

Some stress patterns are harder to learn than others¹

1. A very brief introduction to stress

Stress in linguistics is the relative prominence of one syllable in comparison to other syllables. It is part of a language's prosody and helps to break up the speech stream into smaller units. Stressed syllables are either louder, higher, and/or longer than unstressed syllables, and more resistant to reduction processes. Of all the flavours that stress comes in, we will focus on word stress here (as opposed to higher-level stress such as phrasal or sentence stress). In the following we will have a look at some basic concepts of stress (section 2), before we come to a case study of Modern Greek stress (section 3) and how it can be acquired in computer simulations (section 4). Modern Greek stress is intriguing because of its complexity: there are words with final stress, others with penultimate stress, and yet others with antepenultimate stress, irrespective of the phonological structure of the words. On top of that, stress can shift to the right depending on the case (at least in nouns). These shifts are not always realized, adding to the complex pattern. This makes the learnability of this stress system, i.e. a theoretical approach on how this pattern could in principle be acquired, particularly interesting.

Some words on the terminology: The notions 'stress' and 'accent' are often used interchangeably in the literature, and sometimes used as discriminating between different phonetic aspects. 'Accent' is in general used as a slightly more general term and often refers to sentence accent.

1. Phonetic and phonological aspects of stress

(a) Phonetic aspects: a teaser

Stress manifests phonetically with one or more correlates. Auditorily or perceptually speaking these are length, loudness, pitch and vowel quality. Acoustically speaking, the correlates are reflected in duration, intensity or amplitude, fundamental frequency and spectral structure (e.g. Dogil & Williams 1999; cf. Fry 1955, Lehiste 1970). The use of these correlates is very language-specific. English, for one, is said to have pitch as a stress correlate, combined with a preservation of vowel quality in unstressed syllables and a strong tendency to reduce vowels in unstressed syllables. In Modern Greek, the language of our case study, stress is characterized by a combination of intensity and duration (McKeever Dauer 1980, Botinis 1989). In German, duration/length seems to be the main cue for word stress (Dogil & Williams 1999, Jessen & Marasek 1995).

All of the above correlates are relative, and all of them can express something else than stress. For instance, the duration of a vowel can be a sign for stress in that stressed syllables are often longer in duration than unstressed ones, but it can also be a sign of an underlyingly long vowel, i.e. phonemic vowel length. Pitch can, other than stress, express tone, or prosody on the sentence level. Despite this inconclusiveness, in a lot of languages speakers usually agree in their judgement about which syllable in a word is the most prominent.

We turn now to a brief overview over some functional aspects of stress.

1. (a) Functional aspects: Predictable vs. lexical stress

Stress is said to have several different functions. Depending on the language, the assignment of stress can be rather predictable (e.g. in languages where the beginning or the end of words is canonically stressed) or it can be unpredictable in the sense that it needs to be learned for each word (so-called lexical stress²). In the former case, stress could serve as a means to signal a boundary (see Trubetzkoy 1939, Hyman 1977, Karvonen 2008 for the idea of stress as a demarcative function). In the latter case, stress can carry information about the morphological or lexical make-up of a word. Predictable stress systems are also referred to as *fixed* stress systems, whereas lexical stress systems are also referred to as *free* stress systems.

Languages with predictable stress assign it by phonological principles, for instance to a certain position in the word. Consider Finnish, where words are stressed initially (indicated by an acute accent '´'; examples are taken from Karvonen 2008):

¹ This work was funded by the NWO Rubicon grant No. 446-07-030.

² The expression 'lexical stress' is sometimes used as referring to word stress in contrast to sentence stress.

1. Finnish:

vápa ‘free’
*hél**sink*i ‘Helsinki’
*ér**gon*ómia ‘ergonomics’

In Turkish, stress is for the most part final. No matter how many suffixes are attached, stress is always on the ultimate syllable (examples are from Sezer 1983):

1. Turkish:

*tan*i-*dik* ‘acquaintance’
*tan*i-*dik*-*lár* ‘acquaintances’,
*tan*i-*dik*-*lar*-*ím* ‘my acquaintances’

Stress is in these cases edge-oriented, either towards the left or right edge of words. This does not have to be the initial or final syllable; it can also be near an edge.³ Regular penultimate stress is common (e.g. in Polish; e.g. Comrie 1976; Hayes 1995 and references therein); antepenultimate (e.g. in Macedonian, Comrie 1976) and even postinitial stress are found (e.g. in Dakota, Chambers 1978). Other phonological factors that can play a role in stress assignment are the complexity of the syllable (*heavy* syllables often attract stress in contrast to *light* syllables; see section 2.4).

Languages with largely unpredictable stress pattern are, among others, Russian (Halle 1997, Melvold 1990, Revithiadou 1999)⁴, Bulgarian (Dogil et al. 1999:843), and Modern Greek (e.g. Philippaki-Warbuton 1970, 1976). In Russian, stems and affixes can be inherently (‘lexically’) marked for stress, and words with marked stems have stress on the stem-syllable (3a), whereas words with unmarked stems have stress on the affix (if that is lexically marked) or on the initial syllable (in case no morpheme is marked for stress).

1. Russian

- a. *rabót*+*á* = *rabóta* ‘work-Nom.Sg.’
 rabót+*y* = *rabóty* ‘work-Nom.Pl.’
c. *borod*+*á* = *borodá* ‘beard-Nom.Sg.’
 borod+*y* = *bórody* ‘beard-Nom.Pl.’

Modern Greek, our case study and described in more detail in section 3, behaves quite similar, except that it has a ‘trisyllabic window’, i.e. stress can only occur on one of the final three syllables.

In general, the distinction between predictable and unpredictable is continuous rather than absolute: languages with predominantly predictable stress can have exceptions and languages with unpredictable stress can have some phonological restrictions or a preference for a certain pattern. Languages like English, Dutch or German appear to have stress based to a great extent on phonological properties (van der Hulst 1999, and references therein), but morphology and the lexicon play a role, too. In English, verbs and nouns are sometimes only distinguished by their different stresses: *récord* (noun) versus *recórd* (verb). Since the segmental make-up of verb and noun are the same, the difference in stress has to be lexical rather than phonological. The morphological influence on stress in English shows in words such as *recordability*, where the derivational suffix attracts stress away from the root.

1. (a) Examples of languages without word stress

Most languages make use of some sort of stress on the word level, however, a few languages appear to lack it altogether (e.g. Betawi Malay, Roosman 2007; Javanese Indonesian, Goedemans & van Zanten 2007; Sri Lankan Malay, Nordhoff 2009, Apoussidou & Nordhoff, submitted), or at least have some content words that lack it (Cayuga and Seneca, Chafe 1977; Central Sierra Miwok, Freeland 1951; Japanese, Poser 1990; Kinyambo, Bickmore 1989, 1992; Yupik Eskimo,

³ This seems to hold more for the right edge than the left edge of words; post-postinitial stress is so far missing from the typology. See Hyman (1977) for an indication of frequent and infrequent edge-oriented patterns.

⁴ See Dogil et al (1999:852) for a phonological account of Russian stress.

Krauss 1985). It is debatable whether French (Dell 1984) has word stress or not, or whether it only has stress on the phrasal level (Hayes 1995). Grammatical words are frequently unstressed. The occurrence of these languages suggests that the principle of *culminativity* (that each word or phrase should have one and only one main stress; Liberman & Prince 1977), once seen as an unviolable universal, is either not universal or not unviolable. At least since the advent of Optimality Theory the latter has become an option (e.g. Alderete 1999).

1. (a) Phonological aspects of stress

In systems with only one stress per word that furthermore falls on one of the two possible edges, it suffices to designate the edge as a phonological rule or constraint. These systems are called *unbounded* (Halle & Vergnaud 1987). *Bounded* stress systems, for instance patterns with stress on the second or third syllable from the edge, and patterns with iterative stress (i.e. patterns that have secondary stresses besides the main stress of a word) could be accounted for by counting syllables; this, however, is a rather unelegant approach. Given the often binary nature of stress patterns, for which counting is not necessary, one came up with templates called *feet* that describe the observed patterns. An overview over the initiation of the concept ‘foot’ is given in Hayes (1995:40). Hayes furthermore established the foot inventory that is still the basis for most work on metrical issues. The notion of ‘feet’ stems, among others, from grid theory (Prince 1983, Selkirk 1984), where stressed syllables were displayed as grid marks above a segmental tier, and unstressed ones as dots. This representation, exemplified in (1), is even reminiscent of a stylized foot (here with the leg on the left side and the toes pointing to the right):

1. *
(* .)
mo.ra

Feet were invoked to explain the often alternating behaviour of stressed and unstressed syllables, and the location of stress within a word. They are often binary (i.e. consisting of two syllables), as e.g. languages such as Pintupi (Hansen & Hansen 1969) and Finnish suggest (2)+(3). In these languages, secondary stresses are assigned in an alternating manner to every other syllable next to the main stress:

1. Pintupi: *múŋu* → (múŋu) ‘orphan’
ŋálkuninpa → (ŋálku)(nínpa) ‘eating’
tʃámulimpatʃùŋku → (tʃámu)(límpa)(tʃùŋku) ‘our relation’
1. Finnish: *érgonòmia* → (érgo)(nòmí)a ‘ergonomics’

Languages like Cayuvava (as in Hayes 1981, 1995) can be explained with trisyllabic feet: e.g. *[1F0?]ihiraríama* ‘I must do’, *maràhahaéiki* ‘their blankets’, *ikitàparerépeha* ‘the water is clean’. In other languages such as Modern Greek, monosyllabic (sometimes *degenerate*) feet can play a role (as we will see later).

Crucial to the notion of metrical feet is the division into a strong part (the *head*) and a weak part. Left-headed feet are called trochees, right-headed feet are called iambs. As indicated in (2) and (3), Pintupi and Finnish can be analyzed as having trochees. Pacific Yupik (as in Hayes 1995:335 and references therein) can be analyzed as having iambic feet:

1. Pacific Yupik: *atáka* → (atá)ka ‘my father’
akútam ʼə́k → (akú)(tam ʼə́k) ‘kind of food-abl.sg.’

Iambic languages tend to make a distinction between heavy and light syllables (unstressed syllables are short/shortened and stressed syllables are lengthened/long), whereas trochaic languages do not. This was formulated in an *Iambic/Trochaic Law* (going back to a perceptual experiment by Bolton 1894) that “elements contrasting in intensity naturally form groupings with initial prominence”, and “elements contrasting in duration naturally form groupings with

final prominence” (phrasing taken from Hayes 1995:80). Across languages, this seems to be more of a tendency than a law (see Kager 1993).

Speaking of heavy and light syllables, they bear some explanation. There are languages that do not make a distinction between heavy and light syllables irrespective of their syllable structure. Some languages distinguish between open syllables with a short vowel that are light, and open syllables with a long vowel that are heavy. In these languages, the heavy syllables tend to attract stress. Adding to these are languages that count syllables with closed syllables as heavy (e.g. Latin, Mester 1984; German, Giegerich 1985) or light. Languages that do not have a vowel length distinction but count closed syllables as heavy (e.g. Spanish, Roca 1999) are apparently rare. Modern Greek has closed syllables (i.e. syllables ending in a consonant), but no vowel length distinction. Stress in this case is assigned irrespective of whether a syllable is closed or not.

These are just the very basic principles of stress. As for the acquisition of stress, a learner of a language (at least a L1 learner) has to find out whether his/her language is predominantly predictable, and if so, which phonological grammar renders the correct stress pattern, and if not, what needs to be represented in the lexicon. Let us now turn to a more detailed discussion of stress in Modern Greek, before we move on to the computational treatment.

1. Modern Greek

Modern Greek word stress, especially in nouns, is complex and involves an interaction of the lexicon and the phonology of the language. Modern Greek (henceforth simply Greek, unless it is contrasted with Ancient Greek) has lexical stress, meaning that the morphemes of a word can be (and often are) underlyingly specified for stress. Stress can occur on any of the final three syllables (depending on the word), and in the genitive case stress can shift to the right. It is phonologically restricted in the sense that stress cannot occur farther to the left than on the antepenultimate syllable. The shift in the genitive case is an artefact of Ancient Greek, where it was phonologically conditioned. Nowadays, the shift is lexical and not transparent anymore: speakers use it when using a more formal speech style, but some words undergo it more easily than others. The genitive case is furthermore not frequently used, and speakers reveal insecurities when prompted to produce the genitive stress pattern for certain words. This can be due to the infrequency of the genitive case, i.e. the speakers were not exposed to the genitive case enough to fully acquire the pattern, but it can also be due to the fact that the stress shift in the genitive case is an artefact of Ancient Greek and is in conflict with the contemporary phonology of Greek.

This paper will give a computational learnability account of word stress in Modern Greek nouns, showing how the lexical word stress can be acquired using allomorphy, and furthermore showing how some of the stress patterns occurring in Modern Greek could be more difficult to acquire than others due to both the restrictions of the grammar and to the infrequency of the genitive case.

1. (a) The data

Stress in Greek is lexical in the sense that morphemes can be underlyingly specified for it. Any of the last three syllables of a word can be stressed (examples are taken from Holton et al. 1997/2004; dots indicate a syllable boundary and acute accents indicate stress; citation form is the nominative singular, if not specified otherwise):

1.	antepenultimate	penultimate	ultimate
----	-----------------	-------------	----------

<i>thá.la.sa</i> ‘sea’	<i>kó.ri</i> ‘daughter’	<i>a.go.rá</i> ‘market place’
<i>va.sí.li.sa</i> ‘queen’	<i>el.pí.tha</i> ‘hope’	<i>u.ra.nós</i> ‘sky’
<i>la.ví.rin.thos</i> ‘labyrinth’	<i>fi.ga.té.ra</i> ‘daughter’	<i>a.del.fós</i> ‘brother’
	<i>e.fi.me.rí.tha</i> ‘newspaper’	

In the genitive case, stress can shift from the antepenultimate of the nominative case to the penultimate syllable (9a) or to the ultimate syllable (9b) or from the penultimate to the ultimate syllable (9c). In other cases, stress does not shift (9d).

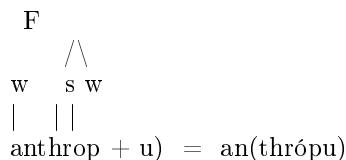
1. a. *la.ví.rin.thos* ~ *la.vi.rín.thon*
 - b. *thá.la.sa* ~ *tha.la.són*
va.sí.li.sa ~ *va.si.li.són*
 - c. *do.má.ta* ~ *do.ma.tón*
 - d. *el.pí.tha* ~ *el.pí.thon*
- In *any* case, stress cannot occur left of the antepenultimate syllable.⁵

1. (a) Previous analyses

There is consensus in the literature that stress in Greek is for the most part lexical. A phonological default applies only when no morpheme of the word is specified for stress; in this case, stress is assigned to the antepenultimate syllable if there is one (Philippaki-Warbuton 1970, 1976, Ralli 1988, Malikouti-Drachman & Drachman 1989; Touratzidis & Ralli 1992, Drachman & Malikouti-Drachman 1996, Revithiadou 1999).⁶ Both roots and suffixes can be specified for stress.

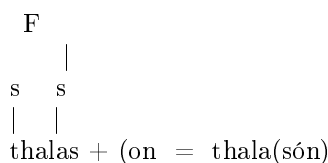
Revithiadou (1999), for instance, proposed that the stress shift of the genitive singular suffix *-u* is caused by an underlying specification in form of a weak foot part. The preceding root gets stressed on its final syllable because the grammar of the language builds a trochaic foot based on the specification of the suffix. While a word like *ánthrop+os* ‘human’ is stressed by the phonology, i.e. (ánthro)pos, the genitive singular case *-u* comes with a lexical foot part, and the phonology will assign a trochaic foot an(thrópu) (‘s’ stands for the strong part of a foot; ‘w’ for the weak part):

1. Pre-stressing foot structure



The genitive plural suffix *-on* is in Revithiadou’s (1999) analysis stressed itself, i.e. equipped with a strong foot part *-(on* underlyingly. This results in a monosyllabic feet around the suffix on the surface:

1. Self-stressing foot structure



Both suffixes can attract stress from the antepenultimate syllable only if adhered to an underlyingly unstressed root. As the data in (5) and (6) show, stress can shift from the antepenult to the penult or ultima, where the suffix *-on* in some cases surfaces as pre-stressing and sometimes as stressed itself (and not only when occurring with roots that are unstressable).

⁵ Apparently, loanwords can violate the trisyllabic window, e.g. *kámeraman* ‘cameraman’ (Revithiadou 1999:95).

⁶ See Protopapas et al. (2006) and reference therein for suggesting that the default is actually stress on the penultimate syllable, based on the frequency of this pattern.

1. Stress shift from the antepenultimate to the penultimate syllable

méthodos ~ *methódon* ‘method’
ánthropos ~ *anthrópon* ‘human’

1. Stress shift from the antepenultimate to the ultimate syllable

thálasa ~ *thalasón* ‘sea’
trápeza ~ *trapezón* ‘bank’

This already indicates that there is some kind of allomorphy involved. As the data in (7) furthermore show, stress can also shift from the penult to the ultima:

1. Stress shift from the penultimate to the antepenultimate syllable

domáta ~ *domatón* ‘tomato’
turístas ~ *turistón* ‘tourist’

According to Revithiadou’s analysis, the suffix should only be able to attract stress away from the root if the root is underlyingly unstressed. If a word surfaces as stressed on the penultimate syllable in the nominative case, then it has to be underlyingly stressed on that syllable, because otherwise it should be stressed by default on the antepenultimate (if the root is disyllabic or longer). If the root is underlyingly stressed, then the inflectional suffix should not be able to attract stress away from the root due to the ranking of root stress over suffix stress. This kind of stress shift cannot be explained by underlying foot structure as in Revithiadou’s analysis (nor by Apoussidou’s 2007 account for that matter).

An alternative would be allomorphy: in the penult-to-the-ultima case; one could assume either stressless and pre-stressing allomorphs for the non-genitive suffixes, assigning penultimate stress, or one could assume that the root has two allomorphs; one unstressed and one stressed on the final syllable, i.e. *méthod-* ~ *methód-*. The latter might be less costly for a learner of the language since it is a straightforward interpretation of the input. Moreover, allomorphy exists anyway in the language. Drachman et al. (1995) give an account how allomorphs of Greek suffixes are chosen on the basis of their own shape and the shape of the root/stem they adhere to. For instance, action nominals can be formed with the suffixes *-imo* and *-ma*. Monosyllabic stems take the disyllabic *-imo*, while polysyllabic stems take the monosyllabic *-ma* (examples taken from Drachman et al. 1995):

1. Action nominals

vréko ‘I wet’ > *vréksimo* ‘wetting’
skupiso ‘I sweep’ > *skúpizma* ‘sweeping’

However, Drachman et al. (1995) are suspicious of suffixal alternants that are segmentally identical but behave differently with respect to stress, as in the deverbal agent nominalizer *-tis*. This suffix surfaces as stressed or unstressed depending on the length (in terms of syllable count) of the preceding root: *kléf-tis* ‘thief’ vs. *skupis-tís* ‘sweeper’. Instead of allomorphy they propose catalexis for the behaviour of suffixes like *-tis*, to account for why the unstressed variant adheres to monosyllabic stems and the stressed variant adheres to polysyllabic stems. While they give an elegant account for the distribution of (other) allomorphs on prosodic grounds in Modern Greek, I am less suspicious of unstressed *-tis*/stressed *-tís* as allomorphy, because the catalectic analysis does not apply in a similar case, the genitive plural suffix *-on*, which pretty much looks like the *-tis/-tís* case in that it has stressed, pre-stressing and unstressed alternants, but has alternation irrespective of the prosodic shape of the root it adheres to (as I will show below). I would like to argue that roots and suffixes can simply have unstressed and stressed alternants, and they adhere to each other by convention, not necessarily out of prosodic reasons. The reason for this assumption is that the stress-shifting pattern caused by some affixes usually belongs to a more formal register stemming from Ancient Greek (Holton et al. 1997/2004) and is ‘learned’. I therefore take that the stress-shifting pattern is not part of the natural language acquisition process but an exceptional pattern that is highly lexicalized.

Since the examples show that 1) stress is lexical in Greek; 2) allomorphy is needed in one way or another anyway (*méthodos* ~ *methódon* and *thálasa* ~ *thalasón*), and 3) underlying foot structure cannot account for all the cases of stress shift (*domáta* ~ *domatón*), I would like to propose that Greek makes use of underlying stress, but that the stress shifts are encoded as allomorphy (similar to Ralli & Touratzidis' 1992 approach).

1. Simplified underlying representations

méthodos ~ *methódon* root allomorphs: |méthod-| and |methód-|
thálasa ~ *thalasón* root allomorphs: |thalas-| and |thálas-|
uranós ~ *uranón* suffix allomorphs: |-ós| and |-ón|.

One more note is in order. The allomorphic behaviour of the affixes cannot be attributed to the declension class or gender of the nouns they belong to. For one, -on is the genitive plural marker for practically all nouns (except for the ones that only occur in the singular). The distribution of stressed/unstressed/pre-stressing -on is rather arbitrary: whether or not a noun takes the stressed or unstressed version does not depend on gender or declension class or prosody (classification basically taken from Holton et al. 2004; I left out imparisyllabic nouns), but on its phonological structure in Ancient Greek.

Drachman et al. (1995), Revithiadou (1999) and Apoussidou (2007) assume underlying foot structure as specification (Inkelas 1994), to account for stress-shifting pattern in nouns caused by e.g. the genitive plural suffix -on. I will give an alternative account here, claiming that morphemes are underlyingly stressed in the language, but that there is no need to assume underlying foot structure or pre- and post-stressing mechanisms. Instead, there are only two straightforward underlying specifications: stressed and unstressed. The complex pattern in the language comes about with allomorphy: roots and affixes have underlyingly stressed and unstressed variants. For acquiring the stress patterns, no intricate underlying representations have to be acquired other than are observable in the data.

1. (a) The shift: a relic

The stress pattern of Modern Greek is complex because it developed out of the Ancient Greek (AG) pitch accent. This accent was lexical in AG as well: any of the last three syllables of a word could bear one. But the shift of the accent within the paradigm (the “recessive accent”) was predictable: stress would shift if the final syllable was “heavy” (see Steriade 1988, Kiparsky 2003). Final syllables were heavy in AG if they contained either a long vowel (AG had phonemic vowel length) or ended in a consonant cluster. The genitive plural suffix -on contained a long [o:], written as ‘ω’ (an *omega* ‘big o’, as opposed to the short *omikron* ‘small o’). The trisyllabic window in AG was therefore a *trimoraic* one (cf. Smith & Apoussidou in prep.). This explains why the accent was attracted away from the antepenultimate syllable in cases like *lavírinthos* ~ *lavirínthon*. In *lavírinthos*, the final syllable is light (-os contained a short vowel: *laví_μri_μntho_μs*) and the accent is on the antepenultimate syllable because this syllable happens to contain the third mora from the end. In *lavirínthon*, the final syllable is heavy (because the /o/ in -on is long: *lavirí_μntho_{μμ}n*), causing the stress to shift a syllable to the right. An accent on the antepenultimate syllable would therefore violate the trimoraic window: **laví_μri_μntho_{μμ}n*.

Newton (1972:12) suggests that vowel length is still preserved in the modern language underlyingly, arguing that under this assumption, the stress shift remains predictable. However, Philippaki-Warbuton (1976) mentions that speakers do not use the shifted forms as much anymore, indicating that speakers are not aware of the Ancient Greek distinction. I argue (in line with Philippaki-Warbuton 1976) that speakers of the modern language are not aware of the underlying phonemic vowel length proposed by Newton and that the stress shift is just lexically conditioned, because a) there is no evidence of phonemic vowel length in the phonetic signal, so the question is how speakers of Greek come to this knowledge and b) nowadays, stress in at least more informal speech does not shift as often anymore (see also Holton et al. 2004), which is not explained under the assumption that underlying vowel length is somehow transparent.

It thus appears that the loss of the vowel length distinction pulls the rug out from under the

phonological condition that caused the stress shift.⁷ And since the language already made use of lexical stress anyway, I argue that at least in the nominal paradigm, stress is lexical all the way.

1. (a) Frequency patterns

As of now, not much quantitative data is available about how many words exist with the different patterns, and how many of them shift. Revithiadou (1998) compiled a small corpus of 16.000 nouns in *-os* and *-a*, of which she classified 67.5% as accented and 18.5% as unaccentable roots (indicating that these words do not shift) and 10.2% as unmarked ones (indicating that these shift in the genitive case). Protopapas (2006) indicates that penultimate stress is the most frequent (but not overwhelmingly frequent) pattern in MG. However, his count is based on words with two or more syllables, and it is not clear whether antepenultimate stress is simply less frequent due to the fact that disyllabic words cannot be stressed pre-penultimately. Protopapas et al. (2006) tested whether the stress diacritic in written MG is necessary for correctly reading a word or whether children have alternative strategies for stressing. Again, penultimate position seems to be the most favoured position for stress in MG, but there is no information about stress shifting patterns. Sims (in press) examined MG speakers in their use of periphrastic constructions to avoid stress shifting patterns in MG, but her sample of nouns does not indicate a percentage of stress-shifting versus non-shifting patterns. None of these studies give a count of the different patterns in terms of possible variation as mentioned by Holton et al. (1997[2004]) or Philippaki-Warbuton (1976). The goal of this paper is not a quantitative survey of the occurring variation, but in the following I will give a sample of it, drawn from the Hellenic National Corpus (HNC; <http://hnc.ilsp.gr/en/default.asp>) of written texts. The examples are composed of words with three to five syllables and compared with Holton et al. (1997[2004]). Words with final stress in the nominative case are disregarded for the moment, since they never show variation.

1. Sample of frequencies (empty cells rendered a count of zero):

gloss	nominative	genitive (shift)	genitive (no shift)	ratio
‘sea’	thálasa (2831)	thalasón (94)	⁸	30:1
‘tomato’	domáta (105)	domatón (1)	⁹	105:1
‘almond’	amígdalo (16)	amigdálon (3)	¹⁰	5:1
‘butter’	vútiro (99)	¹¹	vútiron (1)	99:1
‘sheep’	próvato (119)	prováton (50)	próvaton (2)	2:1 60:1
‘man’	ánthropos (6091)	anthrópon (4281)	ánthropon (11)	1,5:1 554:1
‘headache’	ponokéfalos (177)	ponokefálon (3)	¹²	59:1

Some variation was found in the genitive singular instead of the genitive plural, which is not indicated here. The genitive case is rather rare, with the exception of high-frequency nouns such as *anthrópon* and *thalasón*. There is also no clear pattern as of how frequent one genitive form is over the other, if there is variation. In general, the shifting forms are more frequent than the non-shifting forms (with the exception of one occurrence of *vútiron*). Since the HNC is a corpus of written material only, this rather conservative pattern might be reflecting a more formal register than would be used in spoken language. It suffices to indicate that indeed there exists variation

⁷ The stories by Allen (1689[1999]) and Devine & Stephens (1994) go that the length distinction was lost because the duration of the long vowels was re-interpreted as a stress cue, with a subsequent shortening of all unaccented vowels.

⁸⁺⁹ According to Holton et al. (1997[2004]:57; henceforth HMP), these words should always shift in the genitive.

⁹

¹⁰⁺¹¹ According to HMP:64, these words should show variation.

¹¹

¹² According to HMP:52, these words should not shift.

in the stress patterns; if anything, the variation would be bigger in the spoken language. This variation is apparently acquired by some of the speakers at least, and its learnability will be accounted for here.

1. (a) Harmonic allomorphy instead

I argue that the stress pattern is highly lexical and that the use of allomorphs can account for both the shifting and the non-shifting patterns, but that some of the shifting patterns are more difficult to acquire than others. This can be formalized by adopting a framework such as Harmonic Grammar (Legendre, Miyata & Smolensky 1990, Smolensky & Legendre 2006), differing from Optimality Theory in that constraints can gang up to choose a candidate not preferred by a strict ranking hierarchy.

Determining the underlying representation for an incoming form works as follows. Learners adopt underlying representations based on what can be observed on the overt level (cf. Smolensky 1996 and references therein). A word that is observed in the nominative singular as stressed on the root, e.g. *thálasa*, leads to the creation of an entry with a stressed root morpheme [thálas-] and an entry with an unstressed suffix [-a], in form of lexical constraints connecting the meaning and syntactic information of the morphemes with their phonological representation. Is the word subsequently observed in the genitive plural form as *thalasón*, an unstressed allomorph for the root is created, [thalas-], as well as a stressed suffix morpheme [-ón]. Since the learner cannot know beforehand whether s/he is learning a language with lexically or grammatically assigned stress, the hypothesized underlying representations are evaluated in combination with their surface structures and overt forms.

In the following, I very roughly outline the working ways of Harmonic Grammar and apply it to a “grammar” containing lexical constraints. The lexical constraints stem from what can be observed in the overt form (displayed in square brackets ‘[]’): a stress on the root in the overt form gives rise to the creation of a lexical constraint linking the meaning (in angle brackets ‘< >’) of this root to an underlying representation (in pipes ‘| |’) of this morpheme containing the segments and a mark for the stress on the designated syllable.¹³ For instance, the root ‘sea’ comes in stressed and unstressed flavours: stressed if inflected with the nominative case suffix -a, and unstressed if inflected with the genitive plural suffix -ón. Likewise, a constraint for unstressed -a and stressed -ón are created:

1. Creation of lexical constraints

given:	created:
‘sea-Nom.Sg.F’ [thálasa] →	<sea> thálas- ; <Nom.Sg.F> -a
‘sea-Gen.Pl’ [thalasón] →	<sea> thalas- ; <Gen.Pl> -ón

For the genitive plural suffix, a lexical constraint with an unmarked -on will be created for words such as *prováton* ‘sheep-Gen.Pl’, and so on and so forth.

In Harmonic Grammar, constraints are not strictly ranked, but are assigned numerical weights (the numbers on top of the constraint names in tableau (19)). Each violation of a constraint is assigned a negative value of -1. The harmonic score (the number that determines the winning candidate) is calculated by multiplying the violation value with the constraint weight, and taking the sum of all the products for a candidate. The harmonic value closest to zero (here: -2.5) determines the winning candidate; in the case of (19) it is the candidate without any lexical specification for stress, which is preferred by the constraint without underlying lexical specifications for the root ‘sea’. For ease of exposition I only use the lexical constraints evaluating the underlying representations, leaving out the surface structures and overt forms.

1. Determining the underlying representation for morphemes in HG: /thalas+a|

	3	2.5	1	
--	---	-----	---	--

¹³ These assumptions are not trivial; the learner already needs to know what segments are, needs to be able to hear stress, needs to know the meaning, needs to know that there are two morphemes in the word etc. The acquisition of this knowledge is at this point for future research.

<sea+Nom.Sg.F>	<sea> thalas-	<sea> thálas-	<Nom.Sg> -a	
☞ thalas+a		-1		-2.5
thálas+a	-1			-3

Under the current weighting of constraints in (19), the word *thálasa* in the nominative singular is analyzed as underlyingly unmarked for stress. In combination with the genitive plural suffix, different constraints and candidates come into play: combinations of unstressed/stressed roots and unstressed/stressed suffixes. Tableau (20) shows how the candidate is evaluated as the most harmonic one that has an underlyingly unstressed root and the underlyingly stressed allomorph of the genitive plural suffix, -ón: the candidate violates the lexical constraint for a stressed root and the constraint for an unstressed suffix, but in sum provides the harmonic score closest to zero.

1. Choosing the stressed allomorph of <Gen.Pl>: [thalasón] [F0D5?] |thalas+ón|

	3	2.5	1.1	1	
<sea+Gen.Pl>	<sea> thalas-	<sea> thálas-	<Gen.Pl> -ón	<Gen.Pl> -on	
thalas+on		-1	-1		-3.6
☞ thalas+ón		-1		-1	-3.5
thálas+on	-1		-1		-4.1
thálas+ón	-1			-1	-4

In this way, the shift from the antepenultimate syllable to the ultimate syllable can be accounted for without assuming underlying foot structures that would require ad hoc assumptions about how to acquire them.

Next to the shift from the antepenultimate to the ultimate syllable exists the shift from the antepenult to the penult in Greek. It turns out that this shift is less easy to accomplish, given the weighting of the constraints in (20). Tableau (21) shows that the actual winner is the candidate with a specification on both the root and the suffix; unfortunately, the underlying stress is not on the correct syllable. If this candidate is chosen as the underlying form, a surfacing stress on the antepenultimate or ultimate syllable is likely.

1. Shift from antepenultimate to penultimate syllable? *|provát+ón| /pro(váton)/

	1.5	1.4	1.1	1	
<sheep+Gen.Pl>	<sheep> próvat-	<sheep> provát-	<Gen.Pl> -ón	<Gen.Pl> -on	
provat+on	-1	-1	-1		-4
provat+ón	-1	-1		-1	-3.9
próvat+on		-1	-1		-2.5
☞ próvat+ón		-1		-1	-2.4
provát+on	-1		-1		-2.7
provát+ón	-1			-1	-2.5

There are two candidates that have a harmony score close to the winning candidate of (21), |próvat+on| and |provát+ón|. The latter candidate has the root allomorph that could result in the aspired shift of stress if the weights for <sheep> |próvat-| and <sheep> |provát-| are switched. However, this would lead to another winning candidate in the nominative form as well. There is no weighting of the assumed constraints that both accounts for (20) and (21). If the lexical constraint <sheep> |provát-| outweighs the constraint <sheep> |próvat-|, then the root allomorph with final stress would win, something that under a faithful evaluation would result in the wrong surface structure with penultimate stress in the nominative case:

1. Re-weighting the constraints

	1.5	1.4	1.1	
<sheep+Nom.Sg>	<sheep> provát-	<sheep> próvat-	<Nom.Sg> -o	
provat+o	-1	-1		-2.9
próvat+o	-1			-1.5
☞ provát+o		-1		-1.4

Note that we are still only talking about underlying representations here. There are two ways that could make an antepenultimately stressed representation win in the nominative case and a penultimately stressed representation in the genitive case. One is that unfaithful surface structures assign stress differently than underlyingly present. The other is adopting a stochastic evaluation of the constraint weights (similar to stochastic OT): the candidate with the finally stressed root |provát+ón| could still win in (21) in some cases if one assumes noise that is added to each evaluation. This slight change in the weighting can result in the selection of a different candidate. The stochastic feature is adopted in the simulations described below, where different virtual learners are exposed to different stress patterns. The prediction is that the learners exposed to lexical stress on different positions within a word, but without stress shifts in the genitive case, will learn the pattern correctly, while learners exposed to a stress pattern with a shift in the genitive case will acquire the shift only partially.

1. Simulating the acquisition process

(a) Computational studies on the learnability of stress patterns

There has been a considerable amount of research on the computational learnability of stress. Most studies focused on the learning of the grammatical part (e.g. Dresher & Kaye 1990, Clark & Roberts 1993, Daelemans et al. 1994, Gupta & Touretzky 1994, Tesar 1998, Tesar & Smolensky 2000, Heinz 2006, 2009, Hayes & Wilson 2008), especially on the acquisition of quantity-sensitive or -insensitive systems. More recently the problem of learning on how the respective underlying material could be acquired has been tackled (e.g. Tesar 2004, 2009, Alderete et al. 2005, Jarosz 2006). Most of these approaches assume *offline* or *batch* learning, i.e. learning from the complete set of data presented to the learner at the same time. Since it is more likely that infants process input *online*, with one data item at a time, we need an approach capable of that. Further, since we are dealing with a language here that has unpredictable, i.e. lexical stress, in combination with a phonological restriction, the focus here will be on the acquisition of underlying material in line with the acquisition of the grammatical regularities. For that, Apoussidou's (2007) approach of learning underlying forms is adopted, which is capable of handling several levels of hidden structure.

1. (a) Tackling the acquisition of hidden structures

As outlined, the stress pattern in Greek is complex, but can be broken down into three basic patterns: 1) the phonological default and trisyllabic restriction assigning stress in the antepenultimate (if there is one); 2) lexical stress on different morphemes resulting in lexical stress on the antepenultimate, penultimate and ultimate syllable; 3) like 2), but additionally a stress shift in the genitive case. The patterns co-occur and it is likely that most speakers of Greek use all three patterns, resulting in a hybrid stress system. To test the learnability of the different stress patterns in Greek, I set up different groups of virtual learners that are trained on the three basic stress patterns and on two hybrid patterns. Learners are considered as being successful if they render the pattern they have heard correct, i.e. if they reproduce the words they heard in the training phase as they heard them. In addition to that they will be tested on how well they generalize to words they have not heard. All learners are noisy Harmonic-Grammar learners (Boersma & Pater 2008) and have the same structural and faithfulness constraints. They differ in the lexical constraints depending on which words they are exposed to. The weighting of these constraints comprises the lexicon. The structural constraints are given a head start over the lexical and faithfulness constraints (cf. Jesney & Tessier 2008), simulating the creation of lexical

constraints and with them the faithfulness constraints that the learners should create themselves (in lack of a lexical and faithfulness constraint induction mechanism).

1. (a) The training sets

I tested five different data sets listed in (23), meaning that different groups of virtual learners are trained on different stress patterns, all including forms in the nominative and genitive case with a ratio of 3:1 (i.e. for each occurrence of a genitive case form there are three occurrences of the corresponding nominative case form).

1. The training sets
1. No shift/default
2. No shift/lexical
3. Always shift
4. Sometimes shift
5. Some shift

The different training sets are idealized learning conditions; in real life, speakers of Greek are exposed to different frequencies of all these patterns. The hybrid patterns of (iv.) and (v.) come closest to a real-life scenario; pattern (i.) is a test of the phonological default only, whereas pattern (ii.) comes close to the informal speech style without stress shift, and pattern (iii.) comes close to the formal speech style where stress always shifts.

No shift and a fixed position for stress

The “no shift/default” training set in (i.) tests whether the virtual learners acquire the phonological default (stress on the antepenultimate syllable if there is one) and the trisyllabic window restriction (stress not further to the left than the antepenultimate syllable). It comprises four 2-5-syllable words that have stress on the penult (the 2-syllable words) or on the antepenult (all other words) in all cases, i.e. stress does not shift in the genitive case. The “no shift/default” set is given here:

1. The “no shift/default” training set¹⁴

Nominative singular	Genitive plural
<tree+Nom.Sg.N> [déndro]	<tree+Gen.Pl> [déndron]
<sheep+Nom.Sg.N> [próvato]	<sheep+Gen.Pl> [próvaton]
<almond+Nom.Sg.N> [amígdalo]	<almond+Gen.Pl> [amígdalon]
<headache+Nom.Sg.M> [ponokéfalos]	<headache+Gen.Pl> [ponokéfalón]

The training items consist of the meaning and syntactic information with the phonetic form. Our virtual learners are fed rather these pairs of overt (phonetic) forms and their corresponding meaning than just the phonetic form to enable them to distinguish between lexically and phonologically assigned stress. The overt forms contain segmental information and stress (but no information on foot structure), and the meaning contains the lexical and syntactical information. This means in effect that the virtual learners already know that the words (in our case here) contain a morpheme boundary and also where that boundary is; two things that a learner under more natural conditions is not provided with. What the virtual learners had to come up with themselves were the surface structures (generated by the grammar of the learners; here: feet and stresses) and the underlying representations (generated by the lexicon of the learners; here: underlying stress vs. no underlying stress).

No shift and stress on different positions in different words

The “no shift/lexical” training set (ii.) tests whether virtual learners acquire the trisyllabic restriction and lexical stress on different positions within a word. It comprises six 2-5-syllable words that have stress on either the antepenult, the penult, or ultimate syllable. Stress does not shift to another syllable in the genitive case.

¹⁴ ‘Nom.’ stands for nominative case; ‘Gen.’ for genitive; ‘Sg.’ for singular; ‘Pl.’ for plural; and ‘M’, ‘F’ and ‘N’ for masculine, feminine and neuter gender, respectively.

1. The “no shift/lexical” set

Nominative singular	Genitive plural
<tree+Nom.Sg.N> [déndro]	<tree+Gen.Pl> [déndron]
<sheep+Nom.Sg.N> [próvato]	<sheep+Gen.Pl> [próvaton]
<hope+Nom.Sg.F> [elpída]	<hope+Gen.Pl> [elpídon]
<brother+Nom.Sg.M> [adelfós]	<brother+Gen.Pl> [adelfón]
<almond+Nom.Sg.N> [amígdalo]	<almond+Gen.Pl> [amígdalon]
<headache+Nom.Sg.M> [ponokéfalos]	<headache+Gen.Pl> [ponokéfalón]

Stress on different positions in different words and shift to the right

The “always shift” set in (iii.) comprises six 2-5-syllable words that do not only differ in stress placement, but that furthermore always shift stress in the genitive, either from the antepenult to the penult, from the antepenult to the ultimate or from the penult to the ultimate. This set tests the trisyllabic restriction and lexical stress on different syllables, as does the “no shift/lexical” set, but in addition, stress shifts to the right. The stress shift is not predictable: sometimes it shifts only one syllable to the right (e.g. in the case of *próvato* ~ *prováton*), and sometimes it shifts two syllables (e.g. *thálasa* ~ *thalasón*).

1. The “always shift” set

Nominative singular	Genitive plural
<tree+Nom.Sg.N> [déndro]	<tree+Gen.Pl> [déndron]
<tomato+Nom.Sg.F> [domáta]	<tomato+Gen.Pl> [domatón]
<sheep+Nom.Sg.N> [próvato]	<sheep+Gen.Pl> [prováton]
<sea+Nom.Sg.F> [thálasa]	<sea+Gen.Pl> [thalasón]
<almond+Nom.Sg.N> [amígdalo]	<almond+Gen.Pl> [amígdalon]
<headache+Nom.Sg.M> [ponokéfalos]	<headache+Gen.Pl> [ponokefálon]

The data only contain unstressed nominative suffixes. The genitive plural suffix, which is the same across the genders, appears as stressed in some words and as unstressed in others, depending on the location of the stress in the nominative case and the extent of the stress shift.

Shift of stress only sometimes

The “sometimes shift” set in (iv.) consists of six words (two disyllabic ones, two trisyllabic ones, one quadrisyllabic and one pentasyllabic word), of which two show variation in the genitive plural (*próvato* and *amígdalo*, respectively). It tests whether the virtual learners are able to acquire a pattern where certain words sometimes shift stress in the genitive case and sometimes do not. As before, the trisyllabic restriction still holds:

1. The “sometimes shift” set

Nominative singular	Genitive plural
<tree+Nom.Sg.N> [déndro]	<tree+Gen.Pl> [déndron]
<mountain+Nom.Sg.N> [vunó]	<mountain+Gen.Pl> [vunón]
<tomato+Nom.Sg.F> [domáta]	<tomato+Gen.Pl> [domatón]
<sheep+Nom.Sg.N> [próvato]	<sheep+Gen.Pl> [próvaton]
<almond+Nom.Sg.N> [amígdalo]	<almond+Gen.Pl> [amígdalon]
<headache+Nom.Sg.M> [ponokéfalos]	<almond+Gen.Pl> [amígdalon]
	<headache+Gen.Pl> [ponokefálon]

Again, depending on the extent of the stress shift, the genitive plural suffix appears stressed in some words while it appears as unstressed in others. This set furthermore contains a word with final stress in the nominative case, *vunó*. This means in effect, that there is also variation for the nominative neuter suffix -o, which here appears as stressed in some words (well, one word), but not in others.

Shift of stress only in some words, not in others

The “some shift” set in (v.) consists of eight words of which five words shift stress and three do not. It tests whether the virtual learners are able to acquire a pattern where some words shift stress in the genitive case and some do not. The difference to the set in (iv.) is that there is no variation in the sense that a certain word sometimes shifts the stress in the genitive case, but rather it either always shifts the stress or it never shifts it.

1. The “some shift” set

Nominative singular	Genitive plural
<tree+Nom.Sg.N> [déndro]	<tree+Gen.Pl> [déndron]
<mountain+Nom.Sg.N> [vunó]	<mountain+Gen.Pl> [vunón]
<tomato+Nom.Sg.F> [domáta]	<tomato+Gen.Pl> [domatón]
<sheep+Nom.Sg.N> [próvato]	<sheep+Gen.Pl> [próvaton]
<butter+Nom.Sg.N> [vútiro]	<butter+Gen.Pl> [vutíron]
<brother+Nom.Sg.M> [adelfós]	<brother+Gen.Pl> [adelfón]
<almond+Nom.Sg.N> [amígdalo]	<almond+Gen.Pl> [amigdálon]
<headache+Nom.Sg.M> [ponokéfalos]	<headache+Gen.Pl> [ponokefálon]

This set contains two words that are finally stressed even in the nominative case: *vunó* and *adelfós*. They do not shift stress in the genitive case, i.e. the root remains unstressed in the genitive. As a consequence, the neuter suffix -o and the masculine suffix -os appear as stressed in some words and as unstressed in others. As before, the genitive plural suffix appears as stressed in some words and as unstressed in others.

1. (a) The constraints

Three types of constraints are implemented in the learners: structural constraints evaluating the surface structures and overt forms, faithfulness constraints connecting the phonological surface structures to the underlying representations, and lexical constraints evaluating the underlying representations, comprising the phonological part of the lexicon. The structural and faithfulness constraints shared by all learners are given in (29) (constraints are defined as in Tesar & Smolensky 2000):

1. Structural constraints: Faithfulness constraints:

ALL-FEET-LEFT/RIGHT (AFL/AFR)

FOOTBINARITY (FTBIN)

IAMB

MAXROOT, MAXAFFIX

NONFINALITY (NONFIN)

PARSE

TROCHEE

The number of lexical constraints is not the same for all learners and depend on which forms they are trained on in the learning phase. The lexical constraints take the form of ‘connect meaning and syntactic information to a certain phonological underlying representation’, e.g. <Nom.Sg.F> [-a], where ‘<Nom.Sg.F>’ stands for the nominative case singular feminine, and ‘[-a]’ stands for the underlying phonological representation of the suffix.

1. (a) Predictions

Several predictions as to how the learners of the different sets are going to perform:

- The “no shift/default” learners should be able to acquire the trisyllabic window and assign stress mainly by the grammar, i.e. the structural constraints. However, an interpretation of the forms as sometimes being lexically stressed underlyingly cannot be excluded.
- The “no shift/lexical” learners should acquire the trisyllabic restriction and lexical stress on the final three syllables within, depending on the word.
- The “always shift” learners are expected to acquire stress on the final three syllables depending on the word, and to perform the shift in the genitive case sometimes, but most of the times should display the same stress pattern in the genitive case as in the nominative case.
- The “sometimes shift” and the “some shift” learners are expected to learn lexical stress as well as the shift, but to a lesser extent than the “always shift” learners, due to a less frequent occurrence of the shift.

1. (a) Computer settings

All training sets have words of a length of two to five syllables in common, as well as the trisyllabic restriction (i.e. that stress never occurs to the left of the antepenultimate syllable).

Depending on the training set the virtual learners were supplied with different sets of lexical constraints. Only lexical constraints concerning forms that were actually observed in the training sets were implemented in the virtual learners (for instance, learners of the “no shift/lexical” set did not have a lexical constraint for the word ‘mountain’, <mountain> |vun-|, that the learners of the “sometimes” and “some shift” set had).

In both virtual comprehension and production, the learners could choose from a list of candidate quadruplets consisting of meaning, underlying representation, surface structure and overt forms. The candidates within one tableau differed with respect to the underlying stress specification (stressed/unstressed), the foot and stress structures on the surface level (iambs vs. trochees, monosyllabic vs. disyllabic feet, final syllable extrametricality, and direction of parsing) and different stress positions on the overt level.

The virtual learners were all stochastic Harmonic Grammar learners (Boersma & Pater 2008) raised in the Praat programme (Boersma & Weenink 2008). For each training set, ten virtual learners were conceived. They all heard 200 000 items in their training phase, in a randomized order and with slightly different frequencies (because the forms were drawn randomly from the different sets and the total number of forms of each set are not always dividers of 200 000), but a rough ratio of 3:1 nominative vs. genitive case forms. Plasticity, i.e. the amount that constraints were shifted in case of an error, was set to 1 and did not change in the course of learning. Noise was set to 2 (enabling constraints to switch for each new evaluation of a form). The structural constraints were ranked at a 100 initially, while the faithfulness and lexical constraints were ranked at 0. This was to prevent an initial influence of the lexical constraints over the structural constraints, to simulate the creation of the lexical constraints (that were implemented but should in principle be created by the learners themselves).

1. (a) Results

In all conditions, variation occurred within all learners, not across learners.

The “no shift/default” virtual learners

As mentioned above, the “no shift/default” learners were trained on four different words (one disyllabic, one trisyllabic, one quadrisyllabic and one five-syllable word) in the nominative and the genitive case (eight words in total repeated about 25 000 times each). The virtual learners were supplied with the structural and faithfulness constraints discussed in section (7.2). Since the stress did not shift in the genitive case, seven lexical constraints were implemented: one for each root (in this case underlyingly stressed <tree> |déndr-|, <sheep> |próvat-|, <almond> |amígdal-| and <headache> |ponokéfal-|) and one for each encountered suffix (underlyingly unstressed <Nom.Sg.N> |-o|, <Nom.Sg.M.> |-os| and <Gen.Pl> |-on|). Table (30) shows the results for

the training data (pairs of meaning and phonetic form). Learning can be called successful, since all virtual learners reproduce the data they heard to a hundred percent correct:

1. Results of the “no shift/default” condition:

Nominative singular	%	Genitive plural	%
<tree+Nom.Sg.N> [déndro]	100	<tree+Gen.Pl> [déndron]	100
<sheep+Nom.Sg.N> [próvato]	100	<sheep+Gen.Pl> [próvaton]	100
<almond+Nom.Sg.N> [amígdalo]	100	<almond+Gen.Pl> [amígdalon]	100
<headache+Nom.Sg.M> [ponokéfalos]	100	<headache+Gen.Pl> [ponokéfalon]	100

Variation occurred on the hidden levels that the virtual learners had to come up with themselves: the underlying representations and surface structures, respectively. The candidates that the virtual learners could choose from were quadruplets of meaning, underlying representation, surface structure with feet, and the overt forms. These quadruplets differed in whether the underlying morphemes were stressed or not, and in foot structures on the surface level. For instance, for the meaning <tree>, two possible underlying representations were included, [dendr-] and [déndr-].¹⁵ In addition, all possible underlying representations were combined with surface structures with different foot structures and hence different positions of stress. The combined overt forms only carried the stress of the respective surface structure, i.e. there is never a mismatch between the stress of a surface structure and its accompanying overt form. Table 1. (see appendix) shows a sample of the candidate lists for each word, namely the variation in the winning candidate quadruplets that only differ in the underlying forms (both forms are deemed equally correct because they would sound the same on the phonetic level).¹⁶ We can see that the virtual learners slightly prefer the candidates with underlyingly stressed root morphemes to the underlyingly unmarked ones. The surface structures (represented in slashes ‘/ /’) did not vary: the grammars of the virtual learners assign binary feet, even to the cost of violating final syllable extrametricality in the disyllabic words.

Insert Table 1. here

In short, the virtual learners were able to acquire the stress pattern and assigned stress always on the antepenultimate syllable (except for the disyllabic forms). However, they had a slight preference to assume underlyingly stressed root morphemes. At this point the question arises whether the virtual learners truly acquired the trisyllabic restriction as a phonological rule, or whether they simply assign lexical stress to every word. In anticipation of this question, the virtual learners were implemented before learning with words that matched the training forms in number of syllables, but that the virtual learners did not get to hear during the training phase. In the test phase, when prompted to produce these unheard words, it appeared that even these generalizations were correct: all unheard words were accordingly stressed, even though no lexical constraints for these words existed. They were stressed only by the weighting of the structural constraints, as can be seen in Table 2. (see appendix).

Insert Table 2. here

In these cases, the virtual learners assigned about chance probability of underlyingly stressed and unstressed representations.

The next section shows the outcome of the “no shift/lexical” set, where the virtual learners do not only have to learn the trisyllabic restriction, but also that stress can occur on any of the last three syllables.

No shift/lexical

In addition to the four words of the “no shift/default” set, the “no shift/lexical” set includes two more words: a trisyllabic word with penultimate stress and a trisyllabic word with ultimate stress. Again, stress does not shift to another syllable in the genitive form. The virtual learners of this set are supplied with 16 lexical constraints (in addition to the structural and faithfulness constraints): eight for the roots, and eight for the suffixes. The excess lexical constraints are due to the fact that the two suffixes –os and –on appear as stressed in the ultimately stressed

¹⁵ Although not observed in this training set, unstressed underlying forms were always included as possible candidate parts as the most unmarked representations.

¹⁶ The complete list of all assumed candidates are omitted for reasons of space.

word for “brother”, while they appear as unstressed in the other words. In addition, a feminine suffix *-a* occurs.

It can be said that the “no shift/lexical” virtual learners were also successful in acquiring the correct stress pattern, as can be seen from the table in (31).

1. Results of the “no shift/lexical” condition

Nominative singular	%	Genitive plural	%
<tree+Nom.Sg.N> [déndro]	100	<tree+Gen.Pl> [déndron]	100
<sheep+Nom.Sg.N> [próvato]	100	<sheep+Gen.Pl> [próvaton]	100
<hope+Nom.Sg.F> [elpída]	100	<hope+Gen.Pl> [elpídon]	100
<brother+Nom.Sg.M> [adelfós]	100	<brother+Gen.Pl> [adelfón]	99.9
<almond+Nom.Sg.N> [amígdalo]	100	<almond+Gen.Pl> [amígdalon]	100
<headache+Nom.Sg.M> [ponokéfalos]	100	<headache+Gen.Pl> [ponokéfalón]	100

However, in the hidden structures more variation occurs; this time both on the surface level and the underlying level (Table 3.). All virtual learners chose the according underlying specification (stressed/unstressed) in the roots, as observed in the data, but alternated with respect to the specification of the genitive plural suffix, as can be expected from the training data. On the surface, feet were still invariably binary, but ranged from trochees to iambs. Extrametricality became rather unimportant with the inclusion of finally stressed words.

Insert Table 3. here

As can be seen from the generated unheard forms below, the trisyllabic restriction was acquired as well. However, due to the fact that lexical stress appeared on different positions, variation occurred as to where stress could fall in these words (Table 4.).

Insert Table 4. here

In sum it can be said that the lexical specifications of this training condition are learned: the roots are underlyingly stressed on their respective syllable. The trisyllabic restriction is acquired in the sense that stress is never assigned pre-antepenultimately, even in untrained words. However, the antepenultimate syllable is not the default position in untrained words. Even though variation occurs even on the phonetic level, a preference for underlyingly unstressed, overtly finally stressed forms (e.g. [stafid+a] /sta.(fi.dá)/ [stafidá]) can be observed. This is surprising, because the genitive case suffix occurred as stressed in only one form, *adelfón*.

Structurally speaking, binary feet are preferred over extrametricality and uniformity of foot type (i.e. both iambs and trochees are generated).

Shifting always

The “always shift” set tests the trisyllabic restriction and lexical stress on different syllables. The set comprises six 2-5-syllable words that do not only differ in stress placement, but that also shift stress in the genitive, either from the antepenult to the penult, from the antepenult to the ultima or from the penult to the ultima.

The virtual learners of this condition struggled to acquire the pattern, and had a considerably high error quota.¹⁷ Not only do the learners have problems with learning the lexical stress of the nominative case (something the learners in the second condition had no problems with), but also some shifts in the genitive seem to be harder to acquire than others. Shifts from the penult to the ultima are acquired comparatively well, while shifts from the antepenult to the ultima or the penult are poorly acquired:

1. Results of the “always shift” condition:

¹⁷ It is possible that with even more training, the learners would become a little bit better, but considering the amount of training data and the rather big learning steps, this seems not likely.

Nominative singular	%	Genitive plural	%
<tree+Nom.Sg.N> [déndro]	89.0	<tree+Gen.Pl> [dendró]	93.6
<tomato+Nom.Sg.F> [domáta]	82.2	<tomato+Gen.Pl> [domatón]	45.0
<sheep+Nom.Sg.N> [próvato]	72.5	<sheep+Gen.Pl> [prováton]	12.8
<sea+Nom.Sg.F> [thálasa]	68.4	<sea+Gen.Pl> [thalasón]	2.6
<almond+Nom.Sg.N> [amígdalo]	80.0	<almond+Gen.Pl> [amigdálon]	16.1
<headache+Nom.Sg.M> [ponokéfalos]	68.5	<headache+Gen.Pl> [ponokefálon]	28.8

Even in this case though the trisyllabic restriction is acquired; there is no preference for a clear stress pattern in unheard words, but neither the erroneously stressed words of the trained condition nor the unheard forms are stressed further to the left than the antepenult. These learners therefore acquire the trisyllabic restriction as well.

The virtual learners hence have more difficulty in acquiring the “always shifting” pattern. This connects to what can be observed for real speakers of Greek, which display variation and even insecurities about the stress placement especially in the genitive case.

Shifting sometimes

The “sometimes shift” set tests whether the virtual learners are able to acquire a pattern where certain words sometimes shift stress in the genitive case and sometimes not. The set consists of six words, of which two show variation in the genitive plural. This pattern is acquired better than the “always shifting” condition, but compared to the nominative case, the genitive case is considerably badly acquired.

1. Results of the “sometimes shift” condition:

Nominative singular	%	Genitive plural	%
<tree+Nom.Sg.N> [déndro]	100	<tree+Gen.Pl> [déndron]	100
<mountain+Nom.Sg.N> [vunó]	100	<mountain+Gen.Pl> [vunón]	100
<tomato+Nom.Sg.F> [domáta]	93.5	<tomato+Gen.Pl> [domatón]	50.9
<sheep+Nom.Sg.N> [próvato]	85	<sheep+Gen.Pl> [próvaton]	71.2
<almond+Nom.Sg.N> [amígdalo]	80.8	[prováton]	6.7
<headache+Nom.Sg.M> [ponokéfalos]	76.2	<almond+Gen.Pl> [amígdalon]	64.1
		[amigdálon]	12
		<headache+Gen.Pl> [ponokefálon]	23.9

In the ‘sometimes shift’-condition, the non-shifting forms were better acquired than the shifting forms. This looks like it could not be a frequency effect since both genitive variants were presented equally often; however, considering the nominative forms, the non-shifting stress genitive cases add up to the ones in the nominative case. This result is in contrast to the small sample count of the HNC, where shifting genitive forms outnumbered the non-shifting genitive forms. Even in the untrained forms though, the trisyllabic restriction is obeyed.

Some shift, some don't

The learners of the “some shift” set behave similar to the “sometimes shift” learners, in that they acquire the nominative case forms better than the genitive case forms. Words that shift their stress in the genitive case are furthermore produced less often correct than the nominative forms of not-shifting genitive forms.

1. Results of the “some shift” condition:

Nominative singular	%	Genitive plural	%
<tree+Nom.Sg.N> [déndro]	100	<tree+Gen.Pl> [déndron]	100
<mountain+Nom.Sg.N> [vunó]	100	<mountain+Gen.Pl> [vunón]	100
<tomato+Nom.Sg.F> [domáta]	99.9	<tomato+Gen.Pl> [domatón]	80.3
<sheep+Nom.Sg.N> [próvato]	100	<sheep+Gen.Pl> [próvaton]	99.9
<butter+Nom.Sg.N> [vútiro]	66.1	<butter+Gen.Pl> [vutíron]	32.6
<brother+Nom.Sg.M> [adelfós]	99.3	<brother+Gen.Pl> [adelfón]	80.4
<almond+Nom.Sg.N> [amígdalo]	80.2	<almond+Gen.Pl> [amigdálon]	16.8
<headache+Nom.Sg.M> [ponokéfalos]	72.4	<headache+Gen.Pl> [ponokefálon]	27.8

The unheard words were produced with mainly stress on the penult in the nominative case and on the ultima in the genitive case, with the exception of words ending in *-o* and *-os*: since they occurred as stressed in some nominative case forms, they tilted the results to final stress in the nominative case in words with these suffixes. These learners as well acquired the trisyllabic restriction.

1. (a) Resulting weights

In all conditions, AFR ended up with the highest weight (way above AFL), and the genitive plural unstressed allomorph *[-on]* with one of the lowest. FTBIN and PARSE never moved, indicating that they were never violated by a winning candidate (hence no error detection that could have elicited a re-weighting). This could have been due to the fact that they started out with higher initial ranking than the faithfulness and lexical constraints. TROCHEE always ended up higher than NONFINAL and IAMB, and MAX(R) always ended up higher than MAX(A). The weights of the structural constraints caused binary feet in all surface forms across learners and conditions, to the cost of syllable extrametricality and uniformity of rhythm (the learners both exhibited trochees and iambs in their surface forms). Together, the weights of the structural constraints ensured the preservation of the trisyllabic window across all conditions.

In the ‘no-shift/default’-condition, the lexical constraints hardly moved, as can be expected, since in this condition, stress was supposed to be assigned phonologically and not lexically.

Insert Table 5 here

In the ‘no-shift/lexical’-condition, the lexical constraints pertaining to stressed allomorphs were weighted higher than most of the lexical constraints pertaining to unstressed allomorphs, reflecting the fact that in this condition, stress should have been underlyingly marked.

Insert Table 6 here

In the ‘always shift’-condition, the lexical constraints ended up with weights still close to 0, their starting point. This is due to the fact that the training data contained conflicting items, and therefore led to the nominative case being less well acquired than in the ‘no shift/lexical’-condition (which differed only in the genitive case from the ‘always shift’-condition). The genitive case shift was even more poorly acquired probably because of its lesser frequency in the training data. The shift across two syllables in *thálasa* ~ *thalasón* is especially poorly acquired; this could also be a frequency effect.

Insert Table 7 here

In the ‘sometimes shift’-condition, the main difference to the ‘always shift’-condition is that the lexical constraints for the nominative suffixes have moved, resulting in an even worse acquisition of the shift.

Insert Table 8 here

In the ‘some shift’-condition, the weight of MAX(A) is much lower than in the other conditions, in relation to the other constraints. This is connected to the lexical constraints for the unstressed affix-allomorphs, which end up ranked, in opposition to the other conditions, where these lexical constraints often remained unranked.

Insert Table 9 here

In general, lexical constraints pertaining to unstressed allomorphs often did not move in the course of learning.

1. Discussion & Conclusion

All virtual learners were able to acquire the trisyllabic restriction even for words that they had not been trained on. However, neither stress on the antepenultimate (as proposed by e.g. Philippaki-Warbuton 1970) nor the penultimate syllable (as proposed by Protopapas et al. 2006) were the default pattern for untrained forms; rather, the final syllable was a preferred position. Apart from that, the stress patterns were acquired with different degrees of success. The no shift/default and the no shift/lexical pattern were acquired correctly; the child generations did not differ in their overt forms from the parent generations. In the former pattern, the structural constraints are responsible for stress assignment, in the latter, mainly the lexicon. The patterns including a shift in the genitive case were less successfully acquired. While stress on different positions within words was acquired less well than in the no shift conditions, it was better acquired than the shifts. Among the shifts, the ones from the penult to the ultima were acquired better than shifts from the antepenult to the ultima or the penult. Moreover, the nominative case forms were more poorly acquired in the always-shift condition than in the two hybrid patterns, where the nominative case forms were almost always produced correctly. While an in-depth analysis of the learning paths could shed some light on this issue, it is unlikely that frequency was the cause for this effect. The virtual learners were exposed to nominative vs. genitive forms in a 3:1 ratio, however, the genitive plural suffix occurred much more often than any of the roots or other suffixes simply because it was the only one for the genitive case, while for the nominative case different suffixes occurred depending on the gender of the form. Raising the occurrence of the genitive case (let's say, to a 1:1 ratio) would therefore probably not improve the learnability of the shift, and would only worsen the learnability of the nominative case. One could think of ways to improve the learnability results, by e.g. using a different framework, or by including different representations in the lexicon, or by using a different learning device, or all of them together. For instance, whole-word parses where incoming words are not broken up into morphemes but are parsed as a whole were not included in the candidate set. Neither were pre-stressing representations of suffixes included that could yield different results.¹⁸ However, the aim was to model the existing variation in contemporary Modern Greek, and not the perfect acquisition of the possible patterns. This aim has been achieved. I therefore would like to suggest that the poor learnability of the stress shift in the genitive case of the virtual learners stands for the difficulties and variation that real speakers of Greek display. Transferring the results of the computational simulations to spoken Greek, this would mean that the variation in the spoken language is due to an irreconcilability of grammatical and lexical demands of the different patterns, resulting from the Ancient variant. An empirical study of the variation in real Modern Greek (i.e. whether speakers have problems in producing the genitive shift in general, or whether they only have problems with some shifts) could shed more light on how far the proposed model is correct.

References

- Alderete, J. (1999). Morphologically governed accent in Optimality Theory. Doctoral dissertation, University of Massachusetts Amherst. [New York: Routledge, 2001].
- Alderete, J., A. Brasoveanu, N. Merchant, A. Prince, & B. Tesar (2005). Contrast analysis aids in the learning of phonological underlying forms. In *The Proceedings of WCCFL 24*, pp. 34-42.
- Allen, W. S. (1968[1999]). *Vox Graeca*. Cambridge University Press.
- Apoussidou (2007). *The learnability of metrical phonology*. Doctoral dissertation, LOT Dissertation Series No. 148.
- Apoussidou, D. & S. Nordhoff (submitted to *Phonology*). Feet in Sri Lankan Malay: No stress, please! Ms.
- Bickmore, L. (1989). Kinyambo prosody. Doctoral dissertation, University of California, Los Angeles.
- Bickmore, L. (1992). Multiple phonemic stress levels in Kinyambo. *Phonology* 9:155-198.
- Boersma, P. & J. Pater (2008). Convergence properties of a gradual learning algorithm for Harmonic Grammar. Ms, University of Amsterdam and UMass Amherst. Available at <http://roa.rutgers.edu/>.
- Boersma, P. & D. Weenink (2008). *Praat: doing phonetics by computer*. [Computer pro-

¹⁸ I thank Joe Pater for suggesting this idea to me.

gram]. Retrieved from www.praat.org.

Bolton, T. L. (1894). Rhythm. *American Journal of Psychology* 6:145-238.

Chafe, W. L. (1977). Accent and related phenomena in the Five Nations Iroquois Languages. In L. Hyman, *Studies in stress and accent*. Southern California Occasional Papers in Linguistics 4. University of Southern California: Los Angeles.

Chambers, J.K. (1978). Dakota accent. In E. Cook & J. Kaye (eds), *Linguistic Studies of Native Canada*. University of British Columbia Press: Vancouver, pp 3-18.

Clark, R. & I. Roberts (1993). A computational model of language learnability and language change. *Linguistic Inquiry* 24: 299-345.

Comrie, B. (1976). Irregular stress in Polish and Macedonian. *International Review of Slavic Linguistics* 1:227-240.

Daelemans, W., S. Gillis & G. Durieux (1994). The acquisition of stress: a data-oriented approach. *Computational Linguistics* 20: 421-451.

Dell, F. (1984). L'accentuation des phrases en français. In *Forme sonore du langage*, eds. F. Dell, D. Hirst, and J.-R. Vergnaud. Hermann, Paris, pp. 65-122.

Devine, A. M. & Laurence D. Stephens (1994). *The prosody of Greek speech*. New York, Oxford: Oxford University Press.

Dogil, G. & B. Williams (1999). The phonetic manifestation of word stress. In *Word prosodic systems in the languages of Europe*, ed. by Harry van der Hulst. Mouton de Gruyter: Berlin, New York.

Dogil, G., J. Gvozdanović & S. Kodzasov (1999). Slavic languages. In *Word prosodic systems in the languages of Europe*, ed. by Harry van der Hulst. Mouton de Gruyter: Berlin, New York.

Drachman, G., R. Kager and A. Malikouti-Drachman (1995). Greek allomorphy: an Optimality account. In: M. Dimitrova-Vulchanova & L. Hellan (eds.), *Papers from the First Conference on Formal Approaches to South Slavic Languages*, Plovdiv, 345-361. [University of Trondheim Working Papers in Linguistics 28.]

Dresher, E. B. & J. Kaye (1990). A computational learning model for metrical phonology. *Cognition* 34:137-195.

Freeland, L. S. (1951). Language of the Sierra Miwok. Memoir 6 of *International Journal of American Linguistics*. Indiana University, Bloomington.

Fry, D. (1955). Duration and intensity as physical correlates of linguistic stress. *Journal of the Acoustic Society of America* 27:765-768.

Giegerich, H. (1985). *Metrical phonology and phonological structure*. Cambridge Studies in Linguistics 43. Cambridge University Press: Cambridge.

Goedemans, R. & E. van Zanten (2007). Stress and accent in Indonesian. In V. van Heuven & E. van Zanten (eds.), *Prosody in Indonesian Languages*, pp. 35-62.

Gupta, P. & D. Touretzky (1994). Connectionist models and linguistic theory: Investigations of stress systems in language. *Cognitive Science* 18(1):1-50.

Halle, M. & J.-R. Vergnaud (1987). *An essay on stress*. Cambridge, MA: MIT Press.

Hansen, K. C. & L. E. Hansen (1969). Pintupi phonology. *Oceanic Linguistics* 8(2):153-170.

Hayes, B. (1981). *A metrical theory of stress rules*. Doctoral dissertation, MIT.

Hayes, B. (1995). *Metrical stress theory. Principles and case studies*. University of Chicago Press: Chicago, London.

Hayes, B. & C. Wilson (2008). A maximum entropy model of phonotactics and phonotactic learning. *Linguistic Inquiry* 39:379-440.

Heinz, J. (2006). Learning Quantity-Insensitive Stress Patterns via Local Inference. *Proceedings of The Association for Computational Linguistics Special Interest Group in Phonology* 6 (ACL-SIGPHON 06).

Heinz, J. (2009). On the role of locality in learning stress patterns. *Phonology* 26(2):303-351.

Holton, D., P. Mackridge & I. Philippaki-Warbuton (1997/2004). *Greek: A comprehensive grammar of the modern language*. Routledge: London & New York.

Hulst, H. van der (1999). *Word prosodic systems in the languages of Europe*. Ed. Mouton de Gruyter: Berlin, New York.

Hyman, L. (1977). Studies in stress and accent. *Southern California Occasional Papers in Linguistics* 4, University of Southern California, Los Angeles.

- Hyman, L. 1977. On the nature of linguistic stress. In Larry Hyman (ed.), *Studies in stress and accent*, 37-82. Los Angeles: University of Southern California, Department of Linguistics.
- Inkelas, S. (1994). Exceptional Stress-Attracting Suffixes in Turkish: Representations vs. the Grammar. In H. van der Hulst, R. Kager, and Wim Zonneveld (eds.), *The Prosody-Morphology Interface*. Cambridge University Press.
- Jarosz, G. (2006). Rich lexicons and restrictive grammars: Maximum likelihood learning in Optimality Theory. Doctoral dissertation, Johns Hopkins University, Baltimore, MD.
- Jessen, M. & K. Marasek (1995). Acoustic correlates of word stress and the tense/lax opposition in the vowel system of German. In *Phonetic AIMS* 2.2:143-146.
- Kager, R. (1993). Alternatives to the Iambic - Trochaic Law. In *Natural Language and Linguistic Theory* 11(3):381-432.
- Karvonen, D. (2008). Explaining Nonfinality: Evidence from Finnish. *Proceedings of the 26th West Coast Conference on Formal Linguistics*, ed. C. B. Chang and H. J. Haynie, 306-314. Somerville, MA: Cascadilla Proceedings Project.
- Kiparsky, P. (1972). Explanation in phonology. In Peters, S. (ed.), *Goals in linguistic theory*, 189-227. Englewood Cliffs: Prentice-Hall.
- Kiparsky, P. (2003). Accent, syllable structure, and morphology in Ancient Greek. In E. Mela Athanasopoulou (ed.) *Selected Papers from the 15th International Symposium on Theoretical and Applied Linguistics*, 81-106. Thessaloniki, 2003.
- Krauss, M. (1985). Supplementary notes on Central Siberian Yupik prosody. In M. Krauss, *Yupik Eskimo Prosodic Systems: Descriptive and Comparative Studies*, Alaska Native Language Center, Fairbanks.
- Legendre, G., Y. Miyata, & P. Smolensky (1990). Can connectionism contribute to syntax? Harmonic Grammar, with an application. In *Proceedings of the 26th Regional Meeting of the Chicago Linguistic Society*. ed. by M. Ziolkowski, M. Noske, and K. Deaton, 237-252. Chicago: Chicago Linguistic Society.
- Lehiste, I. (1970). *Suprasegmentals*. Cambridge, MA: MIT Press.
- Melvold, J. L. (1990). Structure and stress in the phonology of Russian. *MIT Working Papers in Linguistics*. MIT, Cambridge.
- Mester, R. A. (1994). The quantitative trochee in Latin. *Natural Language and Linguistic Theory* 12:1-61.
- Newton, B. (1972). *The generative interpretation of dialect. A study of Modern Greek phonology*. Cambridge University Press.
- Nordhoff, S. (2009). *A grammar of Upcountry Sri Lanka Malay*. Doctoral dissertation, LOT Dissertation series.
- Philippaki-Warbuton, I. (1970). *On the verb in Modern Greek*. Bloomington: Indiana University publications.
- Philippaki-Warbuton, I. (1976). On the boundaries of morphology and phonology: a case study from Modern Greek. *Journal of Linguistics* 12:259-278.
- Poser, W. J. (1990). Evidence for foot structure in Japanese. *Language* 66(1):78-105.
- Prince, A. S. (1983). Relating to the Grid. *Linguistic Inquiry* 14:19-100.
- Protopapas, A. (2006). On the use and usefulness of stress diacritics in reading Greek. *Reading and Writing* 19:171-198.
- Protopapas, A., S. Gerakaki & S. Alexandri (2006). Lexical and default stress assignment in reading Greek. *Journal of Research in Reading*, Vol. 29(4), p418-432.
- Ralli, A. & L. Touratzidis (1992). A computational treatment of stress in Greek inflected forms. *Language and Speech* 35(4):435-453.
- Revithiadou, A. (1999). *Headmost accent wins*. Doctoral dissertation, LOT Dissertation Series No. 15.
- Roca, I. M. (1999). Stress in the Romance languages. In *Word prosodic systems in the languages of Europe*. Ed. H. van der Hulst, Mouton de Gruyter: Berlin, New York, pp 659-811.
- Roosman, L. (2006). Melodic structure in Toba Batak and Betawi Malay word prosody. In V. van Heuven & E. van Zanten (eds.), *Prosody in Indonesian Languages*, pp. 89-115.
- Selkirk, E. (1984). *Phonology and Syntax: The Relation between Sound and Structure*. MIT Press, Cambridge, MA, and London, England.

- Sezer, E. (1983). On non-final stress in Turkish. *Journal of Turkish Studies* 5:61-69.
- Sims, A. (in press). Avoidance strategies, periphrasis and paradigmatic competition in Modern Greek. In *Periphrasis and paradigms.*, eds. J.P. Blevins and F. Ackerman. Stanford, CA: CSLI.
- Smith, N. & D. Apoussidou (in prep.). Recessive accent in Ancient Greek revisited: The final coda effect.
- Smolensky, P. (1996). On the comprehension/production dilemma in child language. *Linguistic Inquiry* 27:720-31.
- Smolensky, P., & G. Legendre (2006). *The harmonic mind: From neural computation to Optimality-Theoretic grammar*. Cambridge, MA: MIT Press.
- Steriade, D. (1988). Greek Accent; a case for preserving structure. *Linguistic Inquiry* 19: 271-314.
- Tesar, B. (1998). An iterative strategy for language learning. *Lingua* 104:131-145.
- Tesar, B. (2004). Contrast analysis in phonological learning. Ms., ROA 695.
- Tesar, B. (2009). Learning Phonological Grammars for Output-Driven Maps. To appear in *The Proceedings of NELS 39*. ROA-1013.
- Tesar, B. & P. Smolensky (2000). *Learnability in Optimality Theory*. Cambridge, MA: MIT Press.
- Trubetzkoy, N. S. (1939). *Grundzüge der Phonologie*. Prague. [*Principles of phonology*, Berkeley: University of California University Press, 1969.]

Appendix

Table 1: no shift/default results with hidden structure

Underlying variation ¹⁹	%
<tree+Nom.Sg.N> dendr+o /(dén.dro)/ [déndro]	44.4
déndr+o	55.6
<tree+Gen.Pl> dendr+on /(dén.dron)/ [déndron]	44.2
déndr+on	55.8
<sheep+Nom.Sg.N> provat+o /(pró.va).to/ [próvato]	41.5
próvat+o	58.5
<sheep+Gen.Pl> provat+on /(pró.va).ton/ [próvaton]	41.3
próvat+on	58.7
<almond+Nom.Sg.N> amigdal+o /a.(míg.da).lo/ [amígdalo]	50.2
amígdal+o	49.8
<almond+Gen.Pl> amigdal+on /a.(míg.da).lon/ [amígdalon]	50.2
amígdal+on	49.8
<headache+Nom.Sg.M> ponokefal+os /po.no.(ké.fa).los/ [ponokéfalos]	25.8
ponokéfal+os	74.2
<headache+Gen.Pl> ponokefal+on /po.no.(ké.fa).lon/ [ponokéfalon]	25.6
ponokéfal+on	74.4

Table 2.: results of no shift/default untrained words

Untrained words:	%

¹⁹ Dots represent syllable boundaries that were given the learners for free.

<bath+Nom.Sg.N> banj+o /(bán.jo)/ [bánjo]	49.9
bánj+o /(bán.jo)/	50.1
<bath+Gen.Pl> banj+on /(bán.jon)/ [bánjon]	49.9
bánj+on	50.1
<butter+Nom.Sg.N> vutir+o /(vú.ti).ro/ [vútiro]	50.2
vútir+o	49.8
<butter+Gen.Pl> vutir+on /(vú.ti).ron/ [vútiiron]	50.2
vútir+on	49.8
<smile+Nom.Sg.N> xamojel+o /xa.(mó.je).lo/ [xamójelo]	49.9
xamójel+o	50.1
<smile+Gen.Pl> xamojel+on /xa.(mó.je).lon/ [xamójelon]	50
xamójel+on	50
<railway+Nom.Sg.M> sidirodrom+os /si.di.(ró.dro).mos/ [sidiródromos]	50.2
sidiródrom+os	49.8
<railway+Gen.Pl> sidirodrom+on /si.di.(ró.dro).mon/ [sidiródromon]	49.9
sidiródrom+on	50.1

Table 3.: results for hidden structures for the no shift/lexical condition

Underlying and surface variation	% correct
<tree+Nom.Sg.N> déndr+o /(dén.dro)/ [déndro]	100
<tree+Gen.Pl> déndr+on /(dén.dron)/ [déndron]	27.8
déndr+ón	72.2
<sheep+Nom.Sg.N> próvat+o /(pró.va).to/ [próvato]	100
<sheep+Gen.Pl> próvat+on /(pró.va).ton/ [próvaton]	27.9
próvat+ón	72.1
<hope+Nom.Sg.F> elpíd+a /(el.pí).da/ [elpída]	29.9
/el.(pí.da)/	70.1
<hope+Gen.Pl> elpíd+on /(el.pí).don/ [elpídon]	6.5
/el.(pí.don)/	21.5
elpíd+ón /(el.pí).don/	23.3
/el.(pí.don)/	48.7
<brother+Nom.Sg.M> adelf+ós /a.(del.fós)/ [adelfós]	100
<brother+Gen.Pl> adelf+ón /a.(del.fón)/ [adelfón]	99.9
<almond+Nom.Sg.N> amígdal+o /a.(míg.da).lo/ [amígdalo]	100
<almond+Gen.Pl> amígdal+on /a.(míg.da).lon/ [amígdalon]	27.9
amígdal+ón	72.1
<headache+Nom.Sg.M> ponokéfal+os /po.no.(ké.fa).los/ [ponokéfalos]	5.9
ponokéfal+ós	94.1

<headache+Gen.Pl> ponokéfal+on /po.no.(ké.fa).lon/ [ponokéfalon]	100
--	-----

Table 4.: results for unheard forms for the no shift/lexical condition

Untrained forms:	%
<bath+Nom.Sg.N> banj+o /(bán.jo)/ [bánjo]	17.1
banj+o /(ban.jó)/ [banjó]	58.6
bánj+o /(bán.jo)/ [bánjo]	17.2
banj+ó /(ban.jó)/ [banjó]	7.1
<bath+Gen.Pl> banj+ón /(ban.jón)/ [banjón]	100
<butter+Nom.Sg.N> vutir+o /(vú.ti).ro/ [vútiro]	2.4
vutir+o /(vu.tí).ro/ [vutíro]	9.8
vutir+o /vu.(tí.ro)/ [vutíro]	29.7
vutir+o /vu.(ti.ró)/ [vutiró]	49.3
vútir+o /(vú.ti).ro/ [vútiro]	2.4
vutir+ó /vu.(ti.ró)/ [vutiró]	6.4
<butter+Gen.Pl> vutir+ón /vu.(ti.rón)/ [vutirón]	99.9
<raisin+Nom.Sg.F> stafid+a /(stá.fi).da/ [stáfida]	4.3
stafid+a /(sta.fí).da/ [stáfida]	4.1
stafid+a /sta.(fí.da)/ [stáfida]	12.1
stafid+a /sta.(fi.dá)/ [stáfida]	27.2
stafid+a /(sta.fí).da/ [stáfida]	4
stafid+a /sta.(fí.da)/ [stáfida]	12.0
stafid+á /sta.(fi.dá)/ [stáfida]	36.3
<raisin+Gen.Pl> stafid+ón /sta.(fi.dón)/ [stáfidón]	99.9
<sky+Nom.Sg.M> uran+ós /u.(ra.nós)/ [uranós]	100
<sky+Gen.Pl> uran+ón /u.(ra.nón)/ [uranón]	99.9
<smile+Nom.Sg.N> xamojel+o /xa.(mó.je).lo/ [xamójelo]	2.4
xamojel+o /xa.(mo.jé).lo/ [xamojélo]	9.8
xamojel+o /xa.mo.(jé.lo)/ [xamojélo]	29.8
xamojel+o /xa.mo.(je.ló)/ [xamojeló]	49.3
xamójel+o /xa.(mó.je).lo/ [xamójelo]	2.4
xamojel+ó /xa.mo.(je.ló)/ [xamojeló]	6.3
<smile+Gen.Pl> xamojel+ón /xa.mo.(je.lón)/ [xamojelón]	99.9
<railway+Nom.Sg.M> sidirodrom+ós /si.di.ro.(dro.mós)/ [sidirodromós]	100
<railway+Gen.Pl> sidirodrom+ón /si.di.ro.(dro.món)/ [sidirodromón]	99.9

Resulting weights:

Table 5: The 'no shift/default'-condition

AFR	107
TROCH	106.8

{FTBIN, NONFINAL; PARSE }	100
IAMB	93.2
AFL	93
MAXR	3.8
<headache> ponokéfal-	1.5
<sheep> próvat-	0.5
<tree> déndr-	0.3
{ MAXA; <Nom.Sg> -a , -o , -os ; <Gen.Pl> -on }	0
<almond> amígdal-	0

Table 6: The 'no shift/lexical'-condition

AFR	134.7
IAMB	100.6
{ FTBIN; PARSE }	100
TROCH	99.4
NONFINAL	65.6
AFL	65.3
MAXR	39.5
<headache> ponokéfal-	39.5
<almond> amígdal-	36.7
<sheep> próvat-	36.4
<tree> déndr-	27.5
<hope> elpíd-	26.3
MAXA	12.5
<Nom.Sg.M> -ós	9.2
<Gen.Pl> -ón	7.5
<Nom.Sg.N> -o	2
{ <Nom.Sg.F> -a , -as ; <mountain> vun- ; <tomato> domát- ; <brother> adelf- }	0
<Nom.Sg.N> -ó	-2
<Gen.Pl> -on	-7.5
<Nom.Sg.M> -os	-9.2

Table 7: The 'always shift'-condition

AFR	132.1
TROCH	101.4
{ FTBIN, PARSE }	100
IAMB	98.6
NONFINAL	68.9
AFL	67.9
MAXR	17.3
MAXA	14.5

<Gen.Pl> ón	11.8
<sheep> próvat-	6.3
<almond> amígdal-	5.8
<sea> thalas-	5.5
<tomato> domát-	5.3
<almond> amigdál-	5.2
<sheep> provát-	4.8
{ <Nom.Sg> o ; as ; os ; a }	0
<tree> déndr-	0 ²⁰
<tomato> domat-	-5.3
<sea> thálas-	-5.5
<headache> ponokéfal-	-7.3
<headache> ponokefál-	-7.7
<Gen.Pl> on	-11.8

Table 8: The 'sometimes shift'-condition

AFR	127.8
IAMB	104.4
{ FTBIN; PARSE }	100
TROCH	95.6
NONFIN	73.2
AFL	72.2
<tree> déndr-	42.4
MAXR	42.3
MAXA	18.1
<almond> amígdal-	15.4
<Gen.Pl> ón	14
<sheep> próvat-	13.8
<headache> ponokéfal-	10.4
<mountain> vun-	5.4
<tomato> domat-	4.6
<Nom.Sg.F> a	4.2
<Nom.Sg.M> os	2.9
<Nom.Sg.N> o	1.3
{ <Nom.Sg.M> as ; <hope> elpíd- ; <brother> adelf- }	0
<Nom.Sg.N> ó	-1.3
<almond> amigdál-	-2.2
<Nom.Sg.M> ós	-2.9
<tomato> domát-	-4.6

²⁰ This '0' was the average of all the weights for this constraint across learners and is therefore different from the constraints that did not move.

<sheep> provát-	-5
<headache> ponokefál-	-7.5
<Gen.Pl> -on	-14

Table 9: The 'some shift'-condition

AFR	129.2
IAMB	105.8
{ FTBIN, PARSE }	100
TROCH	94.2
NONFINAL	71.2
AFL	70.8
MAXR	47.9
<tree> dándr-	47.2
<headache> ponokáfál-	42.5
<sheep> próvat-	40.1
<butter> vútír-	32
<almond> amígdal-	29.2
<headache> ponokefál-	27.6
MAXA	26.3
<butter> vutír-	17.1
<Nom.Sg.M> -ós	15.5
<almond> amígdál-	11.2
<Gen.Pl> -ón	11
<Nom.Sg.F> -a	5.5
<tomato> domat-	4.7
<Nom.Sg.N> -o	3.2
<Nom.Sg.M> -as ; <mountain> vun- ; <hope> elpíd- ; <brother> adelf-	0
<Nom.Sg.N> -ó	-3.2
<tomato> domát-	-4.7
<Gen.Pl> -on	-11
<Nom.Sg.M> -os	-15.5

Index

- accent, 1, 7
Alderete, 3, 12
Allen, 8
allomorphy, 4, 6, 7, 9
Apoussidou, 2, 6, 7, 12

Betawi Malay, 2
Bickmore, 2
Boersma, 12, 16
Bolton, 3
Botinis, 1
Bulgarian, 2

Cayuga, 2
Cayuvava, 3
Central Sierra Miwok, 2
Chafe, 2
Chambers, 2
Clark, 12
Comrie, 2
constraint, 9, 10, 15
 faithfulness, 12, 15, 16
 lexical, 9, 10, 12, 15–17, 20
 structural, 12, 15–17, 20, 21
culminativity, 3

Daelemans, 12
Dakota, 2
Dell, 3
Devine, 8
Dogil, 1, 2
Drachman, 5–7
Dresher, 12
duration, 1, 3, 8
Dutch, 2

English, 1, 2
extrametricality, 16–18, 20

Finnish, 1–3
foot, 3, 5–7, 10, 13, 16–18
Freeland, 2
French, 3
Fry, 1
fundamental frequency, 1

German, 1, 2, 4
Giegerich, 4
Goedemans, 2
Greek
 Ancient, 4, 6, 7, 24
 Modern, 1, 4–7, 10, 12, 13, 19, 21
grid theory, 3
Gupta, 12

Halle, 2, 3
Harmonic Grammar, 9, 16
harmonic score, 9, 10
Hayes, 2–4, 12
Heinz, 12
Holton, 4, 6–8
Hyman, 1, 2

Iambic/Trochaic Law, 3
iambs, 3, 16, 18, 20
Inkelas, 7
intensity, 1, 3

Japanese, 2
Jarosz, 12
Javanese Indonesian, 2
Jesney, 12
Jessen, 1

Kager, 4
Karvonen, 1
Kaye, 12
Kinyambo, 2
Kiparsky, 7
Krauss, 3

Latin, 4
learnability, 1, 4, 9, 12, 21
Legendre, 9
Lehiste, 1
length, 1, 4, 6–8, 16
Lieberman, 3
loudness, 1

Macedonian, 2
Malikouti-Drachman, 5
Marasek, 1
McKeever Dauer, 1
Melvold, 2
Mester, 4
Miyata, 9
Modern Greek, 1–4

Newton, 7
Nordhoff, 2

Optimality Theory, 3, 9

Pacific Yupik, 3
Pater, 12, 16, 21
Philippaki-Warburton, 2, 5, 7, 8, 21
Pintupi, 3
pitch, 1, 7
Polish, 2

Poser, 2
 Prince, 3
 prominence, 1, 3
 prosody, 1, 7
 Protopapas, 5, 8, 21

 Ralli, 5, 7
 Revithiadou, 2, 5–8
 Roberts, 12
 Roca, 4
 Roosman, 2
 Russian, 2

 Selkirk, 3
 Seneca, 2
 Sezer, 2
 shift, 1, 4–8, 10, 12–21, 24–29
 Sims, 8
 Smith, 7
 Smolensky, 9, 12, 15
 Spanish, 4
 spectral structure, 1
 Sri Lankan Malay, 2
 Stephens, 8
 Steriade, 7
 Stress, 1, 2, 4, 6, 13, 14
 stress
 bounded, 3
 fixed, 1
 free, 1
 lexical, 1, 8, 12–14, 16–18
 main, 3
 secondary, 3
 sentence, 1
 unbounded, 3
 word, 1–4
 syllable
 heavy, 2–4, 7
 light, 2–4, 7

 Tesar, 12, 15
 Tessier, 12
 Touratzidis, 5, 7
 Touretzky, 12
 trisyllabic window, 2, 5, 7, 13, 16, 20
 trochees, 3, 16, 18, 20
 Trubetzkoy, 1
 Turkish, 2

 van der Hulst, 2
 van Zanten, 2
 Vergnaud, 3
 vowel quality, 1

 Weenink, 16
 weight, 9, 20

 weighting, 10–12, 17, 20
 Williams, 1
 Wilson, 12

 Yupik Eskimo, 2