΡΕ	619	90.6
κάτι	PU	high	2	577	87.5	ΚΑΤΙ	582	94
κεντρικής	U	high	3	590	100	ΚΕΝΤΡΙΚΗΣ	701	96.9
κερδίσει	PU	high	3	548	100	ΚΕΡΔΙΣΕΙ	578	96.9
κερί	U	low	2	670	93.8	ΚΕΡΙ	672	78.1
κιλό	U	low	2	564	96.8	ΚΙΛΟ	604	100
κινήσεις	PU	high	3	519	100	ΚΙΝΗΣΕΙΣ	585	96.9
κινώ	U	low	2	671	84.4	ΚΙΝΩ	701	87.1
κοινωνική	U	high	4	541	96.9	ΚΟΙΝΩΝΙΚΗ	647	96.9
κοίταγμα	APU	low	3	738	96.9	ΚΟΙΤΑΓΜΑ	772	90.6
κοπή	U	low	2	588	87.5	ΚΟΠΗ	616	87.5
κύλινδρος	APU	low	3	654	93.8	ΚΥΛΙΝΔΡΟΣ	694	90.6
κυματιστή	U	low	4	722	96.9	ΚΥΜΑΤΙΣΤΗ	835	65.6
κυπριακό	U	high	4	614	100	ΚΥΠΡΙΑΚΟ	628	96.8
κωνοφόρα	PU	low	4	736	78.1	ΚΩΝΟΦΟΡΑ	831	78.1
λειτουργούν	U	high	3	596	96.9	ΛΕΙΤΟΥΡΓΟΥΝ	647	96.9

λέξη	PU	high	2	514	96.9	ΛΕΞΗ	520	97
λιγότερο	APU	high	4	511	93.8	ΛΙΓΟΤΕΡΟ	611	100
λιτή	U	low	2	660	84.4	ΛΙΤΗ	662	71.9
μαζί	U	high	2	510	93.8	ΜΑΖΙ	550	100
μαμή	U	low	2	748	71.9	ΜΑΜΗ	744	67.7
μάχη	PU	high	2	651	77.4	ΜΑΧΗ	685	87
μέλλον	PU	high	2	542	100	ΜΕΛΛΟΝ	485	100
μετά	U	high	2	469	96.9	ΜΕΤΑ	511	96.9
μεταξύ	U	high	3	523	100	ΜΕΤΑΞΥ	607	93.8
μεταφορά	U	high	4	493	100	ΜΕΤΑΦΟΡΑ	550	100
μέτοικοι	APU	low	3	806	90.6	ΜΕΤΟΙΚΟΙ	783	78.1
μιλώντας	PU	high	3	572	100	ΜΙΛΩΝΤΑΣ	655	87.5
μισητές	U	low	3	630	93.8	ΜΙΣΗΤΕΣ	726	78.1
μοναδική	U	high	4	500	100	ΜΟΝΑΔΙΚΗ	570	100
μοναχική	U	low	4	540	96.9	ΜΟΝΑΧΙΚΗ	584	90.6
μονομερής	U	low	4	624	100	ΜΟΝΟΜΕΡΗΣ	668	100
μουσικής	U	high	3	503	100	ΜΟΥΣΙΚΗΣ	583	100
μπερές	U	low	2	671	90.6	ΜΠΕΡΕΣ	654	80.6
μπορούσαν	PU	high	3	595	100	ΜΠΟΡΟΥΣΑΝ	576	100
μύδι	PU	low	2	646	100	ΜΥΔΙ	546	90.6
νεότητα	APU	low	4	536	90.6	ΝΕΟΤΗΤΑ	633	100
νερό	U	high	2	513	100	ΝΕΡΟ	490	100
νησί	U	high	2	495	100	ΝΗΣΙ	537	100
νικημένη	PU	low	4	588	90.6	ΝΙΚΗΜΕΝΗ	678	96.9
νωρίτερα	APU	high	4	510	100	ΝΩΡΙΤΕΡΑ	571	100
ξανά	U	high	2	487	100	ΞΑΝΑ	521	100
ξεκίνησε	APU	high	4	539	100	ΞΕΚΙΝΗΣΕ	675	96.9

ξέρω	PU	high	2	551	96.9	ΞΕΡΩ	537	97
ξύνω	PU	low	2	687	76.7	ΞΥΝΩ	767	78.1
ξυρισμένα	PU	low	4	658	90.6	ΞΥΡΙΣΜΕΝΑ	674	96.9
οικείος	PU	low	3	582	100	ΟΙΚΕΙΟΣ	649	93.8
οικονόμος	PU	low	4	598	100	ΟΙΚΟΝΟΜΟΣ	631	100
ομιλία	PU	high	4	500	100	ΟΜΙΛΙΑ	611	100
ομπρέλες	PU	low	3	598	100	ΟΜΠΡΕΛΕΣ	629	93.8
ορδή	U	low	2	663	87.1	ΟΡΔΗ	654	71.9
ορθό	U	low	2	551	90.6	ΟΡΘΟ	599	90
ορισμένες	PU	high	4	519	96.9	ΟΡΙΣΜΕΝΕΣ	589	100
οφείλεται	APU	high	4	556	100	ΟΦΕΙΛΕΤΑΙ	632	96.9
παγίωση	APU	low	4	707	87.1	ΠΑΓΙΩΣΗ	869	75
παιδείας	PU	high	3	559	100	ΠΑΙΔΕΙΑΣ	640	100
παιχνίδια	PU	high	3	530	100	ΠΑΙΧΝΙΔΙΑ	625	96.9
πάντοτε	APU	high	3	603	93.8	ΠΑΝΤΟΤΕ	609	71.9
παπί	U	low	2	647	96.9	ΠΑΠΙ	610	96.9
παραβολή	U	low	4	521	100	ΠΑΡΑΒΟΛΗ	593	100
παραγωγή	U	high	4	531	100	ΠΑΡΑΓΩΓΗ	593	96.9
παράδειγμα	APU	high	4	542	100	ΠΑΡΑΔΕΙΓΜΑ	569	100
παράδοση	APU	high	4	493	100	ΠΑΡΑΔΟΣΗ	569	100
παραπάνω	PU	high	4	563	100	ΠΑΡΑΠΑΝΩ	614	96.9
παράσιτο	APU	low	4	654	93.8	ΠΑΡΑΣΙΤΟ	735	87.5
παρασκευή	U	high	4	523	100	ΠΑΡΑΣΚΕΥΗ	571	100
παροδικοί	U	low	4	662	96.9	ΠΑΡΟΔΙΚΟΙ	690	93.8
πατώ	U	low	2	594	96.9	ΠΑΤΩ	634	90.6
πεζή	U	low	2	658	96.9	ΠΕΖΗ	720	74.2
περασμένη	PU	high	4	616	93.8	ΠΕΡΑΣΜΕΝΗ	714	96.9

περίοδο	APU	high	4	532	100	ΠΕΡΙΟΔΟ	552	96.9
περιοχή	U	high	4	500	100	ΠΕΡΙΟΧΗ	543	100
πηγή	U	high	2	538	96.8	ΠΗΓΗ	592	96.8
πήζω	PU	low	2	645	93.8	ΠΗΖΩ	609	100
πινακίδα	PU	low	4	569	100	ΠΙΝΑΚΙΔΑ	565	93.8
πιστεύουν	PU	high	3	554	100	ΠΙΣΤΕΥΟΥΝ	568	100
πίσω	PU	high	2	565	96.9	ΠΙΣΩ	526	100
πλαίσιο	APU	high	3	518	100	ΠΛΑΙΣΙΟ	567	96.8
πλακώσει	PU	low	3	655	100	ΠΛΑΚΩΣΕΙ	663	96.8
πληθυσμού	U	high	3	617	96.9	ΠΛΗΘΥΣΜΟΥ	643	100
ποικίλους	PU	low	3	690	87.5	ΠΟΙΚΙΛΟΥΣ	658	90.6
πόκα	PU	low	2	760	67.7	ΠΟΚΑ	743	74.2
πολιτικό	U	high	4	518	100	ΠΟΛΙΤΙΚΟ	553	100
πολύ	U	high	2	531	96.9	ΠΟΛΥ	581	93.8
πολύμηνη	APU	low	4	839	45.2	ΠΟΛΥΜΗΝΗ	894	60
πολυτελή	U	low	4	558	100	ΠΟΛΥΤΕΛΗ	635	90.6
πονηρούς	U	low	3	552	96.9	ΠΟΝΗΡΟΥΣ	567	96.9
πράγματι	APU	high	3	572	96.9	ΠΡΑΓΜΑΤΙ	617	90.6
πρέπει	PU	high	2	548	93.8	ΠΡΕΠΕΙ	535	94
προαύλιο	APU	low	4	610	96.9	ΠΡΟΑΥΛΙΟ	715	100
προβλέπει	PU	high	3	530	100	ΠΡΟΒΛΕΠΕΙ	567	96.9
πρόγραμμα	APU	high	3	564	100	ΠΡΟΓΡΑΜΜΑ	567	96.9
προηγμένη	PU	low	4	562	100	ΠΡΟΗΓΜΕΝΗ	689	96.9
προϊόντα	PU	high	4	568	100	ΠΡΟΪΟΝΤΑ	572	96.9
προκαλεί	U	high	3	513	100	ΠΡΟΚΑΛΕΙ	544	100
πρόκειται	APU	high	3	543	100	ΠΡΟΚΕΙΤΑΙ	597	96.9
προκρίνει	PU	low	3	613	90.6	ΠΡΟΚΡΙΝΕΙ	728	87.5

προοπτική	U	high	4	537	100	ΠΡΟΟΠΤΙΚΗ	610	100
προπονεί	U	low	3	608	96.9	ΠΡΟΠΟΝΕΙ	688	90.6
προσέλθουμε	APU	low	4	689	93.8	ΠΡΟΣΕΛΘΟΥΜΕ	722	96.9
πρόσθετοι	APU	low	3	673	93.8	ΠΡΟΣΘΕΤΟΙ	693	96.9
προσμένει	PU	low	3	643	96.9	ΠΡΟΣΜΕΝΕΙ	686	93.8
προσπαθεί	U	high	3	535	100	ΠΡΟΣΠΑΘΕΙ	566	100
πρόσφατα	APU	high	3	554	100	ΠΡΟΣΦΑΤΑ	585	96.9
προσφορά	U	high	3	559	100	ΠΡΟΣΦΟΡΑ	557	100
προσωπικό	U	high	4	498	100	ΠΡΟΣΩΠΙΚΟ	550	100
προτάσεις	PU	high	3	564	100	ΠΡΟΤΑΣΕΙΣ	560	100
πρότεινα	APU	low	3	568	93.8	ΠΡΟΤΕΙΝΑ	678	100
πρότυπες	APU	low	3	589	93.8	ΠΡΟΤΥΠΕΣ	810	90.6
προφανώς	U	high	3	489	100	ΠΡΟΦΑΝΩΣ	525	100
πρώιμοι	APU	low	3	644	90.6	ΠΡΩΙΜΟΙ	721	90.6
πώρωση	APU	low	3	843	75.9	ΠΩΡΩΣΗ	707	83.9
ροπή	U	low	2	582	93.8	ΡΟΠΗ	588	93.8
ρύθμιση	APU	high	3	563	93.8	ΡΥΘΜΙΣΗ	583	87.1
σενάριο	APU	high	4	492	100	ΣΕΝΑΡΙΟ	514	100
σημασίες	PU	low	4	529	100	ΣΗΜΑΣΙΕΣ	697	93.5
σημερινή	U	high	4	503	100	ΣΗΜΕΡΙΝΗ	556	100
σιγά	U	high	2	490	100	ΣΙΓΑ	557	96.9
σκοτεινής	U	low	3	643	93.8	ΣΚΟΤΕΙΝΗΣ	708	93.8
σπουργίτι	PU	low	3	721	87.5	ΣΠΟΥΡΓΙΤΙ	759	93.8
στάσιμα	APU	low	3	683	93.8	ΣΤΑΣΙΜΑ	734	81.2
στέλνουμε	APU	low	3	603	96.9	ΣΤΕΛΝΟΥΜΕ	645	93.8
στιγμή	U	high	2	516	100	ΣΤΙΓΜΗ	526	96.9
στρέφομαι	APU	low	3	623	93.8	ΣΤΡΕΦΟΜΑΙ	716	93.8

συγκρουσθεί	U	low	3	761	83.9	ΣΥΓΚΡΟΥΣΘΕΙ	796	83.9
συζυγικά	U	low	4	591	96.9	ΣΥΖΥΓΙΚΑ	751	87.5
συμβαίνει	PU	high	3	518	100	ΣΥΜΒΑΙΝΕΙ	566	100
σύμβαση	APU	high	3	567	100	ΣΥΜΒΑΣΗ	540	100
συναφείς	U	low	3	603	100	ΣΥΝΑΦΕΙΣ	695	93.8
σύνεση	APU	low	3	618	90.3	ΣΥΝΕΣΗ	615	90.6
συνετές	U	low	3	671	75	ΣΥΝΕΤΕΣ	736	84.4
συνολικά	U	high	4	539	100	ΣΥΝΟΛΙΚΑ	538	96.9
συστήνω	PU	low	3	582	100	ΣΥΣΤΗΝΩ	619	96.9
σφαιρικοί	U	low	3	621	96.9	ΣΦΑΙΡΙΚΟΙ	673	93.8
σχεδόν	U	high	2	524	100	ΣΧΕΔΟΝ	500	96.9
σχολεία	PU	high	3	493	93.8	ΣΧΟΛΕΙΑ	550	93.8
τάζω	PU	low	2	652	90.3	ΤΑΖΩ	640	87.5
τακτική	U	high	3	525	100	ΤΑΚΤΙΚΗ	627	100
τάξη	PU	high	2	498	100	ΤΑΞΗ	534	97
ταραξίες	PU	low	4	635	100	ΤΑΡΑΞΙΕΣ	750	93.8
ταυτίζουν	PU	low	3	580	96.9	ΤΑΥΤΙΖΟΥΝ	650	100
τελευταίο	PU	high	4	522	96.9	ΤΕΛΕΥΤΑΙΟ	591	100
τέσσερις	APU	high	3	586	100	ΤΕΣΣΕΡΙΣ	668	96.9
τιμή	U	high	2	504	100	ΤΙΜΗ	566	100
τιμωρίες	PU	low	4	558	100	ΤΙΜΩΡΙΕΣ	610	93.8
τμήματος	APU	high	3	632	96.9	ΤΜΗΜΑΤΟΣ	739	71.9
τόπι	PU	low	2	597	96.9	ΤΟΠΙ	604	84.4
τουλάχιστον	APU	high	4	537	100	ΤΟΥΛΑΧΙΣΤΟΝ	595	96.9
τριμελούς	U	low	3	690	96.9	ΤΡΙΜΕΛΟΥΣ	672	90.6
τρόπος	PU	high	2	543	100	ΤΡΟΠΟΣ	554	100
τυχαίνουν	PU	low	3	624	96.9	ΤΥΧΑΙΝΟΥΝ	629	87.5

τώρα	PU	high	2	558	100	ΤΩΡΑ	502	100
υδραυλικά	U	low	4	562	100	ΥΔΡΑΥΛΙΚΑ	620	100
υπακοής	U	low	4	538	100	ΥΠΑΚΟΗΣ	656	96.8
υπέφεραν	APU	low	4	638	96.9	ΥΠΕΦΕΡΑΝ	617	96.9
υπηρέτες	PU	low	4	566	100	ΥΠΗΡΕΤΕΣ	722	96.9
υποτιμώ	U	low	4	533	100	ΥΠΟΤΙΜΩ	616	100
υπουργού	U	high	3	590	100	ΥΠΟΥΡΓΟΥ	612	96.9
φακή	U	low	2	601	100	ΦΑΚΗ	571	93.8
φιλόζωο	APU	low	4	660	93.8	ΦΙΛΟΖΩΟ	683	90.3
φόλα	PU	low	2	644	83.9	ΦΟΛΑ	680	71.9
φόρτος	PU	low	2	638	93.8	ΦΟΡΤΟΣ	666	84.4
φυγόπονη	APU	low	4	808	81.2	ΦΥΓΟΠΟΝΗ	813	73.3
φυλετικών	U	low	4	742	84.4	ΦΥΛΕΤΙΚΩΝ	795	84.4
φωνή	U	high	2	515	100	ΦΩΝΗ	508	100
χαλώ	U	low	2	652	87.1	ΧΑΛΩ	704	74.2
χαρά	U	high	2	489	100	ΧΑΡΑ	563	100
χαρακτήρα	PU	high	4	515	100	ΧΑΡΑΚΤΗΡΑ	573	100
χείριστος	APU	low	3	704	90.6	ΧΕΙΡΙΣΤΟΣ	800	80.6
χέρι	PU	high	2	504	100	ΧΕΡΙ	477	100
χιλιάδες	PU	high	3	542	93.8	ΧΙΛΙΑΔΕΣ	589	100
χιτώνιο	APU	low	4	802	65.6	ΧΙΤΩΝΙΟ	904	65.6
χλωρός	U	low	2	597	100	ΧΛΩΡΟΣ	557	96.9
χτεσινή	U	low	3	595	100	ΧΤΕΣΙΝΗ	616	96.9
χωμάτινο	APU	low	4	610	87.5	ΧΩΜΑΤΙΝΟ	734	84.4
χώρα	PU	high	2	551	100	ΧΩΡΑ	538	100
ψάλτης	PU	low	2	574	96.9	ΨΑΛΤΗΣ	529	100
ψιλή	U	low	2	647	93.3	ΨΙΛΗ	735	93.8

ψυχή	U	high	2	490	96.9	ΨΥΧΗ	501	100

Notes. APU: Antepenultimate stress; PU: Penultimate stress; U: Ultimate stress. The first Response Time (ms) and Accuracy (%) measurements presented in the table correspond to the lowercase items and the subsequent columns to the uppercase items. In the experimental sessions, all items in this table were presented for 500 ms and then disappeared from screen regardless of whether participants had input a response by the end of this period or not.

Table B. 8 Item-level measurements regarding response time and accuracy of all nonword stimuli used in the lexical decision Experiment 1 (involving polysyllabic items) in Chapter 3.

Item	Stress	Syllables	Response Time (ms)	Accuracy (%)	Lowercase	Response Time (ms)	Accuracy (%)
αιρά	final	2	674	100	ΑΙΡΑ	773	90.3
αρζί	final	2	837	84.4	ΑΡΖΙ	739	79.3
άρτε	prefinal	2	621	90.3	ΑΡΤΕ	659	90.6
βάος	prefinal	2	653	96.9	ΒΑΟΣ	608	96.9
βαπί	final	2	800	87.5	ΒΑΠΙ	788	71
βίλω	prefinal	2	616	100	ΒΙΛΩ	631	96.9
βοκή	final	2	654	100	ΒΟΚΗ	601	100
βόνω	prefinal	2	616	100	ΒΟΝΩ	655	96.9
γιλή	final	2	607	96.9	ΓΙΛΗ	652	100
γναρός	final	2	757	90.6	ΓΝΑΡΟΣ	806	87.5
γόκη	prefinal	2	608	96.9	ΓΟΚΗ	591	100
γόπι	prefinal	2	661	90.6	ΓΟΠΙ	679	90.6
γορτής	final	2	737	77.4	ΓΟΡΤΗΣ	731	87.1
γύτα	prefinal	2	614	100	ΓΥΤΑ	635	100
δελύ	final	2	801	84.4	ΔΕΛΥ	854	62.1
ζανώ	final	2	654	96.9	ΖΑΝΩ	613	100
ζωρά	final	2	746	100	ΖΩΡΑ	666	90.6
θελά	final	2	723	96.9	ΘΕΛΑ	722	93.8
θενή	final	2	708	100	ΘΕΝΗ	721	93.8
θέχη	prefinal	2	654	93.8	ΘΕΧΗ	693	93.8
θηζή	final	2	666	96.9	ΘΗΖΗ	675	93.8
θώβα	prefinal	2	640	100	ΘΩΒΑ	661	96.9
καγά	final	2	640	100	ΚΑΓΑ	621	96.8
καμή	final	2	785	93.3	ΚΑΜΗ	744	80.6
κάβη	prefinal	2	644	100	ΚΑΒΗ	632	100
κάρπει	prefinal	2	686	96.8	ΚΑΡΠΕΙ	690	93.5
κάσω	prefinal	2	601	100	ΚΑΣΩ	632	100
κέδη	prefinal	2	666	96.9	ΚΕΔΗ	653	93.8
κιζώ	final	2	639	90.3	ΚΙΖΩ	611	100
κίθο	prefinal	2	732	96.9	ΚΙΘΟ	694	96.8
κόδι	prefinal	2	679	100	ΚΟΔΙ	671	100
κόνα	prefinal	2	653	96.9	ΚΟΝΑ	681	96.9
λέτα	prefinal	2	660	96.9	ΛΕΤΑ	683	96.8
λίδα	prefinal	2	684	90.6	ΛΙΔΑ	790	92.9
μάλω	prefinal	2	652	96.9	ΜΑΛΩ	643	93.8
μαρώ	final	2	659	100	ΜΑΡΩ	670	100
μάφη	prefinal	2	712	96.9	ΜΑΦΗ	730	87.5
μέλδον	prefinal	2	671	96.9	ΜΕΛΔΟΝ	773	87.5
μέμα	prefinal	2	627	100	ΜΕΜΑ	613	100
μπέγος	prefinal	2	662	100	ΜΠΕΓΟΣ	712	96.9

μύμη	prefinal	2	716	100	ΜΥΜΗ	742	93.8
νέμα	prefinal	2	663	84.4	ΝΕΜΑ	730	77.4
νήρα	prefinal	2	689	100	ΝΗΡΑ	686	96.9
νορί	final	2	771	90.3	ΝΟΡΙ	734	71.9
ξαρά	final	2	648	96.9	ΞΑΡΑ	742	87.5
ξέση	prefinal	2	657	90.6	ΞΕΣΗ	661	96.9
ξυτώ	final	2	826	80	ΞΥΤΩ	953	71.9
ορπή	final	2	817	56.7	ΟΡΠΗ	844	62.5
όρτι	prefinal	2	686	96.9	ΟΡΤΙ	693	77.4
παζώ	final	2	697	96.9	ΠΑΖΩ	747	96.9
πάκα	prefinal	2	633	93.8	ΠΑΚΑ	760	84.4
πέμα	prefinal	2	669	100	ΠΕΜΑ	716	93.5
πηρί	final	2	687	96.8	ΠΗΡΙ	717	96.9
πηρώ	final	2	709	90.6	ΠΗΡΩ	756	96.9
πιρά	final	2	697	100	ΠΙΡΑ	744	80
ποξή	final	2	720	41.9	ΠΟΞΗ	713	93.8
ποτή	final	2	786	87.5	ΠΟΤΗ	818	72.4
πρέλον	prefinal	2	665	96.9	ΠΡΕΛΟΝ	700	100
ρολί	final	2	725	96.9	ΡΟΛΙ	758	78.1
σίχη	prefinal	2	642	100	ΣΙΧΗ	679	96.8
στιπός	final	2	693	96.9	ΣΤΙΠΟΣ	701	96.9
σχεγμή	final	2	658	100	ΣΧΕΓΜΗ	647	93.5
τάλο	prefinal	2	616	96.8	ΤΑΛΟ	614	96.8
τάνη	prefinal	2	597	100	ΤΑΝΗ	634	96.9
τίκα	prefinal	2	591	96.9	ΤΙΚΑ	596	100
τορί	final	2	646	96.9	ΤΟΡΙ	701	90.3
τροδιά	final	2	723	96.9	ΤΡΟΔΙΑ	702	96.9
τωρώ	final	2	732	96.9	ΤΩΡΩ	697	93.8
φαλά	final	2	673	96.9	ΦΑΛΑ	652	96.9
φοπή	final	2	660	96.9	ΦΟΠΗ	683	93.8
φορρίς	final	2	799	71	ΦΟΡΡΙΣ	721	87.5
φωξή	final	2	686	93.8	ΦΩΞΗ	662	93.8
χάκω	prefinal	2	586	100	ΧΑΚΩ	669	96.9
χατί	final	2	724	96.9	ΧΑΤΙ	755	93.8
χερό	final	2	718	100	ΧΕΡΟ	704	90.6
χλώτος	prefinal	2	760	87.5	ΧΛΩΤΟΣ	765	77.4
χώθε	prefinal	2	681	41.9	ΧΩΘΕ	706	25.8
ψάλθος	prefinal	2	708	90.6	ΨΑΛΘΟΣ	725	90.6
ψιφώ	final	2	827	77.4	ΨΙΦΩ	714	84.4
ψύσι	prefinal	2	716	96.9	ΨΥΣΙ	697	93.5

Notes. The first Response Time (ms) and Accuracy (%) measurements presented in the table correspond to the lowercase items and the subsequent columns to the uppercase items. In the experimental sessions, all items in this table were presented for 500 ms and then disappeared from screen regardless of whether participants had input a response by the end of this period or not. Nonword items from Experiment 2 of Chapter 3 are not presented as they were not systematically measured and analysed.

Table B. 9 Item-level measurements regarding response time and accuracy of all word stimuli used in the lexical decision Experiment 3 in Chapter 3.

Item	Stress	Frequency	Syllables	Response Time (ms)	Accuracy (%)
ΑΓΝΩΣΤΟΙ	APU	low	3	860	86.4
ΑΓΧΩΔΗΣ	PU	low	3	829	81.8
ΑΘΡΟΙΖΕΙ	PU	low	3	805	90.9
ΑΙΧΜΗΡΟΥ	U	low	3	576	100
ΑΚΜΑΙΟΣ	PU	low	3	719	90.9
ΑΚΟΝΙΣΕ	APU	low	4	701	100
ΑΚΡΑΙΟΥΣ	PU	low	3	904	81.8
ΑΝΗΣΥΧΩ	U	low	4	682	100
ΑΠΑΙΧΤΟΣ	APU	low	3	716	90.9
ΑΠΟΒΛΕΠΕΙΣ	PU	low	4	803	90.9
ΑΠΟΣΤΑΤΟΥΝ	U	low	4	732	100
ΑΠΩΘΕΙ	U	low	3	894	95.5
ΑΣΠΛΑΧΝΗ	APU	low	3	818	90.9
ΑΥΘΑΔΗΣ	PU	low	3	840	86.4
ΑΦΡΩΔΕΙΣ	PU	low	3	894	81.8
ΒΑΔΙΣΕ	APU	low	3	672	100
ΒΑΠΤΙΖΕ	APU	low	3	705	100
ΒΑΣΙΖΕΙΣ	PU	low	3	555	100
ΒΟΗΘΟΥΝ	U	low	3	687	100
ΓΑΛΑΖΙΟΥΣ	PU	low	3	681	100
ΓΑΤΙΣΙΕΣ	PU	low	3	715	81.8
ΓΕΛΟΙΟΥΣ	PU	low	3	583	100
ΓΕΥΟΜΑΙ	APU	low	3	898	95.5
ΓΥΦΤΙΚΑ	APU	low	3	584	100
ΔΙΕΡΧΕΤΑΙ	APU	low	4	832	95.5
ΔΙΟΙΚΕΙΣ	U	low	3	937	90.9
ΔΥΣΒΑΤΟΣ	APU	low	3	772	95.5
ΔΥΣΤΥΧΕΙ	U	low	3	824	95.5
ΕΚΑΤΣΕΣ	APU	low	3	660	100
ΕΚΒΑΛΛΕΙ	PU	low	3	734	90.9
ΕΚΘΕΤΩ	PU	low	3	712	95.5
ΕΚΛΥΟΥΝ	PU	low	3	913	95.5
ΕΚΤΕΛΕΙΣ	U	low	3	653	100
ΕΚΤΕΛΕΣΤΕΙ	U	low	4	777	95.5
ΕΛΛΙΠΕΙΣ	U	low	3	874	100
ΕΜΜΕΤΡΟΣ	APU	low	3	812	86.4
ΕΜΠΕΙΡΟΙ	APU	low	3	677	100
ΕΜΠΙΣΤΟΙ	APU	low	3	677	100
ΕΝΑΣΤΡΟΣ	APU	low	3	803	95.5
ΕΝΔΗΜΟΥΝ	U	low	3	935	81.8
ΕΝΣΤΟΛΟΙ	APU	low	3	867	86.4
ΕΝΤΕΧΝΕΣ	APU	low	3	743	86.4

ΕΞΑΝΤΛΗΘΕΙ	U	low	4	662	95.5
ΕΞΑΠΑΤΩ	U	low	4	643	95.5
ΕΞΑΣΚΕΙ	U	low	3	790	90.9
ΕΞΟΦΛΟΥΝ	U	low	3	682	100
ΕΞΟΧΙΚΕΣ	U	low	3	788	90.9
ΕΠΙΒΑΛΛΩ	PU	low	4	826	95.5
ΕΠΙΚΤΗΤΗ	APU	low	4	981	81.8
ΕΠΙΣΥΡΕΙ	PU	low	4	880	95.5
ΕΠΟΝΤΑΙ	APU	low	3	749	100
ΕΡΓΑΖΕΣΤΕ	APU	low	4	819	95.5
ΕΡΗΜΙΚΗ	U	low	4	773	86.4
ΕΡΧΕΣΤΕ	APU	low	3	734	81.8
ΕΥΘΥΝΕΣΑΙ	APU	low	4	936	95.5
ΕΥΛΟΓΟΥΝ	U	low	3	864	81.8
ΕΥΣΕΒΩΝ	U	low	3	835	81.8
ΕΥΧΟΜΑΣΤΑΝ	APU	low	4	985	95.5
ΕΥΧΡΗΣΤΟ	APU	low	3	872	95.5
ΖΕΣΤΑΙΝΕΙΣ	PU	low	3	680	100
ΗΓΕΙΤΑΙ	PU	low	3	841	95.5
ΘΑΡΡΑΛΕΟ	PU	low	4	790	90.9
ΘΟΡΥΒΩΔΗ	PU	low	4	814	90.9
ΙΔΡΩΝΕΙ	PU	low	3	652	100
ΙΣΟΠΟΣΑ	APU	low	4	779	100
ΚΑΗΜΕΝΟΣ	PU	low	3	789	86.4
ΚΑΘΑΡΙΖΩ	PU	low	4	811	95.5
ΚΑΙΝΟΤΟΜΟ	PU	low	4	763	86.4
ΚΑΙΝΟΥΡΙΩΝ	PU	low	3	651	100
ΚΑΤΑΚΤΟΥΝ	U	low	3	851	95.5
ΚΡΕΜΑΣΕ	APU	low	3	640	100
ΚΡΙΣΙΜΟΥΣ	APU	low	3	832	95.5
ΛΑΘΡΑΙΟΣ	PU	low	3	878	86.4
ΜΑΛΛΙΑΡΟΣ	U	low	3	866	95.5
ΜΙΣΗΤΕΣ	U	low	3	741	100
ΜΟΝΟΠΛΕΥΡΗ	APU	low	4	1045	81.8
ΜΟΝΤΕΡΝΕΣ	PU	low	3	571	100
ΜΟΥΛΩΧΤΟΙ	U	low	3	976	86.4
ΝΤΡΕΠΕΣΤΕ	APU	low	3	724	90.9
ΞΕΡΙΖΩΝΕΙ	PU	low	4	770	95.5
ΟΙΚΕΙΟΣ	PU	low	3	768	95.5
ΟΙΚΟΝΟΜΟΣ	PU	low	4	729	90.9
ΟΡΕΙΝΟΥΣ	U	low	3	659	100
ΟΡΕΞΑΤΟΣ	PU	low	4	733	90.9
ΠΑΡΟΔΙΚΟΙ	U	low	4	855	95.5
ΠΗΓΑΖΟΥΝ	PU	low	3	882	95.5
ΠΛΑΚΩΣΕΙ	PU	low	3	624	100
ΠΟΙΚΙΛΟΥΣ	PU	low	3	734	90.9

ΠΟΝΗΡΟΥΣ	U	low	3	690	100
ΠΡΟΚΡΙΝΕΙ	PU	low	3	636	100
ΠΡΟΠΟΝΕΙ	U	low	3	688	95.5
ΠΡΟΣΕΛΘΟΥΜΕ	APU	low	4	948	81.8
ΠΡΟΣΜΕΝΕΙ	PU	low	3	657	100
ΠΡΟΤΕΙΝΑ	APU	low	3	647	95.5
ΠΡΟΩΘΕΙ	U	low	3	978	81.8
ΠΡΩΙΜΟΙ	APU	low	3	825	81.8
ΣΕΒΟΝΤΑΙ	APU	low	3	842	95.5
ΣΙΓΟΥΡΟΥΣ	APU	low	3	625	100
ΣΚΕΠΑΣΤΟ	U	low	3	902	86.4
ΣΚΕΦΤΗΚΕΣ	APU	low	3	824	95.5
ΣΤΕΛΝΟΥΜΕ	APU	low	3	719	95.5
ΣΤΡΕΦΟΜΑΙ	APU	low	3	824	90.9
ΣΥΓΚΙΝΕΙΣ	U	low	3	870	95.5
ΣΥΓΚΡΟΥΣΘΕΙ	U	low	3	914	95.5
ΣΥΖΥΓΙΚΑ	U	low	4	928	90.9
ΣΥΝΑΝΤΑΣ	U	low	3	736	100
ΣΥΝΑΦΕΙΣ	U	low	3	872	86.4
ΣΥΝΕΛΘΕ	APU	low	3	940	95.5
ΣΥΣΤΗΝΩ	PU	low	3	624	100
ΣΦΑΙΡΙΚΟΙ	U	low	3	756	100
ΤΑΥΤΙΖΟΥΝ	PU	low	3	758	100
ΤΕΜΠΕΛΗΣ	PU	low	3	656	95.5
ΤΟΛΜΗΡΟΙ	U	low	3	647	100
ΤΡΙΜΕΛΟΥΣ	U	low	3	902	81.8
ΤΥΧΑΙΝΟΥΝ	PU	low	3	757	100
ΦΙΛΟΤΕΧΝΟΙ	APU	low	4	949	81.8
ΦΟΥΝΤΩΤΗ	U	low	3	851	95.5
ΦΥΛΕΤΙΚΩΝ	U	low	4	807	90.9
ΧΤΕΣΙΝΗ	U	low	3	662	100
ΧΩΜΑΤΙΝΟ	APU	low	3	762	100

Notes. In the experimental session, all items in this table were presented on screen until participants input a response. Nonword items from Experiment 3 of Chapter 3 are not presented as they were not systematically measured and analysed. In the same experiment, stimuli were only presented on uppercase, hence the absence of lowercase measurements on this table.

Appendix C - Experimental materials used in Chapter 5

Table C. 1 List of the stimuli used in both Experiment 1 and Experiment 2 of Chapter 5.

Minimal pairs		Disyllabic baselines		Monosyllabic filler words			
Prefinal dominant	Final dominant	Prefinal stress	Final stress				
annex	affect	annum	afraid	angst	aisles	aired	choice
compound	combine	comrade	commend	clinched	checked	cleanse	cramped
conflict	complex	concrete	compare	clothes	cracked	claimed	chopped
contest	construct	context	connect	crashed	classed	charged	climbed
contract	convert	constant	confirm	crossed	chipped	cleared	cleaned
default	dictate	deepest	disgust	drought	drained	drawers	drilled
desert	discard	dentist	diffuse	dreams	draught	drowned	ditched
discount	discharge	district	dispatch	strapped	drenched	dressed	dragged
fragment	exploit	fracture	extinct	freight	weighed	freaked	wrecked
impact	extract	impulse	explode	missed	springs	leagues	whipped
incense	impress	injure	improve	clamped	trapped	stocked	dropped
instinct	invite	inkling	indulge	strengths	stepped	tricked	plucked
insult	produce	insect	prolong	weighs	planned	starred	prepped
mandate	recall	mansion	redeem	matched	rolled	threats	risked
misprint	refresh	mistress	reflect	screened	reigned	switched	reached
perfect	refuse	person	regard	pleased	ripped	picked	rounds
project	reject	product	relate	stopped	robbed	pressed	rocked
rebel	reprint	relish	repent	roast	realms	roped	racked
replay	torment	reflex	terrain	ranked	thrived	rammed	thieves
retail	update	reason	uphold	rained	blocked	raised	snowed

Note. Prefinal dominant: minimal pairs whose entry with stress on the prefinal syllable has a higher frequency than the entry with stress on the final in SUBTLEX-UK (van Heuven, Mandera, & Keuleers, 2014). Final dominant: minimal pairs whose entry with stress on the final syllable has a higher frequency than the entry with stress on the prefinal in SUBTLEX-UK.

Table C. 2 Item-level measurements regarding response time and accuracy of all word stimuli used in the readind aloud Experiment 1 in Chapter 5.

Item	Type	Stress	Response Time (ms)	Accuracy (%)
affect	minimal pair	final	509	96.7
afraid	baseline	final	483	100
annex	minimal pair	prefinal	548	96.4
annum	baseline	prefinal	571	89.3
combine	minimal pair	final	494	100
commend	baseline	final	578	92.6
compare	baseline	final	468	100
complex	minimal pair	final	499	100
compound	minimal pair	prefinal	501	100
comrade	baseline	prefinal	554	58.6
concrete	baseline	prefinal	496	100
confirm	baseline	final	503	100
conflict	minimal pair	prefinal	508	100
connect	baseline	final	498	100
constant	baseline	prefinal	514	100
construct	minimal pair	final	545	100
contest	minimal pair	prefinal	479	96.7
context	baseline	prefinal	523	96.7
contract	minimal pair	prefinal	503	100
convert	minimal pair	final	513	96.7
deepest	baseline	prefinal	598	96.6
default	minimal pair	prefinal	544	100
dentist	baseline	prefinal	565	100
desert	minimal pair	prefinal	561	92.3
dictate	minimal pair	final	604	96.4
diffuse	baseline	final	518	100
discard	minimal pair	final	518	100
discharge	minimal pair	final	515	96.7
discount	minimal pair	prefinal	526	96.6
disgust	baseline	final	501	100
dispatch	baseline	final	525	100
district	baseline	prefinal	543	92.6
explode	baseline	final	493	96.7
exploit	minimal pair	final	494	96.7
extinct	baseline	final	532	83.3
extract	minimal pair	final	505	100
fracture	baseline	prefinal	545	96.4
fragment	minimal pair	prefinal	525	100
impact	minimal pair	prefinal	494	100
impress	minimal pair	final	499	100
improve	baseline	final	465	100
impulse	baseline	prefinal	502	100

incense	minimal pair	prefinal	569	92.6
indulge	baseline	final	510	96.6
injure	baseline	prefinal	515	100
inkling	baseline	prefinal	552	100
insect	baseline	prefinal	522	100
instinct	minimal pair	prefinal	497	93.1
insult	minimal pair	prefinal	482	100
invite	minimal pair	final	487	100
mandate	minimal pair	prefinal	546	100
mansion	baseline	prefinal	519	100
misprint	minimal pair	prefinal	543	96.7
mistress	baseline	prefinal	525	96.6
perfect	minimal pair	prefinal	516	100
person	baseline	prefinal	491	100
produce	minimal pair	final	539	93.3
product	baseline	prefinal	530	96.6
project	minimal pair	prefinal	542	96.7
prolong	baseline	final	541	100
reason	baseline	prefinal	493	100
rebel	minimal pair	prefinal	506	96.7
recall	minimal pair	final	495	96.7
redeem	baseline	final	515	100
reflect	baseline	final	515	100
reflex	baseline	prefinal	515	96.7
refresh	minimal pair	final	506	96.6
refuse	minimal pair	final	475	100
regard	baseline	final	491	100
reject	minimal pair	final	510	96.6
relate	baseline	final	504	100
relish	baseline	prefinal	546	93.1
repent	baseline	final	565	96.7
replay	minimal pair	prefinal	508	96.7
reprint	minimal pair	final	561	96.7
retail	minimal pair	prefinal	532	100
terrain	baseline	final	555	96.6
torment	minimal pair	final	514	96.6
update	minimal pair	final	478	100
uphold	baseline	final	532	100

Notes. In minimal pairs, final or prefinal stress indicates the dominant stress position of each orthographic form, i.e. the phonological version of each form with the highest frequency between the two. In the experimental session, all items in this table were presented on screen until participants initiated their response. Monosyllabic items are not presented as they were not systematically measured and analysed. In the same experiment, stimuli were only presented on lowercase, hence the absence of uppercase measurements on this table.

Appendix D - Outputs of computational simulations discussed in Chapter 5 and Chapter 6

Table D. 1 List of the minimal pairs present in the lexicon of CDP++ (Perry, Ziegler, & Zorzi, 2010), the stress position of each entry, the output of the TLA nodes, the final output of the model, and the congruency between the two. All entries were considered in the first step of Simulation 1 in Chapter 5 whereas only the incongruent ones were considered in the second phase of analysis.

Word	Stress (A)	Freq (A)	Stress (B)	Freq (B)	Cum. freq.	Cycles	TLA 1	TLA 2	TLA output	Output node 1	Output node 2	Output stress position	Congruent
absent	1	16	2	235	251	78	0.328	0.661	2	0.076	0.103	2	YES
addict	2	25	1	0	25	98	0.848	0.203	1	0.427	0.073	1	YES
addicts	1	39	2	0	39	99	0.854	0.196	1	0.321	0.077	1	YES
affix	1	0	2	4	4	87	0.89	0.126	1	0.398	0.008	1	YES
allied	1	50	2	436	486	79	0.747	0.26	1	0.115	0.088	1	YES
allies	2	356	1	7	363	79	0.837	0.177	1	0.109	0.087	1	YES
alloy	1	24	2	0	24	81	0.633	0.381	1	0.228	0.12	1	YES
alloys	1	15	2	0	15	86	0.476	0.507	2	0.143	0.134	1	NO
ally	2	96	1	28	124	78	0.943	0.091	1	0.445	0.019	1	YES
annex	1	8	2	36	36	83	0.869	0.15	1	0.338	0.017	1	YES
august	1	19	2	940	959	195	0.648	0.303	1	0.411	0.087	1	YES
collect	1	0	2	468	468	144	0.779	0.238	1	0.58	0.091	1	YES
collects	1	2	2	51	53	182	0.787	0.23	1	0.542	0.059	1	YES
combine	1	54	2	244	298	118	0.551	0.447	1	0.478	0.175	1	YES
combines	2	16	1	72	88	156	0.564	0.436	1	0.373	0.181	1	YES
commune	2	98	1	4	102	98	0.339	0.627	2	0.159	0.228	2	YES
communes	2	75	1	0	75	153	0.351	0.617	2	0.165	0.386	2	YES
compact	2	39	1	110	149	112	0.457	0.512	2	0.408	0.197	1	NO
compacts	2	5	1	0	5	125	0.47	0.501	2	0.31	0.28	1	NO

compound	2	214	1	24	238	99	0.193	0.767	2	0.211	0.099	1	NO
compounds	1	161	2	14	175	229	0.201	0.758	2	0.064	0.486	2	YES
compress	2	2	1	28	30	153	0.269	0.691	2	0.093	0.599	2	YES
concert	2	272	1	0	272	88	0.886	0.141	1	0.104	0.099	1	YES
concerts	2	98	1	0	98	148	0.899	0.125	1	0.577	0.066	1	YES
conduct	1	278	2	144	422	84	0.6	0.423	1	0.1	0.077	1	YES
confab	1	0	2	0	0	91	0.509	0.504	1	0.19	0.168	1	YES
confabs	2	0	1	0	0	93	0.543	0.469	1	0.134	0.1	1	YES
confines	2	9	1	62	71	88	0.286	0.686	2	0.102	0.061	1	NO
conflict	1	834	2	56	890	82	0.811	0.234	1	0.179	0.05	1	YES
conflicts	1	175	2	11	186	107	0.524	0.496	1	0.249	0.053	1	YES
conjunct	1	0	2	0	0	99	0.435	0.588	2	0.105	0.074	1	NO
conjure	2	16	1	0	16	90	0.543	0.463	1	0.098	0.103	2	NO
conjured	2	15	1	0	15	216	0.215	0.765	2	0.031	0.591	2	YES
conjures	2	13	1	0	13	99	0.577	0.428	1	0.099	0.105	2	NO
conscript	2	4	1	4	8	95	0.612	0.445	1	0.104	0.044	1	YES
conscripts	2	15	1	0	15	97	0.612	0.445	1	0.103	0.058	1	YES
console	1	34	2	40	74	90	0.314	0.655	2	0.122	0.113	1	NO
consoles	1	6	2	2	8	161	0.325	0.644	2	0.158	0.373	2	YES
construct	1	148	2	25	173	84	0.773	0.281	1	0.146	0.048	1	YES
constructs	2	15	1	11	26	109	0.278	0.713	2	0.221	0.049	1	NO
content	2	590	1	394	984	92	0.747	0.253	1	0.28	0.079	1	YES
contents	1	366	2	7	373	147	0.756	0.244	1	0.618	0.057	1	YES
contest	2	164	1	36	200	110	0.783	0.225	1	0.509	0.085	1	YES
contests	2	42	1	3	45	146	0.791	0.217	1	0.58	0.073	1	YES
contract	1	538	2	72	610	72	0.899	0.123	1	0.102	0.052	1	YES
contracts	1	214	2	14	228	80	0.796	0.217	1	0.1	0.059	1	YES

contrast	1	729	2	16	745	72	0.899	0.123	1	0.102	0.052	1	YES
contrasts	2	38	1	34	72	89	0.532	0.442	1	0.103	0.064	1	YES
converse	2	20	1	36	56	90	0.378	0.636	2	0.101	0.064	1	NO
convert	1	31	2	168	199	88	0.779	0.265	1	0.116	0.085	1	YES
converts	2	32	1	27	59	91	0.801	0.238	1	0.101	0.067	1	YES
convict	1	16	2	28	44	115	0.56	0.455	1	0.462	0.166	1	YES
convicts	2	15	1	0	15	98	0.573	0.444	1	0.111	0.077	1	YES
decoy	2	13	1	4	17	81	0.451	0.578	2	0.151	0.203	2	YES
decoys	2	14	1	0	14	85	0.302	0.696	2	0.087	0.177	2	YES
defect	2	72	1	8	80	136	0.229	0.74	2	0.056	0.617	2	YES
defects	1	131	2	3	134	129	0.238	0.731	2	0.082	0.605	2	YES
defile	1	2	2	12	14	82	0.162	0.794	2	0.054	0.141	2	YES
defiles	1	2	2	4	6	90	0.17	0.786	2	0.061	0.111	2	YES
desert	1	666	2	108	694	78	0.572	0.439	1	0.113	0.082	1	YES
deserts	2	69	1	36	79	139	0.605	0.404	1	0.389	0.178	1	YES
digest	1	12	2	60	72	110	0.641	0.374	1	0.382	0.229	1	YES
digests	1	3	2	5	8	95	0.652	0.364	1	0.164	0.132	1	YES
entrance	1	842	2	0	842	203	0.21	0.713	2	0.102	0.398	2	YES
escort	2	114	1	28	142	80	0.092	0.868	2	0.08	0.114	2	YES
escorts	1	24	2	0	24	90	0.104	0.851	2	0.087	0.105	2	YES
excess	2	165	1	140	305	80	0.351	0.652	2	0.103	0.107	2	YES
exploit	1	13	2	216	229	95	0.505	0.554	2	0.183	0.177	1	NO
exploits	2	35	1	15	50	164	0.539	0.519	1	0.295	0.239	1	YES
export	2	225	1	48	273	100	0.219	0.764	2	0.119	0.409	2	YES
exports	1	181	2	7	188	178	0.243	0.738	2	0.08	0.472	2	YES
extract	2	105	1	104	209	86	0.198	0.777	2	0.102	0.054	1	NO
extracts	1	47	2	9	56	124	0.206	0.769	2	0.146	0.439	2	YES

ferment	2	29	1	16	45	88	0.855	0.165	1	0.107	0.063	1	YES
fragment	2	100	1	12	112	82	0.998	0.005	1	0.063	0.105	2	NO
fragments	2	282	1	0	282	88	0.993	0.017	1	0.073	0.112	2	NO
frequent	2	8	1	396	404	169	0.786	0.245	1	0.225	0.424	2	NO
inland	2	134	1	78	212	155	0.395	0.566	2	0.163	0.336	2	YES
minute	2	1321	1	304	1625	163	0.55	0.427	1	0.295	0.19	1	YES
niger	2	3	1	9	12	140	0.992	0.019	1	0.659	0	1	YES
object	1	1008	2	288	1296	208	0.28	0.703	2	0.062	0.472	2	YES
objects	2	851	1	0	851	224	0.29	0.693	2	0.037	0.555	2	YES
perfect	2	24	1	1131	1155	198	0.62	0.384	1	0.444	0.082	1	YES
perfects	2	2	1	7	9	186	0.632	0.373	1	0.44	0.093	1	YES
perfume	1	116	2	4	120	86	0.281	0.682	2	0.1	0.061	1	NO
perfumes	2	28	1	0	28	99	0.291	0.673	2	0.107	0.103	1	NO
permit	1	70	2	248	318	79	0.914	0.099	1	0.121	0.083	1	YES
permits	1	25	2	79	104	88	0.924	0.087	1	0.111	0.077	1	YES
pervert	1	10	2	8	18	89	0.874	0.154	1	0.119	0.055	1	YES
perverts	2	7	1	1	8	98	0.889	0.136	1	0.106	0.056	1	YES
premise	2	72	1	0	72	231	0.548	0.437	1	0.293	0.129	1	YES
premiss	2	72	1	0	72	183	0.666	0.334	1	0.446	0.087	1	YES
present	2	536	1	3850	4386	101	0.606	0.393	1	0.393	0.101	1	YES
presents	1	121	2	215	336	87	0.606	0.393	1	0.101	0.081	1	YES
proceeds	1	70	2	70	140	94	0.169	0.798	2	0.09	0.102	2	YES
process	1	2631	2	56	2687	73	0.948	0.072	1	0.101	0.072	1	YES
processed	1	10	2	95	105	97	0.242	0.72	2	0.088	0.101	2	YES
produce	1	147	2	1692	1839	70	0.935	0.085	1	0.064	0.1	2	NO
project	1	798	2	152	950	88	0.733	0.28	1	0.202	0.068	1	YES
projects	1	441	2	18	459	81	0.733	0.28	1	0.101	0.07	1	YES

prospect	2	539	1	0	539	82	0.906	0.122	1	0.076	0.118	2	NO
prospects	2	302	1	0	302	131	0.712	0.309	1	0.486	0.138	1	YES
protest	2	521	1	100	621	94	0.872	0.14	1	0.303	0.077	1	YES
protests	1	182	2	7	189	85	0.872	0.14	1	0.101	0.068	1	YES
real	1	5464	2	0	5464	152	0.999	0.002	1	0.688	0.013	1	YES
rebel	2	74	1	48	122	70	0.861	0.17	1	0.115	0.059	1	YES
rebels	1	95	2	19	114	79	0.877	0.151	1	0.12	0.067	1	YES
rebound	1	12	2	8	20	90	0.193	0.785	2	0.085	0.116	2	YES
recoil	2	7	1	8	15	84	0.634	0.427	1	0.147	0.109	1	YES
record	2	1190	1	228	1418	78	0.286	0.718	2	0.088	0.113	2	YES
records	1	598	2	52	650	81	0.315	0.688	2	0.102	0.074	1	NO
refuse	2	59	1	528	587	210	0.089	0.889	2	0.018	0.654	2	YES
reject	1	0	2	296	296	139	0.338	0.655	2	0.095	0.538	2	YES
rejects	2	11	1	70	81	204	0.349	0.644	2	0.099	0.39	2	YES
second	2	6089	1	0	6089	68	0.486	0.514	2	0.063	0.105	2	YES
seconds	2	742	1	0	742	86	0.499	0.502	2	0.084	0.101	2	YES
segment	2	60	1	4	64	103	0.96	0.07	1	0.444	0.075	1	YES
segments	1	69	2	1	70	90	0.962	0.067	1	0.101	0.07	1	YES
subject	2	2952	1	0	2952	96	0.762	0.3	1	0.325	0.113	1	YES
subjects	1	1014	2	0	1014	88	0.772	0.291	1	0.134	0.059	1	YES
survey	1	543	2	76	619	152	0.916	0.104	1	0.623	0.033	1	YES
surveys	1	155	2	3	158	150	0.852	0.162	1	0.596	0.042	1	YES
suspect	1	173	2	496	669	78	0.643	0.37	1	0.106	0.066	1	YES
suspects	1	56	2	56	112	87	0.643	0.37	1	0.102	0.06	1	YES

Notes. Stress (A) and (B) represent the syllabic position of each minimal pair in the order of occurrence in the lexicon and Freq (A) and (B) their corresponding word frequencies. Cum. freq: The cumulative frequency of the two. Cycles: the number of cycles that the model needed to produce an output. TLA 1 and 2: The association of each stress position with the specific orthographic form as calculated by its two-layer sublexical network (TLA). Output node 1 and 2: Calculations of each competing stress node's values determining the final stress position output. Congruent: Consistency between the dominant position of the TLA network and the final stress choice of the model. Stress position is represented as 1: prefinal position, 2: final position.

Table D. 2 Comparison of the stress position preferences between the output of the computational model and human readers. The within-readers consistency refers to the level of agreement on stress position assignment among participants regarding each given word.

Word	Stress position		Consistency	
	Model output	Human output	Model - Human	Readers consistency
annex	1	1	YES	96.3
compound	1	2	NO	63.3
conflict	1	1	YES	76.7
contest	1	1	YES	55.2
contract	1	1	YES	73.3
desert	1	2	NO	63.5
fragment	2	1	NO	100
perfect	1	1	YES	96.7
project	1	1	YES	72.4
rebel	1	1	YES	52.3
combine	1	2	NO	100
construct	1	2	NO	70
convert	1	2	NO	82.8
exploit	1	2	NO	79.3
extract	1	2	NO	66.7
produce	2	2	YES	89.3
refuse	2	2	YES	100
reject	2	2	YES	92.9

Table D. 3 Output of Simulation 1 reported in Chapter 6.

High Frequency				Low Frequency			
Prefinal		Final		Prefinal		Final	
Word	Cycles	Word	Cycles	Word	Cycles	Word	Cycles
αίμα	24	αργά	24	βάφω	23	βαφή	26
γύρω	24	αρχή	23	βίος	26	θωρώ	26
δέκα	24	κακό	25	βόας	25	κερί	29
ζώνη	24	καλά	25	βόλι	28	κιλό	25
θέλω	24	κατά	24	γίδα	27	κινώ	26
θέμα	23	μαζί	24	γόβα	25	κοπή	30
θέση	24	μετά	23	γόμα	26	λιτή	25
κάθε	25	νερό	25	έλκω	27	μαμή	27
κάτι	24	νησί	24	ζάρι	26	ορδή	27
λέξη	25	ξανά	24	θήκη	27	ορθό	27
μάχη	24	πηγή	25	μύδι	25	παπί	26
ξέρω	24	πολύ	22	ξύνω	31	πατώ	27
πίσω	24	σιγά	24	πήζω	21	πεζή	26
τάξη	24	τιμή	24	πόκα	31	ροπή	24
τώρα	24	φωνή	25	τάζω	27	φακή	27
χέρι	24	χαρά	23	τόπι	30	χαλώ	28
χώρα	25	ψυχή	25	φόλα	26	ψιλή	26

Note: Prefinal and Final refer to the syllabic position of stress

Table D. 4 Output of Simulation 2 reported in Chapter 6.

Prefinal		Final	
Word	Cycles	Word	Cycles
αίμα	15	αργά	15
γύρω	18	αρχή	16
δέκα	17	κακό	18
ζώνη	17	καλά	15
θέλω	17	καρδιά	15
θέμα	16	κατά	15
θέση	17	μαζί	15
κάθε	17	μετά	16
κάτι	16	νερό	15
λέξη	18	νησί	14
μάχη	17	ξανά	14
μέλλον	18	πηγή	16
ξέρω	15	πολύ	15
πίσω	17	σιγά	15
πρέπει	16	στιγμή	17
τάξη	17	σχεδόν	18
τρόπος	17	τιμή	17
τώρα	15	φωνή	17
χέρι	17	χαρά	17
χώρα	17	ψυχή	16

Note: Prefinal and Final refer to the syllabic position of stress