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PRODUCTION OF VERBS IN GREEK: THE EFFECT OF REGULARITY AND INFLECTIONAL ENTROPY

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Table of Contents

Abstract

This study examines the effect of regularity and inflectional entropy on the production of Greek verbs. A previous study on the production of Greek verbs found no difference in producing Greek regular and irregular verbs (Terzi et al., 2005). It was suggested that Greek irregular verbs, like regular verbs in Greek and unlike, for instance, irregular verbs in English, involve decomposition and consequently the two types of verbs have no difference regarding the memory systems involved in their past tense formation. However, in this study, I suggest that an effect of regularity on past tense formation is nonetheless expected due to a morphological priming effect. It is proposed that error rates, the measurement used in the Terzi et al. (2005) study, are not sensitive enough to detect the effect of regularity, at least for healthy people. Therefore, a sentence completion task was administered to 32 healthy Greek speakers to test for the effect of regularity on verb production, using 48 verbs, half of which were regular and half irregular, measuring both the response times and the error rates. The results revealed a significant effect of regularity on the response times of the correct answers, with the regular verbs being produced faster than irregular verbs. Although a relatively high error rate was observed (4.69%), regularity was not attested to be the source of it. The high error rate was, however, explained by the inflectional entropy of the verbal paradigm, an information-theoretic measure of complexity that has been previously shown to correlate with processing latencies (e.g. Van Ewijk, 2013; Tabak, 2010; Baayen & Moscoso del Prado Martin, 2005). Specifically, the results showed that the higher the inflectional entropy, the higher the probability of error. No significant effect of inflectional entropy on response times was detected. In an attempt to see if inflectional entropy has the same effect on the error rates of other populations, the data of the Terzi et al. (2005) study on the production of verbs by Greek Parkinson's disease patients were reanalyzed. This analysis revealed no significant effect of inflectional entropy on error rates possibly because of the small amount of data and the small range of inflectional entropies of the verbs in the Terzi et al. study. Therefore, it cannot be concluded that inflectional entropy has a different effect on the performance of Parkinson's disease patients than that of healthy people. This is the first study, at least to my knowledge, suggesting an effect of regularity on the production of verbs in a relatively understudied language, Greek, and it also provides further data for a (relatively) new measure of complexity, inflectional entropy. Based on all the data collected for Greek, a model of past tense formation is proposed, which could be the baseline for future research for a more holistic theory of lexical access.

1. Introduction

Language production can be affected by various factors, sometimes pertaining to the target linguistic structures or items themselves. The complexity level of producing certain structures and items can affect the performance of particular populations, either healthy or impaired, depending on the populations' capabilities. In verb production, the regularity condition of a verb has been found, among other factors, to affect the complexity of lexical access (see for example Pinker, 1991; Ullman, 2004). In most languages, verbs are distinguished into two types: regular and irregular verbs. Crucially, the type of the verb is only realized in its past tense form. There is nothing intrinsic in a verb form that defines whether a verb is regular or irregular.

Traditionally, verbs' regularity is associated with the two most extensively studied memory systems: the declarative and the procedural memory systems. The procedural memory system is responsible for the control and learning of rule-based procedures, whereas the declarative memory system stores events and facts. Based on this distinction, Ullman (2004) extends this memory model to language and argues that the two memory systems, declarative and procedural, are related to the mental lexicon and mental grammar respectively. The declarative memory is associated with the storage of the lexical items, whereas the procedural memory is related to the morphological and syntactic rules that need to be applied. Consequently, past tense formation of regular verbs is associated with the procedural memory system, as a standard rule-based procedure is required to bring together the stem and the suffix. Note, though, that in order to bring the two items together, first they need to be retrieved from the declarative memory, thus suggesting an interaction between the two memory systems. On the other hand, past tense formation of irregular verbs is only associated with the declarative memory system because the lexical item is retrieved from memory as a whole, and no rules apply.

The first evidence suggesting that separate memory systems are involved in the past tense formation of the two types of verbs came from cognitively unimpaired speakers of English (e.g. Prasada, Pinker & Snyder, 1990; Pinker, 1999). Irregular past tense forms are memorized and stored as single items, so their frequency affects the ease of access. More specifically, the more frequent an item is, the easier it is to be retrieved. On the contrary, regular past tense forms involve decomposition and are reconstructed every time. The frequency of occurrence of the constructed item does not affect the ease of access because the stem and the suffix are stored separately (for discussion, see Pinker, 1991). Further empirical evidence from impaired populations like Parkinson's and Alzheimer's disease patients, mainly in English and Italian (e.g. Ullman et al., 1997; Walenski et al., 2009, Cappa & Ullman, 1998) also support the approach that separate memory systems are involved in the past tense formation of regular and irregular verbs. Specifically, Parkinson's disease

(PD) patients have problems with the procedural memory system, and since regular verbs involve a rule-based procedure (i.e. attach the suffix to the stem), PD patients have difficulty producing them. Alzheimer's disease (AD) patients have problems with the declarative memory system, and since irregular verbs are single items stored by the declarative memory that need to be retrieved, this particular population shows poor performance on their production.

However, Terzi et al. (2005) show that Greek PD patients perform poorly on both regular and irregular verbs. According to the authors, this is to be expected if we take into account the Greek morphological system. In Greek, verbs are inflected for person and number, and, depending on the stem, the augment *e-* is also added. Therefore, the formation of the past tense of an irregular verb requires the application of particular morphological rules, similarly to a regular verb. Terzi and her colleagues argue then that the procedural memory system is involved in the production of the past tense of both regular and irregular Greek verbs, thus affecting the performance of PD patients on both types of verbs.

As mentioned earlier, the declarative and the procedural memory systems interact when it comes to the past tense formation of regular verbs (Ullman, 2004) and according to a previous study, the past tense formation of Greek irregular verbs also requires this kind of interaction (Terzi et al., 2005). It is expected, then, that in Greek the two memory systems affect the past tense formation of regular verbs in the same way they affect the formation of irregular verbs. However, memory is just one factor associated with the regularity condition of the verb and could affect their past tense formation. Consider, for example, a situation where you are presented with the present tense form of a verb (i.e. the prime word) and you are required to produce the past tense form (i.e. the target word). The morphological similarity of the two items is expected to affect the production of the target item. This effect, known as the morphological priming effect, facilitates the past tense formation of regular verbs, because the stem is the same in both the present and the past tense, but it will not facilitate (at least not to the same extent) the past tense formation of irregular verbs, where the stem is different in the two tenses. However, Terzi et al. (2005), who tested the production of regular and irregular verbs by healthy people and Parkinson's disease patients, failed to detect this morphological priming effect.

So far I have discussed verb production in relation to its regularity condition and the implication this has for the memory systems involved, as well as for the possibility of a morphological priming effect. Another factor of complexity in language production is inflectional entropy. Inflectional entropy is a relatively new measure of complexity of lexical access which is based on principles of Information Theory (Shannon, 1948). Contrary to the regularity condition of a verb, inflectional entropy concerns the whole paradigm of a verb, and not just its past tense form. Inflectional entropy characterizes the distribution of the items of an inflectional paradigm, and makes certain predictions about its effect on lexical access.

The present study contributes new data and analyses to these issues by investigating the effect of regularity and entropy on the production of Greek verbs. To this end, an experiment was conducted on the production of regular and irregular verbs by Greek healthy speakers, primarily measuring reaction times. Due to the unexpected number of errors found in the data, which could not be explained by regularity, further analysis was conducted to test for the effect of inflectional entropy on verb production. In an attempt to investigate the effect of entropy on other, impaired populations, the data from a previous study (Terzi et al., 2005) on the production of regular and irregular verbs by Greek Parkinson's' disease patients are reanalyzed. The results of the current study contribute to our understanding of the complexity of past tense formation and the impact of regularity and inflectional entropy on lexical access, while providing new data for a relatively understudied language, Greek.

2. Theoretical Framework

2.1 Greek Past Tense

Modern Greek distinguishes present, past and future tense which are closely associated with aspect; perfective and imperfective (Terzi et al., 2005; Fyndanis et al., 2013). Perfective aspect expresses an action as a whole, as something completed that is not distinguished in parts, whereas imperfective aspect expresses an action while in progress (Comrie, 1976). This interaction between tense and aspect creates two different tenses for past and future (Table 1). Present tense is not affected by aspect, as an action that is currently in progress can only be viewed as imperfect.

Table 1: The interaction of tense and aspect in Greek

	Imperfective	***Perfective***
Present	lin-o 'I solve'	N.A.
Past	e-lin-a 'I was solving'	e-lis-a 'I solved'
Future	θa lin-o 'I will be solving'	θa lis-o 'I will solve'

The imperfective past tense in Greek is called *Paratatikos* and it is equivalent to the past continuous (or progressive) tense in English; it expresses an incomplete action in the past. The perfective past tense in Greek is called *Aoristos*, and corresponds to the simple past tense in English; it states a completed action in the past (Triantafillidis, 1941). However, in Greek, and sometimes in English as well, the speaker is quite flexible as to which tense to use (Fyndanis et al., 2013). For instance, although an action might have been completed in the past, it is up to the speaker to decide whether to express it as a perfective or an imperfective action. Take for instance the following sentences:

1. *Xϑes to vradi evapsa to spiti.*
   Yesterday the night painted the house.
   'Yesterday night I painted the house.'

2. *Xϑes to vradi evafa to spiti.*
   Yesterday the night painting the house.
   'Yesterday night I was painting the house.'

The Greek speaker is allowed to choose any of the two sentences to express what happened the night before, without sounding odd to the hearer.

Both the perfective and the imperfective past tense forms are accented on the antepenultimate syllable, and when the stem is monosyllabic and starts with a consonant, a stressed augment *e-* prefixes the form (Triantafillidis, 1941; Fyndanis et al, 2013). For example, *e-kan-a* 'I did' contains the augment e- as the stem is monosyllabic and starts with a consonant), whereas *potis-a* "I watered", which is disyllabic, does not contain the augment.

Perfective past tense, contrary to the imperfective, distinguishes between two forms, the sigmatic and the non-sigmatic ones, named after 'sigma' (*σ, '*s') in the Greek alphabet. The former contains an -s- affix before the number and person suffix, whereas the latter does not. Sigmatic past tense forms have been considered to be *regular*, since there is a standard way to construct them, whereas non-sigmatic past tense forms have been considered as *irregular* since their past form does not follow any rules (for discussion see Terzi et al., 2005; Stavrakaki and Clahsen, 2009; Tsakpini et al., 2002). The following examples provide all possible past tense forms in Greek:

1. (a) hala-o, hala-s-a 'I break down, I broke down'
   (b) rav-o, e-rap-s-a 'I sew, I sewed'
   (c) plek-o, e-plek-s-a 'I knit, I knitted'
   (d) luz-o, e-lu-s-a 'I bathe, I bathed'
   (e) vuliaz-o, vuliak-s-a 'I sink, I sank'
2. (a) sern-o, e-sir-a 'I drag, I dragged'
   (b) kan-o, e-kan-a 'I make, I made'
   (c) trog-o, e-fag-a 'I eat, I ate'
3. pul-o, puli-s-a 'I sell, I sold'

The examples in (1) are pure sigmatic past tense forms. The stem of the present tense remains the same and, if it ends in a vowel, the -s- affix attaches to it, followed by the person and number suffix (1a). If the stem ends in a labial consonant, then the -s- becomes -p-s- (1a); if it ends in a velar consonant then it becomes -k-s- (1b); and if it ends in a dental or fricative consonant it can be either -s- (1c) or -k-s- (1d) (Triantafillidis, 1941). The examples in (2) illustrate the non-sigmatic past tense. In both (2a) and (2b) the vowel of the stem idiosyncratically changes without following a particular pattern. In some rare cases, like (2c) the whole stem changes. The past tense form in (3) is a mixture of an idiosyncratic stem and the sigmatic -s- affix. Although the distinction between the past tense forms in (1) and (2) in terms of their regularity condition is straightforward, namely the sigmatic past tense forms are the regular verbs of Greek and the non-sigmatic past tense forms are the irregular verbs of Greek, the past tense forms in (3) are the grey area of Greek verbs. When these verbs need to be classified, they are usually considered to be regular, due to the sigmatic -s- affix (see for example Terzi et al., 2005; Stavrakaki & Clahsen, 2009).

In an attempt to determine frequency differences between the sigmatic and the non-sigmatic past tense in Greek, Stavrakaki and Clahsen (2009) report that the sigmatic past tense forms are a lot more frequent that the non-sigmatic past tense forms. From a corpus of 100.000.000 Greek words, 2.266 verb lemmas were extracted, out of which only the 147 were non-sigmatic. The high frequency of the sigmatic past tense forms, in combination with the systematic insertion of -s- make these forms comparable to the regular past tense forms found in other languages, like English. On the other hand, the low frequency and the idiosyncratic patterns of the non-sigmatic past tense forms make them comparable to the irregular past tense forms.

2.2 The Procedural and Declarative Memory Systems: Verb Production

Memory is an indispensable part of the cognitive system. The declarative and procedural memory systems are two systems that have been extensively studied (Cohen & Squire, 1980). The declarative system is believed to be responsible for the storage of facts and events. The procedural system is considered to subserve the learning and control of various rule-based procedures, either cognitive or motor.

Based on the idea of two separate memory systems expressed by Cohen and Squire, Ullman (2004) proposed the declarative-procedural model of language. According to this model, the declarative memory system underlies the mental lexicon. All arbitrary and idiosyncratic word-specific knowledge, like the word's meaning, its sound and class, is stored by this system. Free morphemes and bound morphemes, also belong to this system and are retrieved as single items. On the other hand, the procedural memory system subserves the mental grammar. All the procedures required to bring particular items together into complex structures are stored by this system. Bringing morphemes together into inflected words, as well as bringing words together into meaningful sentences, are procedures executed by this particular memory system.

The two systems do not operate in total isolation from one another. Rather, they are hypothesized to interact in several ways (for discussion, see Ullman, 2004). For instance, in order for the procedural memory to form complex structures, it needs to retrieve the items stored by the declarative memory system. The items retrieved from the declarative memory system are temporarily stored in working memory and are put into structure following the rules of the procedural memory system.

Based on the declarative-procedural memory system for language, past tense verb production utilizes both memory systems (Ullman, 2004). Regular verbs require decomposition and, consequently, the application of a rule, depending on the inflectional morphology of the language. A systematic change, which is the same across all regular verbs of a language, yields the final past tense form. The stem and the suffix which are retrieved from the declarative memory system are put together, in a sequential and hierarchical order, controlled by the procedural memory (Ullman, 2004). Irregular verbs are called irregular because they do not follow any rules. The changes they undergo are not predictable and their final past tense forms are unique. In order to produce an irregular verb, the declarative memory system activates and seeks to find a single form that would fulfill the criteria of the search in the mental lexicon. This form is not reconstructed every time it is produced; rather it is retrieved similarly to an event or a fact (Ullman, 2004). The procedural memory system does not seem to be involved in the production of irregular verbs.

Take for instance the past tense verb production in English. The past tense of the English regular verbs is constructed by adding the suffix *–ed* to the verb stem (e.g. play, play-ed). The same process applies to all regular verbs. The past tense of the irregular verbs, though, is unforeseeable. *Go* becomes *went* but no rules can give that form. Based on the declarative-procedural memory account, in order to produce *played,* the procedural memory system activates and gives effect to the rule-based procedure that will bring together the stem (i.e. play) and the suffix (i.e. –ed). However, the stem and the suffix need to be retrieved from somewhere. The procedural memory system is not responsible for that, but the declarative memory system is. On the other hand, in order to produce *went,* the declarative memory system will simply retrieve that single lexical item from lexicon, without the need for the procedural memory system.

Support for the declarative-procedural model can be found in studies with clinical populations, mainly in English. AD, semantic dementia, posterior aphasia, and adult-onset temporal-lobe aphasia are the most prominent syndromes that share the same memory damage. These syndromes affect brain areas related to the declarative memory system (Ullman, 2004). Patients from these groups are better at acquiring and expressing cognitive and motor skills, as well as at producing regular past tense verb forms, than retrieving names and facts and producing irregular past-tense verb forms (Ullman et al., 1997, Cortese et al., 2006; Patterson et al., 2001; Ullman et al., 2005). On the other hand, PD and Huntington's disease (HD) are associated with dysfunction in brain areas related to the procedural memory system, demonstrating difficulty in acquiring and expressing motor and cognitive sequences, while their error rate in producing regular past tense forms is higher than for irregular past tense forms (Ullman et al., 1997).

The past tense formation in English is relatively simple; either the suffix -ed is added for the regular verbs or a single lexical entry is retrieved for the irregular verbs. But what happens in a language with a more composite morphological system? Could a more complex morphology affect the impact of the two memory systems on past tense production of verbs? Previous studies on Italian have addressed this question. Italian AD patients have been shown to have greater difficulty producing the past participle forms of irregular rather than regular verbs (Walenski et al., 2009, Cappa & Ullman, 1998). The results of these studies are comparable to the results of studies conducted on English, demonstrating a cross-linguistic generality of this effect.

2.3 A previous study on verb production in Greek

Another morphologically rich, but relatively understudied language is Greek. Terzi et al. (2005) conducted a study on the production of regular and irregular verbs on Greek PD patients. The participants were required to do a sentence completion production task, comprising of 20 pairs of sentences. The first sentence of the pair had the verb in present tense and the other sentence was missing the past tense form of that verb. An example from their study is the following:

O	*Vassilis*	*kapnizei*	*5-6*	*tsigara*	*tin*	*imera.*	*Xtes*	*omos*	*itan*	*agxomenos*
The	Vassilis	smokes	5-6	cigarettes	the	day.	Yesterday	but	was	stressed

ke	*[ ]*	*ena*	*paketo.*
and	[ ]	one	pack.

'Vassilis smokes 5-6 cigarettes per day. But yesterday, he was stressed and he smoked a pack'

Ten of the sentences were missing a regular verb and the other 10 sentences were missing an irregular verb. As discussed earlier, regular verbs in Greek are the verbs with a sigmatic past-tense form, whereas irregular verbs are those with a non-sigmatic past tense form. Verbs with past tense forms that include both an idiosyncratic stem and the -s- affix were taken to be regular in the particular study. Twenty-seven PD patients were tested and compared against 27 matched healthy controls. The results of the study showed that, compared to the healthy controls, PD patients scored significantly lower in total but no significant difference was found between the regular and irregular past tense formation for either of the two groups.

The authors argue that these results were to be expected considering the Greek morphology. The stems of the past tense forms of the verbs are distinguished into the two categories, sigmatic and non-sigmatic (in other words, regular and irregular). However, if the stem is monosyllabic and starts with a consonant, both types of verbs include the augment *e-,* which is attached as a prefix on the stem. In addition to that, all verbs, either regular or irregular, have the same person and number inflectional suffix attached to their stem. In other words, a systematic procedure takes place during the past tense formation of irregular verbs, similar to regular verbs. Taking these morphological features into consideration, the authors argue that 'there is no (irregular) past tense form which involves mere retrieval from the lexicon and thus contrasts (regular) past tense forms that involve application of the corresponding rule' (Terzi et al., 2005, p.298). The strict line that distinguishes regular and irregular verbs in a language like English falls apart in a language like Greek, because in Greek, both types of verbs require the application of rules for the final form to be produced. Hence, the verb production skills for Greek PD patients, the population that has problems with rule-based procedures, are equally poor for both regular and irregular verbs.

Summarizing, the results of the Terzi et al. (2005) study show that for Greek PD patients, both regular and irregular verbs are equally hard to produce. The authors argue that these results reflect the fact that, in Greek, the past tense forms of types of verbs require decomposition, thus tapping into the procedural memory system. PD patients with languages that do not share this idiomorphic morphological behavior between regular and irregular verbs have problems producing only regular verbs and they achieve better in producing irregular verbs.

3. Rationale and Objectives of the Study

In the previous section I discussed a prominent factor affecting complexity of lexical access, namely regularity. The regularity condition of a verb defines what processes are required to produce them and for the execution of these processes the relevant memory systems are activated. If an item needs to be retrieved, like the past tense form of an irregular English verb, then the declarative memory system is involved. If an item needs to be constructed following particular rules like the past tense form of an English regular verb, then the procedural memory system provides the rules for that. Note, though, that the items needed to construct the regular past tense form, namely the stem and the suffix, first have to be retrieved by the declarative memory system. According to a previous study (Terzi et al., 2005), in a richer morphological system than that of English, namely Greek, the production of irregular verbs also requires the application of particular morphological rules because both regular and irregular verbs require the addition of certain affixes. As a result, the irregular past tense formation in Greek involves not only the declarative memory system, but also the procedural memory system.

Summarizing, so far there is evidence suggesting that, in Greek, both regular and irregular verbs require both the declarative and the procedural memory systems for their past tense formation. Based on this conclusion, one could argue then that the production of Greek verbs is of the same complexity level, irrespectively of their type.

Recall now the task that Terzi et al. (2005) used for the formation of past tense. It was a sentence completion task, during which the participants were presented with the present tense form of the verb in a sentence context and a second sentence was eliciting the past tense form of that verb (for an example see section 2.3). Previous studies in both Germanic languages, like English and German (e.g. Stanners et al., 1979; Weyerts et al., 1996) as well Latin languages whose morphology is more similar to Greek, like Spanish and Italian (e.g. Rodriguez-Fornells et al., 2002; Say & Clahsen, 2002), provide evidence that the formation and comprehension of the past tense of regular verbs in such a task is easier than that of irregular verbs. The observed difference between the two types of verbs is due to an effect known as the morphological priming effect. Various studies have shown that the response to a target word can be facilitated when a morphologically related prime word precedes it. This priming effect can occur even when the prime and the target words are separated by several intervening items (for a review, see Drews 1996). In the case of regular verbs, the stem of the prime word is identical to the stem of the target word, thus facilitating ones' performance. In the case of irregular verbs though, the stems of the prime and the target word differ, so even if there is morphological priming, its effect will be more subtle than for regular verbs.

We expect, then, that the same priming effect should be found in the production of Greek past tense forms as well, in the relevant task. Take for example the transformation of the sigmatic verb *halao-halasa* ('I break down - I broke down') and the non-sigmatic verb *leo*-*ipa* ('I say - I said'). In the first case, the stem (*hala*-) is the same in both tenses. The morphological similarity of the two will cause a morphological priming effect that will facilitate the production of the past tense form. In the latter case, although the past tense stem of an irregular verb (*eip*-)is expected to receive a certain amount of activation as a nearby item to the present tense stem (*le-)*, the priming effect (if any) is expected to be less pronounced because it is a separate lexical item that needs to be accessed. This might be taken as an extreme case of an irregular verb past tense formation, but in other, less radical transformations like *serno-esira* ('I drag – I dragged'), the morphological priming effect is still expected to be less pronounced than for a pure sigmatic form because the present tense stem (*sern-*) is similar yet not identical to the past tense stem (*sir-*).

In the Terzi et al. (2005) study, once the participants were presented with the present tense form of a verb, the present tense stem was activated. When they were asked to produce the past tense form of that verb, the sigmatic verbs should show an advantage over the non-sigmatic verbs because of the morphological priming effect. Taking all this into consideration, the production of the past tense form of an irregular verb in the Terzi et al. (2005) study is expected to be more demanding than that of a regular verb. However, the results of that study did not show an effect of morphological priming for regular verbs, either for PD patients or for healthy participants. The poor performance of the PD patients on both types of verbs presumably reflects their procedural memory problems. Since both regular and irregular verbs involve the procedural memory system, both are hard to produce. However, the performance of the healthy people, who do not face any problems with either of the two memory systems, should reflect this difference in ease of access (due to the morphological priming effect) between the two verb types. Contrary to this prediction, Terzi and her colleagues do not detect any effect of verb type for healthy people.

The fact that in the Terzi et al. (2005) study no effect of verb type is found could be due to methodological issues. The speech of healthy native speakers of a language is usually flawless. Errors are hardly ever found in their speech. However, some small, hard to realize differences in speed of production should occur due to the morphological priming effect. The purpose of the present study is to test whether regularity is a factor of complexity affecting the production of verbs in healthy speakers, using response times (RTs). Response times are generally considered as a more sensitive measure than errors that will help detect the predicted morphological priming effect, which was not detected in the Terzi et al. (2005) study by measuring error rates only.

4. Experiment

4.1 Materials & Procedure

The task used for this experiment was a variation of the past tense sentence completion task used by Ullman et al. (1997), which has been adapted for several other similar experiments (see for example Walenski et al., 2007; Terzi et al., 2005; Prado & Ullman, 2009).

The experiment consisted of 128 trials: 48 experimental items and 80 fillers (Appendix A lists all experimental items). An additional 10 items were used for the training phase (4 items similar to the experimental items and 6 items similar to the fillers). Each trial included two sentences: one completed sentence in the present tense and one sentence in the past tense with an item missing. The verb and the object were the missing items in the experimental items and the fillers respectively, as shown in the examples below:

(1) Example of Experimental Items:

Kaϑe	*mera*	*i*	*ieris*	*lene*	*tin*	*prosefhi.*
Every	day	the	priests	say	the	prayer.

‘Every day the priests say the prayer.’

Hϑes	*i*	*ieris,*	*gia*	*mia*	*stigmi,*	*[ ]*	*tin*	*prosefhi.*
Yesterday	the	priests,	for	one	moment,	[ ]	the	prayer.

‘Yesterday the priests, for a moment, [ ] the prayer.’

(2) Example of Fillers:

Kaϑe	*mera*	*o*	*skinoϑetis*	*alazi*	*to*	*scenario.*
Every	day	the	director	changes	the	script.

‘Every day, the director changes the script.’

Xϑes	*o*	*skinoϑetis,*	*gia*	*mia*	*stigmi,*	*alakse*	*ta*[1]	*[ ].*
Yesterday	the	director,	for	one	moment,	changed	the	[ ].

‘Yesterday, for a moment, the director changed the [ ].’

For the experimental items 24 regular verbs and 24 irregular verbs were used (Appendix B). Ten out of the 24 regular verbs and 10 out of the 24 irregular verbs were the same as those used by Terzi et al. (2005). The regular verbs consisted of verbs with sigmatic past tense forms and irregular verbs consisted of verbs with non-sigmatic past tense forms. Verbs whose past tense form is a mixture of an idiosyncratic stem and the sigmatic -s- affix were also listed as regular verbs, comparably to the Terzi et al. (2005) study. Half of the 80 fillers required a transformation of the object from singular to plural and the other half required a transformation of the object from plural to singular. This variation was used to make the fillers less trivial.

[1] The article *τα* is for plural neuter nouns and would therefore elicit a response like “scripts”.

All pairs of sentences, both the experimental items and the fillers, were identical in terms of structure but different subjects, verbs and objects were used. Each verb and each noun was used only once throughout the experiment to avoid any possible repetition effects. All subjects were common nouns (e.g. the officer, the lawyer). For the experimental items, the subjects and objects consisted of three syllables each to keep the length of the sentences the same, while the words used in subject position were balanced in number (plural and singular) as well as gender (masculine and feminine). All participants were presented with the whole list of items, in a repeated measures design. The items were pseudo-randomized so that no more than two experimental items or fillers of the same type would appear consecutively. The order of the items was different for each participant to avoid any variability attributable to item presentation order.

The stimuli were visually presented on a computer screen, with the two sentences one below the other as in the examples (1) and (2). All pairs were presented for 6500msec, which is enough time to read both sentences but also forces the participants to be focused and answer quickly[2]. The participants were instructed to silently read the sentences and, based on the first sentence, to produce the missing item out loud as fast as possible. A short training phase preceded the actual experimental task. The experiment was presented using the ZEP experimental software (Veenker, 2011). The participants completed the task in a soundproof booth of the UiLOTS labs in Utrecht, in approximately 25-minute sessions.

4.2 Participants

Thirty-four Greek native speakers participated in the experiment, out of which fourteen were female and twenty were male, aged 20-36. The participants were students and working people coming from different parts of Greece but currently living in the Netherlands. They were all paid for their participation and where naïve as to the purpose of the study.

The data from two of the participants were excluded from the analysis. The first participant was excluded because she gave some feedback that forced me to slightly change the experimental items. As discussed in a previous section, Greek speakers are more flexible as to the aspect they use (i.e. whether the tense is perfective or imperfective). However, the stem of the irregular verbs changes only in the perfective past tense (i.e. Simple Past), but not the imperfective (i.e. Past Continuous). The original items did not include the adverb phrase ‘for a moment’, therefore they were more ambiguous as to which tense should be used. When, the adverb phrase was added, it was more

[2] Previous studies with a variation of the particular task have either auditorily presented the stimuli or the visual presentation of the stimulus initiated a software timer that was terminated by the subject’s oral response. Since there was no previous indication as to the appropriate stimulus visual presentation latency, after multiple test trials with different people, the 6500msec latency was decided.

explicit that the target form was the Simple Past form of the verb and not the Past Continuous form. The second participant was excluded because she did not understand the instructions correctly and completed the experiment in an unexpected manner. Instead of providing the verbs of the first sentence in the correct form she provided the correct form of new verbs, not used in the experiment.

4.3 Analysis

RTs were manually marked from the audio files of each trial and collected using the PRAAT software (Boersma & Weenink, 2014). Some of the participants pointed out that one of the verbs was not correctly used in the sentences. It was one of the regular verbs that in some dialects of Greek is used as transitive and in some other dialects as intransitive. As such, the observations for that verb were overall removed from the analysis.

The data were analyzed using mixed-effects models with multiple random factors (LMER, Baayen et al., 2008; Quene & Van den Bergh, 2008). RTs of the correct answers were crossed with verb type (regular/irregular). Random terms for item and participant were added in the model to account for subject and item variation.

A number of potentially confounding item-level factors were included as covariates in the models. First, I considered the number of syllables of the verb, based on the target verb (i.e. the past tense form). Word frequency can affect the time to produce words in a past-tense production task (e.g. Barry, Morrison & Ellis, 1997; Prado & Ullman, 2009). Thus, two different types of frequency were included as covariates: surface form frequency and lemma frequency. The surface form frequencies were taken from the Hellenic National Corpus (ILSP, 2009). The lemma frequency is the cumulative frequency of all the surface form frequencies of all the items in a paradigm, again based on the Hellenic National Corpus (ILSP, 2009).

The RTs of the correct answers were then compared against the RTs of the erroneous answers using the Wilcoxon rank sum test, a non-parametric test, because the distribution of the RTs of the errors was not normal.

Due to the, relatively[3], great number of mistakes, a post-hoc analysis with Generalized Linear Mixed Models (GLMM) was conducted on the errors, crossed with verb type. A list of all the types of errors that the participants made is provided in Table 2. Following this, the two types of errors with higher

[3] Since the participants were healthy native speakers of Greek, errors were not expected. Thus, 72 errors were considered as a great number in this case.

error rate (i.e. Past Continuous and Double Answers) were analyzed separately using GLMM crossed with verb type, to see if regularity is a significant factor for the particular types of errors.

Table 2: Description of Errors

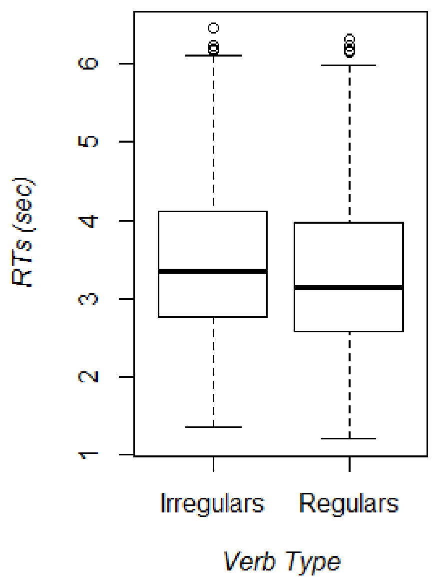
Type of Error	***Description***	***#of Errors***
Past Continuous	Provide the Past Continuous form instead of the Simple Past	52
Double Answers	Provide two answers for the same trial	11
Incorrect Number	Provide the wrong number of the verb form	5
Incorrect Verb	Provide the correct form but of a different verb	4
Non-existent Verb	Provide a non-existent verb form	2
		Total= 72 errors

4.4 Results

The analysis of RTs concerns the correct responses. There was also a high error rate of 4.69% to which I will return later. All collected RTs were square-root transformed to approximate normality. The results presented below are significant at a level of α=.05 or lower.

The maximal model best fitting the data revealed a significant effect of verb type on RTs (*β*=-0.049, *SE*=0.017, *t*=-2.83). Irregular verbs (*M*= 3.459) required more time than regular verbs (*M*= 3.2819), as it is graphically depicted in Figure 1. Number of syllables, surface and lemma frequency failed to reach significance.

Figure 1: Effect of the Verb Type on RTs



The comparison between the RTs of the correct answers and the RTs of the erroneous answers revealed that the participants took longer to give a wrong answer than a correct one (median latencies for the erroneous and the correct answers were 4.266 and 3.258 respectively, W= 71884, p<.001), indicating that when a wrong answer is given the particular item is hard to process.

Regarding the error analysis, all errors were first analyzed together but no significant effect of regularity was detected (*β*=-0.365, *SE*=0.796, *p*=0.646). The analysis for an effect of regularity on the Past Continuous type of errors did not reveal a significant effect (*β*=0.789, *SE*=0.556, *p*=0.155). The analysis for an effect of regularity on the Double Answers type of errors did not reveal a significant effect (*β*=-1.271, *SE*=0.902, *p*=0.187) either.

4.5 Discussion

The results of the study support the hypothesis that there is an effect of regularity on the production of regular and irregular verbs in Greek. Regular verbs were produced faster than irregular verbs, crucially independent of the verb's length or frequency, which is interpreted as a difference in the complexity level between the two types of verbs. Since irregular past tense forms required more time than regular past tense forms, we can conclude that irregular verbs are of higher complexity than regular verbs.

Based on the declarative-procedural memory system approach by Ullman (2004), the production of regular verbs involves both the declarative and the procedural memory systems. Terzi et al. (2005) provide evidence that, for Greek, the production of irregular verbs patterns that of regular verbs, suggesting that both types require both memory systems. However, we cannot assume that the complexity of the formation of the past tense forms of both regular and irregular verbs is the same in Greek. The present and the past tense forms of the regular verbs share the same stem, but the past and the present tense forms of the irregular verbs do not. In the particular experiment, the participants were first presented with the present tense form of the verbs, and had to produce the past tense form of that verb. As expected, the production of regular and irregular past tense forms in this task shows a morphological priming effect, stronger for regular verbs. Indeed, the regular (sigmatic) verbs showed an advantage over the irregular (non-sigmatic) verbs because the same stem was accessed and activated again. In the case of irregular verbs the stem had received some activation by being connected to the present tense stem, but it was still a different stem that had to be accessed for the past tense formation. This morphological priming effect is realized on the significantly lower response latencies of the regular verbs, compared to irregular verbs.

The previous study on the production of past tense forms of regular and irregular verbs in Greek (Terzi et al., 2005) failed to detect this priming effect, probably due to methodological issues. In that study, the measurement used was error rates. Error rates are in general less sensitive as a measurement; therefore, no effect of regularity was detected for their group of healthy people. The present study utilizes a different type of measurement, namely response times, and the predicted difference between regular and irregular verbs is detected.

Although errors were not the primary type of measurement in the current study, a relatively great number of errors has been observed. Similarly to the results reported by Terzi et al. (2005) though, regularity does not seem to have a significant effect on error rates. As seen from the present results, regularity affects the level of complexity of a verb, but error rates are not the most appropriate type of measurement to use, at least for healthy populations. The only significant effect detected in relation to errors was that the RTs of the erroneous answers were higher than those of correct answers. This result does not come as a surprise because when a wrong answer is given it is assumed that the particular item is hard to process. If an item is hard to process then more time is needed to cope with it (Kolk, 1995). However, if only regularity is relevant, no explanation can be given as for the source of difficulty of the items that caused higher error rates.

5. Exploring another factor of complexity: Inflectional Entropy

The original purpose of the present study was to test the hypothesis that regularity affects the production of verbs in Greek healthy people. Although errors were not the primary type of measurement and were not expected, a relatively high error rate was observed. In an attempt to explain those errors, that regularity failed to explain, I asked what other property of verbs could affect their level of complexity. Inflectional entropy is a relatively new measure of processing complexity that is based on principles of Information Theory (Shannon, 1948). Several studies have shown a significant effect of inflectional entropy on language production and comprehension (e.g. Van Ewijk, 2013; Tabak, 2010; Baayen & Moscoso del Prado Martin, 2005; Manika, 2014). In order to investigate whether inflectional entropy could explain the current data better than regularity, the data were reanalyzed for the effect of inflectional entropy both on RTs and errors. Before diving into the analysis, the following section introduces the basic notions of Information Theory and explains how inflectional entropy can be related to verb production.

5.1 Information Theory & Language

Information Theory was first introduced as a means to study the transmission of signals over (technical) channels. Around the 1940s, it was believed that an increase in the transmission rate of information over a communication channel would increase the probability of an error. Shannon (1948) and Shannon and Weaver (1949) refuted that hypothesis and suggested that what actually affects the error probability is the complexity level of the encoded information. Notions like channels, signals and encoded information might seem unrelated to verb production but, if we think of the human language brain in terms of channels transmitting information in order to communicate then we have a viable and palpable theory to work with.

Information Theory relies on two basic concepts: *information* and *uncertainty*. In the context of Information Theory, 'information' has a different meaning than in our everyday life. Shannon does not use 'information' to address what one says, but rather, what one *could* say. If I am in a city and I ask someone where I am, if I already know the answer, the response of that person will not be informative for me. In other words, the message of that person 'tells' me nothing. The uncertainty is zero, just like the information value of the message. If I know the country in which I am but not the city, then the uncertainty increases. I have many possible candidates to choose from, so the answer to my question will be informative. If I have no idea where I am, the uncertainty is even greater. In this case, the answer given will be even more informative. In other words, the bigger the set of possible candidates, the greater the uncertainty is, and consequently, the greater the information of the message.

If we assume that the probability of occurrence of the different candidates (*c*) is the same, the individual information value is measured with Formula 1[4]:

Formula 1: Information load carried by an item $_i$, measured in bits of information

$I_i = - \log_2 p_i =- \log_2 1/c$

where p is the probability of $_i$, that is the same for each possible candidate *c*. In general, when an element has high probability of occurrence, then there is low informative value. In other words, if an element occurs relatively often, it is not a great surprise when it appears. On the contrary, when an element has low probability of occurrence then there is high information value. This element does not occur very often, therefore when it appears the surprise is greater.

If there is just one possible candidate, then the information load would be $-\log_2 1/1 = 0$ bits of information. If there are two or three possible candidates then the information load of each one would be $-\log_2 1/2 = 1$ bit of information and $-\log_2 1/3 = 1.585$ bits of information, respectively. Taken that the probabilities of the different items is the same, then the more possible candidates there are, the higher the uncertainty is and consequently the higher the individual information

[4] The possibility to get one item over the others is always under 1. This means that the number we get from the equation *$\log_2 k$* is always a negative number. The minus sign is used to transform that negative number into a positive number.

value that each items carries. In cases where the probabilities of the possible items differ, each item will carry a different individual information value, depending on its probability.

The second important notion in Information Theory, namely the uncertainty that a set carries, or in other words the *entropy (H) of a set,* is expressed with the following formula:

Formula 2: Entropy of a set

$$H = - \Sigma\, p_i \log_2 p_i,$$

where Σ sums over all the items in the set. To understand this formula, take for instance a set of cars. If this is a singleton set, in other words if there is just one car in this set, then the probability of choosing that car will be $p_i=1$. Since picking this one and only car is our only choice, there is no uncertainty. This is expressed by the entropy of the set: $H = - \Sigma\, p_i \log_2 p_i = - (1 \log_2 1) = 0$ bits.

Now consider that the set we are dealing with has more than one item. For instance, think that you have 5 cars to choose from (c=5), but they are all identical so their probability of choosing one over the other is the same. The entropy of this set is calculates as follows: $H = - \Sigma\, p_i \log_2 p_i = - \Sigma\, 1/c \log_2 1/c = - \Sigma(1/5 \log_2 1/5) = - (5*1/5 *\log_2 1/5) = 2.321$ bits. In a different scenario, you still have 5 cars to choose from, but these cars are now different and so their probabilities differ: p1= 1/10, p2=p3=p4=2/10 and p5=3/10. The entropy of this set changes: $H = - \Sigma\, p_i \log_2 p_i = - [(1 \times 1/10 \times \log_2 1/1) + (3 \times 2/10 \times \log_2 2/10) + (1 \times 3/10 \times \log_2 3/10)] = 2.256$ bits. The above calculations show that even when the number of items in a set is the same, the entropy of that set changes, depending on the probabilities of the items.

Formulas 1 and 2 are also used to investigate language. In the early 1990's, Kostić argued that, based on the results of Lukatela et al. (1978), mere frequency cannot be the only factor responsible for processing effects. Apart from frequency, inflected forms also differ in terms of number of syntactic roles they can take in a sentence. Kostić originally suggested that, based on the number of functions a Serbo-Croatian noun form can have. For example, *konja* ('horse') in Serbo-Croatian can be either the masculine singular genitive form, or the masculine plural genitive form, or the masculine singular accusative form of the same noun. Therefore, we say that the form *konja* has three syntactic functions. Based on this observation, Kostić (1991) proposed Formula 3 that encompasses the effect of the syntactic roles a form covers together with frequency.

Formula 3: Information Load of verb form $_i$

$$I_{\mathrm{i}} = -\, log_2 \frac{\frac{F_i}{R_i}}{\sum_1^c \frac{F_m}{R_m}}$$

Based on this formula, the information load of a verb form $_i$ is a function of both the form's relative frequency (F) and the number of linguistic functions (R) that form can serve, of a *c*-item set, in an event *m* where we need to choose one of those forms.

Entropy has been adapted to language by Moscoso del Prado Martin and his colleagues (2004), and has been shown to influence processing complexity. The inflectional paradigm of a word with the various inflected forms replaces the set with the possible candidates that the original definition of entropy referred to. For instance, the inflectional paradigm of the verb *go* in English consists of five elements: go, goes, went, going, gone. The entropy of an inflectional paradigm is called *inflectional entropy of a set*. However, Van Ewijk (2013) combined Kostić's (1991) measure of information load as adapted to language together with Moscoso del Prado Martin's (2004) inflectional entropy to create a new version of inflectional entropy, that comprises both the effect of frequency and the syntactic functions covered by an inflectional form (Formula 4).

Formula 4: Inflectional Entropy of an inflectional paradigm *f*

$$H_f = -\sum_{i=1}^{c} \frac{\frac{F_i}{R_i}}{\sum_1^c \frac{F_m}{R_m}} * log_2 \frac{\frac{F_i}{R_i}}{\sum_1^c \frac{F_m}{R_m}}$$

where *F* is the relative frequency and *R* the number of syntactic functions a particular form has. An example of calculation of the information load of a (Greek) verb can be found in the following section.

Inflectional entropy has been experimentally shown to affect both language production and comprehension but in a different manner in each case. High inflectional entropy hinders production while facilitating comprehension. An increase in inflectional entropy has been shown to decrease response latencies in comprehension experiments (Van Ewijk, 2013; Tabak, 2010; Baayen & Moscoso del Prado Martin, 2005), while increasing the response latencies in production experiments (Tabak, 2010; Bien, Baayen & Levelt, 2011). Inflectional entropy itself predicts this contrast and it is to be expected if we understand what inflectional entropy really measures. Inflectional entropy depends on the distribution of the individual information values of the items of a paradigm. When the distribution of the individual information values is more discrete (i.e. the values are dissimilar) the inflectional entropy is low, for there is less uncertainty (Figure 2). When there is a more uniform distribution of the individual information values, the inflectional entropy is higher because the uncertainty is higher (Figure 3). If all individual information values are the same then the inflectional entropy of the set is at its maximum level because it is impossible to distinguish between the various items.

Figure 2[5]: Inflectional paradigm with low inflectional entropy

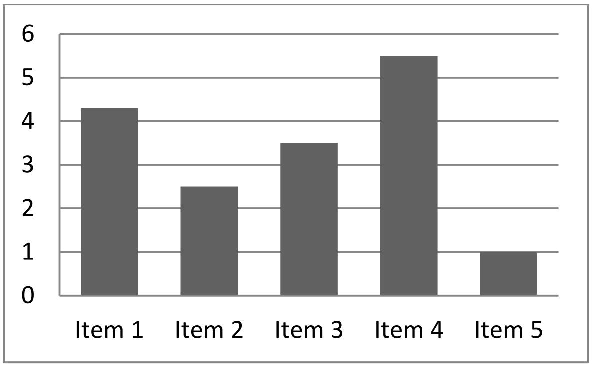
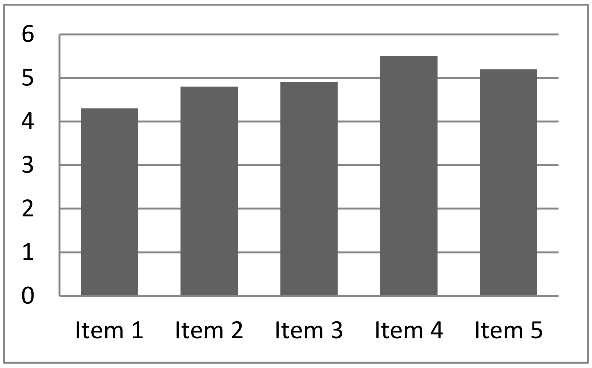


Figure 3: Inflectional paradigm with high inflectional entropy



This distinction is due to the different cognitive components involved in comprehension and production. Comprehension is *perceptually* driven. This means that once you hear a word, this word activates the representation from memory. When an item is activated, the neighborhood items also receive some activation (Anderson, 2005). An inflectional paradigm with high inflectional entropy implies that that their base levels of activation are similar. Consequently, less energy is lost on the non-target items when they are closer to each other than when they are more distinct. Therefore, the comprehension of the target item is faster for an item that belongs to a high inflectional entropy paradigm than for an item that belongs to a low inflectional paradigm. Production, on the other hand, is *conceptually* driven. When you want to produce something, you start with a concept and then select the corresponding lemma from the lexicon. If the individual information values of the

[5] Both Figure 2 and Figure 3 represent simplified versions of inflectional paradigms that do not correspond to any existing verbal paradigms

other members of the inflectional paradigm are similar then it is more difficult to choose the target one, than what it would be if their values were more distinct (for discussion see Van Ewijk, 2013).

In conclusion, Information Theory provides us with a useful tool to assess processing complexity: inflectional entropy. Since Shannon's first definition of entropy, this measure has been developed to research language. Inflectional entropy, a function of the relative frequency and the number of syntactic functions a particular form has, has been already shown to be highly associated with processing cost and successfully predict response latencies. Thus, the particular measure is a useful tool to advance our understanding of language production (and comprehension).

5.2 Entropy in the Inflectional Paradigms of Greek Verbs

The formulas presented in the previous section apply for the inflectional paradigms of all languages. However, the number of inflected forms a paradigm includes, the frequencies, and the syntactic functions are always different. Greek, as a highly inflected language, has different forms for every different person in every number. Whether a verb has both active and passive voice also adds to the number of inflected forms. Table 3 provides an example of calculation of the information load of the Greek verb *erhome* 'I come', which has 24 different forms.

F (i.e. frequency) is calculated based on the frequencies of the forms found in The Hellenic National Corpus (ILSP, 2009), which includes more than 47.000.000 words, from more than 50.000 texts. The number of appearances of each inflected form was divided by the sum of the appearances of all the forms included in an inflected paradigm. Different forms of the same word were counted as a single inflected form. For example, in some cases in Greek, [r] and [l] are allophones of the same phoneme. Therefore, as item 3 in Table 3 shows, the words *irϑe* and *ilϑe* are actually two versions of the same inflected form. In cases where more than one word exists for the same inflected form, the frequencies of those words were summed up and a single information value was calculated.

R (i.e. number of syntactic functions) for verbs is related to tense formation. Greek distinguishes 8 tenses: *Enestotas (*Present*), Paratatikos (*Past Continuous*), Aoristos (*Simple Past*), Eksakoluϑitikos Mellondas (*Future Continuous*), Stiɣmieos Mellondas (*Simple Future*), Parakimenos (*Present Perfect Simple*), Hypersindelikos (*Past Perfect Simple*)* and *Sindelesmenos Mellondas (*Future Perfect Simple*).* The first three tenses are formed with a single word, whereas the rest are formed periphrastically. Table 4 gives examples for all 8 tenses.

Table 3: Example of calculation of information load of the Greek verb *erhome* 'I come'

c=24	*Inflected Form*	*F*	*R*	F_i/R_i	$P_i=(F_i/R_i)/\Sigma(F_i/R_i)$	$I=-logP_i$	$H_i=-P_i*logP_i$	$H=Sum(H_i)$
1	*erhete* 'He/She/It comes/is coming'	0.206	1	0.206	0.120	3.057	0.367	**3.361**
2	*irϑe/ ilϑe* 'He/She/It came'	0.210	1	0.210	0.122	3.030	0.371	
3	*erϑi/ elϑi* 'He/She/It will come'	0.159	1	0.159	0.093	3.429	0.318	
4	*erhonde* 'They are coming'	0.107	1	0.107	0.063	3.995	0.251	
5	*irϑan/ ilϑan/ irϑane* 'They came'	0.069	1	0.069	0.040	4.631	0.187	
6	*erϑun/ elϑun/ erϑune* 'They will come'	0.054	1	0.054	0.031	4.996	0.157	
7	*erhotan/ erhotane* 'He/She/It was coming'	0.033	1	0.033	0.019	5.699	0.110	
8	*erhome* 'I come/am coming'	0.030	1	0.030	0.017	5.857	0.101	
9	*erhomaste/ erhomasϑe* 'We come/are coming'	0.017	1	0.017	0.010	6.662	0.066	
10	*erheste/ erhesϑe/ erhosaste* 'You come/are coming' (plural)	0.022	1	0.022	0.013	6.310	0.080	
11	*irϑa/ ilϑa* 'I came'	0.016	1	0.016	0.010	6.713	0.064	
12	*erhondan/ erhondousan* 'They were coming'	0.014	1	0.014	0.008	6.899	0.058	
13	*irϑame/ ilϑame* 'We came'	0.012	1	0.012	0.007	7.146	0.050	
14	*erϑo/ elϑo* 'I (will) come'	0.013	1	0.013	0.008	7.048	0.053	
15	*erϑume/ elϑume/ erϑome* 'We (will) come'	0.013	1	0.013	0.008	7.048	0.053	
16	*irϑate/ ilϑate* 'You came' (plural)	0.006	1	0.006	0.004	8.090	0.030	
17	*erϑete/ elϑete* 'You (will) come' (plural)	0.006	1	0.006	0.003	8.162	0.028	
18	*irϑes/ ilϑes* 'You came' (singular)	0.003	1	0.003	0.002	8.970	0.018	
19	*erhese* 'You come/are coming' (singular)	0.003	1	0.003	0.002	9.138	0.016	
20	*erϑis/ elϑis* 'You (will) come' (singular)	0.003	1	0.003	0.002	9.239	0.015	
21	*erhomun/ erhomuna* 'I was coming'	0.002	1	0.002	0.001	10.059	0.009	
22	*erhomastan* 'We were coming'	0.001	1	0.001	0.000	11.526	0.004	
23	*erhosun/ erhosuna* 'You were coming' (singular)	0.001	1	0.001	0.000	11.366	0.004	
24	*erhosastan* 'You were coming' (plural)	0.001	1	0.001	0.000	11.707	0.004	

Table 4: The 8 Greek tenses for 3rd Person Singular

Tense	***3rd Person Singular***	
Enestotas *(*Present*)*	*erhete*	'He/She/It comes'
Aoristos (Simple Past)	*irϑe*	'He/She/It came'
Paratatikos (Past Continuous)	*erhotan*	'He/She/It was coming'
Eksakoluϑitikos Mellondas (Future Continuous)	*ϑa erhete*	'He/She/It will be coming'
Stiγmieos Mellondas (Simple Future)	*ϑa erϑi*	'He/She/It will come'
Parakimenos (Present Pefect Simple)	*ehi erϑi*	'He/She/It has come'
Hypersindelikos (Past Perfect Simple)	*ihe erϑi*	'He/She/It had come'
Sindelesmenos Mellondas (Future Perfect Simple)	*ϑa ehi erϑi*	'He/She/It will have come'

As shown in Table 4, in order to form the Present and Future Continuous for the 3rd person singular in Greek the same verb form is used (i.e. *erhome*). Similarly, Simple Future, Present Perfect Simple, Past Perfect Simple and Future Perfect Simple also share the same verb form for the 3rd person singular (i.e. *erϑi*). In both cases, the form that is used is the same, not just on the surface level but on the syntactic level as well. When *erhome* is used in isolation, it denotes the Present tense, but when the same Present tense form is used in combination with *ϑa* ('will'), it expresses the Future Continuous. When *erϑi* is used in the four different tenses, what defines the tense is the two items preceding it: *ϑa* ('will') and/or *eho* ('have') in the correct form. The word *erϑi* itself is an indeclinable past tense form with the 3rd person singular ending of the Present tense. Since *ϑa* ('will') and/or *eho* ('have') are the items carrying the different morphosyntactic functions, *erhome* and *erϑi* have only one syntactic function each, similarly to *irϑe* (Simple Past) and *erhotan* (Past Continuous) that only appear once.

Once the *F* and *R* for each inflected form are defined, the relevant calculations will give the value of the inflectional entropy of the inflectional paradigm. In Greek, since all forms have only one syntactic function (Table 3, column '*R'*), only frequency contributes to the calculation of the inflectional entropy of a verbal paradigm. As shown in the last column of Table 3, the inflectional entropy value of the Greek verb *erhome* 'I come' is 3.361 bits.

6. Inflectional entropy in the current data

The data of the present study revealed a significant effect of regularity on response times. However, the 4.69% error rate observed could not be explained by regularity. These data should not remain unexplained. Since inflectional entropy is an index of complexity of lexical access, the data collected were reanalyzed to test for a possible effect of inflectional entropy.

As discussed in the previous section, production is hindered by high levels of inflectional entropy. Previous studies have provided evidence that inflectional entropy affects both the RTs (e.g. Baayen & Moscoso del Prado Martin, 2005) as well as the error rates (e.g. De Lange, 2008). Therefore, both the errors and the RTs were reanalyzed to see if inflectional entropy is a factor that could explain all the data. Irrespectively of the effect of regularity on the RTs, inflectional entropy makes its own predictions. Verbs with higher inflectional entropy values are predicted to cause higher RTs, as well as more errors.

6.1 Analysis

The error rates and RTs of all 32 participants were analyzed. The entropies of the verbs varied from 1.479 to 4.740 bits, a relatively wide distribution of entropies. All inflectional entropy values were calculated as described in section 5.2 and listed in Appendix B.

The errors were analyzed in Generalized Linear Mixed Models (GLMM), crossed both with inflectional entropy, as well as verb type to test for an interaction effect between inflectional entropy and verb type. Following this, the two types of errors with higher error rate (i.e. Past Continuous and Double Answers) were analyzed separately using GLMM crossed with inflectional entropy, to see if inflectional entropy is a significant factor for the particular types of errors, as well as verb type to test for an interaction effect between inflectional entropy and verb type.

Comparably to the previous analysis, only the RTs of the correct answers were analyzed, and they were square-root transformed to approximate normality. The RTs were analyzed using mixed-effects models with multiple random factors (LMER). The RTs were crossed both with inflectional entropy, as well as verb type to test for an interaction effect between inflectional entropy and verb type.

Random terms for participant and item, as well as main terms for number of syllables, surface frequency and lemma frequency were included in the models.

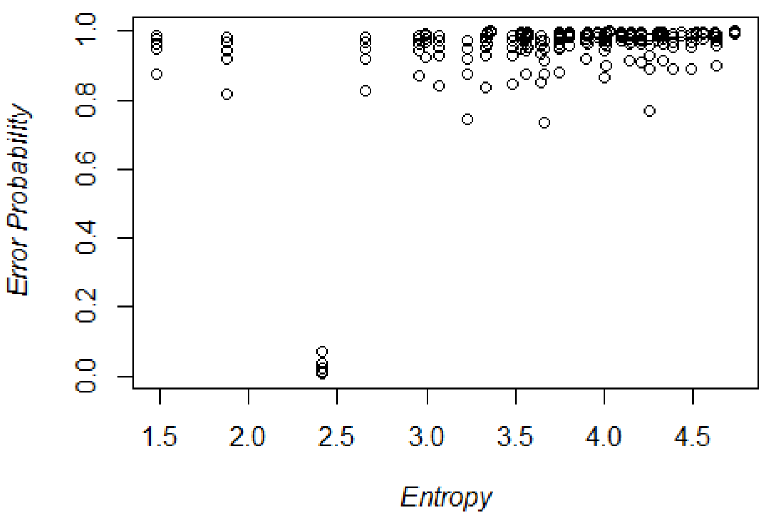
6.2 Results

The results presented below are significant at a level of α=.05 or lower.

All errors were first analyzed together. The maximal model best fitting the data revealed a significant effect of H on errors, (*β*=1.261, *SE*=0.525, *p*=0.016). The interaction between regularity and entropy did not reach significance (*β*=0.573, *SE*=1.144, *p*=0.617). Number of syllables, surface and lemma frequency failed to reach significance.

When the logits are transformed into probabilities, it means that when the inflectional entropy increases with 1 point, the probability of getting an error increases with 0.99. As it is graphically depicted in Figure 4, the verbs with higher inflectional entropy have higher error probability.

Figure 4: Effect of H on Errors



The analysis for an effect of inflectional entropy on the Past Continuous type of errors did not reveal a significant effect (*β*=-0.060, *SE*=0.394, *p*=0.877). The interaction between inflectional entropy and regularity on the Past Continuous type of errors also failed to reach significance (*β*=-0.217, *SE*=0.908, *p*=0.811). The analysis for an effect of inflectional entropy on the Double Answers type of errors did not reveal a significant effect (*β*=0.748, *SE*=0.862, *p*=0.385) either. The interaction between inflectional entropy and regularity on the Double Answer type of errors also failed to reach significance (*β*=-0.217, *SE*=0.908, *p*=0.811).

Finally, H did not have a significant effect on the RTs (*β=0.014*, *SE*=0.013, t=1.03), neither did the interaction of verb type with H (*β*=-0.004, *SE*=0.027, t=-0.18).

6.3 Discussion

The results of this analysis suggest that the errors that the healthy Greek participants made were not random. As the current data show, the probability of making an error increases when the inflectional entropy of a verb paradigm increases. This evidence is in line with previous studies where the higher the inflectional entropy value of an item is, the harder it is to produce. When the inflectional entropy of an inflectional paradigm is higher, it means that the distribution of the items is similar to one another. In production, one needs to identify the target item amongst the other members of the set in order to activate it. Since the items of an inflectional paradigm with high inflectional entropy are similar, this task will be harder for the speaker. This increase in complexity results, as the current findings suggest, in an increase of the error probability for the production of the particular item.

As discussed in section 5.2, the inflectional entropy of a verbal paradigm in Greek is calculated based only on the surface frequency, for the number of syntactic functions is always 1. Previous studies have shown an effect of frequency on verb production (e.g. Stemberger & MacWhinney, 1986; Alegre & Gordon, 1999), but surface frequency did not have a significant effect on the current data. Since inflectional entropy has been shown to significantly affect the error rates here, this study suggests that entropy is a more robust measure of complexity than pure surface frequency.

In one of the previous analyses, the results showed that the erroneous answers had higher RTs than the correct answers (section 4.4). The current analysis shows that the items with higher inflectional entropy values were those with higher probability of error. Since the higher RTs are related to errors and errors are related to higher inflectional entropies, it can be inferred that the higher inflectional entropies are also related to the higher RTs of the erroneous answers. High inflectional entropy increases the error probability and, if eventually an error is produced, then as expected, the response latency will be higher than if a correct answer was produced. The increased complexity level of an item with high inflectional entropy is not only realized as an erroneous answer but also as an increased response latency for that erroneous answer.

However, inflectional entropy seems to have no effect on the RTs of the correct answers. Inflectional entropy has been previously shown to correctly predict response latencies in responses that do not necessarily contain errors (see for example Baayen & Moscoso del Prado Martin, 2005). RTs were expected to positively correlate with the inflectional entropy values of the verbs, but instead no significant effect was found, except for an inferred effect of inflectional entropy on the RTs of the incorrect answers. Thus, the predictions regarding the effect of inflectional entropy on RTs are only partially borne out.

The non-significant effect of inflectional entropy on the RTs of the correct answers is probably due to a ceiling effect. As expected, low inflectional entropy verbs are easier to produce, and hence, these were the verbs with more correct answers. Since these verbs are of lower complexity, the participants were able to respond correctly and quickly to all of them. This clustering around a minimum amount of time, denoting ease of performance, is known as ceiling effect. The RTs of the correct answers were probably so similar to each other that no effect of entropy could be detected. A more sensitive measurement, like eye-tracking, could possibly reveal any effect of entropy on the correct answers that was not detectable by measuring the RTs.

7. Exploring Previous and Current Data

7.1 The effect of Inflectional Entropy on verb production in Parkinson's disease

Terzi et al. (2005) is the first and only study, at least to my knowledge, testing the production of Greek verbs by PD patients. The results of that study showed that although the performance of PD patients was in general poorer than that of healthy people, no statistically significant difference was found between the production of regular and irregular past tense forms, for either of the two groups. The measurement used for that study was error rates, but the results of the present experiment suggest that regularity does not significantly affect errors.

The errors on the production of past tense forms in the current study were significantly affected by the inflectional entropy level of the verb. Since the data collected by Terzi and her colleagues were only tested for regularity effects, without any statistically significant results, it is interesting to reanalyze those data and test for a possible effect of inflectional entropy. Investigating the possible effect of inflectional entropy on the production of past tense forms by PD patients is one of the few attempts to assess the effect of inflectional entropy on the language abilities of clinical populations[6].

7.1.1 Analysis

From all the data collected in the Terzi et al. (2005) study, I gained access to the raw data of the 25[7] PD patients, but not to any data from the healthy controls. In the data it was only stated whether the answer was correct or not, without any description of the errors. Hence, the errors could not be categorized as in the current study. The inflectional entropy values of the 20 verbs used in the Terzi et al. (2005) study ranged from 3.336-4.740 bits, a relatively small range of entropies.

The errors were analyzed in Generalized Linear Mixed Models (GLMM), crossed both with inflectional entropy, as well as verb type to test for an interaction effect between inflectional entropy and verb type. Random terms for participant and item were included in the model.

[6] Van Ewijk (2013) has investigated the effect of inflectional entropy on language processing by aphasic people

[7] The original study by Terzi et al. (2005) reports the results from 27 PD patients. However, I only had access to the data from the 25 out of the 27 patients.

7.1.2 Results & Discussion

The results of this analysis revealed no significant effect of either of H (β*=0.441*, *SE*=0.642, *p=0.492*) or of an interaction between verb type and H on the errors (β*=-0.730*, *SE*=1.256, *p*=0.561).

Three possible explanations are discussed for the non-significant effect of inflectional entropy on the data by Terzi et al. (2005). The first one concerns the inflectional entropy values of the verbs. In the current study, where 48 verbs were used, the range of the entropies of the verbs was greater than in the study by Terzi and her colleagues: 1.479 to 4.740 bits and 3.336-4.740 bits respectively. In the latter case, the range is so small that it may not be big enough to reveal any effect of inflectional entropy on the production of past tense forms.

A second possible explanation concerns the number of observations collected. In the Terzi et al. study, only 500 observations were collected (25 participants x 20 verbs) whereas in the present study 1536 observations were collected (32 participants x 48 verbs). Having less than three times the amount of data than the current study to analyze might have been responsible for not detecting any significant effect. These first two explanations are related to some extent. The fact that only 20 verbs were used in the Terzi et al. (2005) study, relates both to the small range of entropies as well to the small number of observations.

The third explanation pertains to the population tested. The data re-analyzed were the data from the PD patients. The effect of inflectional entropy on PD patients' performance has never been tested before though. One could argue that, for some reason that we do not yet know, Greek PD patients' deficits alter the effect of inflectional entropy on language production. For example, the procedural memory deficits of this population might affect their abilities to deal with inflectional entropy in general, suggesting a floor effect. However, this is just a speculation for which the current analysis does not provide evidence for.

The first two explanations address the importance of a meticulous methodological design, whereas the third one creates the possibility that inflectional entropy has a different effect on different populations. Although at this point all three explanations seem equally plausible, the impact that each of these could have on future research varies. Therefore, further investigation is required to address this issue.

7.2 Inflectional Entropy and Regularity in smaller data samples

As shown in the previous section, the data of the PD patients collected by Terzi et al. (2005) do not reveal any significant effect of inflectional entropy on the production of past tense forms by PD patients. Three possible explanations were provided for the obtained results. The first two possible explanations suggest some methodological flaw in the study, whereas the third could have important implications for the effect of inflectional entropy on the language abilities of PD patients. *Psycholinguistically* speaking, the third explanation seems to be the most interesting one. Before diving into theories and assumptions to explain why PD patients could be unsusceptible to inflectional entropy though, we could try to disentangle the first two explanations from the third one. A possible way to do that would be to test if the small number of verbs would have the same non-significant effect of inflectional entropy on error rates for healthy people as well.

Unfortunately, the data from the healthy controls of the Terzi et al. (2005) study were not available. Thus, the data from the healthy Greek participants of the present study were used. Out of the 48 verbs used in the current experiment, 20 were the verbs used by Terzi and her colleagues. The responses for those 20 verbs were isolated and analyzed again, separately from the remaining 28 verbs. In other words, the current experiment was treated as if it included only those 20 verbs. If the same significant effects were found in this analysis as in the original analysis with all 48 verbs, it would suggest that the third explanation regarding the PD patients is more plausible than the first two. If no significant effects were detected, similarly to the reanalysis of the data from the PD patients, then the first two explanations would be more probable.

In order to further explore the impact that a small sample can have on the obtained results, the same data set was also analyzed for the effect of regularity on RTs of healthy people that previously showed a significant effect.

7.2.1 Analysis

The errors were analyzed in Generalized Linear Mixed Models (GLMM), crossed with inflectional entropy. The RTs were analyzed using mixed-effects models with multiple random factors (LMER), and they were crossed with verb type. Comparably to the previous analysis, only the RTs of the correct answers were analyzed, and they were square-root transformed to approximate normality. Random terms for participant and item, as well as main terms for number of syllables, surface frequency and lemma frequency were included in the models.

7.2.2 Results & Discussion

The analyses revealed no significant effect either of H on errors ($\beta=-0.242$, SE=0.559, p=0.665), or of regularity on RTs ($\beta=-0.052$, SE=0.031, t=-1.7). Number of syllables, surface and lemma frequency failed to reach significance.

The goal of this reanalysis was twofold: to investigate which explanation is more plausible for the non-significant effects of inflectional entropy reported for the data from Greek PD patients, and to investigate the effect of regularity on RTs in a small sample. The significant effect of inflectional entropy on error rates originally found for the data of the current study disappears when only the responses for the 20 verbs are analyzed. This result suggests that the non-significant effects for the data collected from the Greek PD patients are due to either, or both of, the first two explanations: the range of the entropies of the 20 verbs was too small and/or the observations collected were too few to reveal any effect of inflectional entropy. The current data cannot provide any evidence as to which of the two factors, or if both factors, were responsible for the non-significant effect of inflectional entropy on error rates. In order to separate the two we could use the same 20 verbs but administer the task to 70-80 people. This way, we would have the same number of observations, close to 1500, but the range of entropies would be the same. If a significant difference is found in such an experiment, it would imply that what caused the non-significant effect of entropy on the current analysis is the small set of observations. If no significant effect is found then only the small entropy range explains the obtained results.

The effect of regularity on the response latencies in a small sample has interesting implications for the original study by Terzi et al. (2005). The effect of regularity on the RTs reported in the first analysis of the data of the present study (section 4.4) also disappeared when only the responses for the 20 out of the 48 verbs were analyzed. Assuming that the number of observations analyzed is indeed the cause of the non-significant effect, if Terzi and her colleagues had used more verbs in their study and had bigger data samples both for healthy people and PD patients, a significant effect of regularity should have been detected. Although earlier in this paper it was argued that Terzi et al. did not find any significant effects due to the type of measurement they used, namely error rates, the current reanalysis creates the possibility that the amount of the data collected is an additional factor that confounded their results. However, these speculations should be confirmed or denied through further research.

8. General Discussion

The purpose of this study was to test whether regularity is a factor of complexity that affects past tense formation of Greek verbs. To this end, a sentence completion task was administered to a group of healthy Greek speakers. The results show that regular verbs are produced significantly faster than irregular verbs, suggesting that a Greek verb's regularity condition affects the production of its past tense form.

As discussed in section 2.3, the behavioral data by Terzi et al. (2005) suggest that the past tense formation of irregular verbs in Greek requires decomposition, like all regular verbs but unlike the irregular verbs of a language with poorer morphology, like English. More specifically, both regular and irregular past tense forms in Greek require a person and number suffix, and in some cases they also need the stressed augment *e-*. These affixes, as well as the stems, are retrieved by the declarative memory system and are composed into the final form using rules from the procedural memory system. Consequently, the processes required for the past tense formation of Greek irregular verbs are the same as for Greek regular verbs.

Although both types of verbs require both the declarative and the procedural memory systems for their past tense formation, irregular verbs are still expected to be of higher complexity in a task like the one presented, due to a morphological priming effect. Morphological priming is expected to facilitate the past tense formation of regular verbs, because the prime and the target word, namely the present and the past tense verb form respectively, share the same stem. However, it will not facilitate (at least not to the same extent) the past tense formation of irregular verbs, for the stem is different in the two tenses.

Contrary to the results of the current study on healthy Greek people, Terzi et al. (2005) did not find an effect of regularity on the past tense formation either by PD patients or by healthy controls. It is assumed that the reason Terzi and her colleagues did not find this difference, at least for healthy people, is because their measurement, error rate, is not sensitive enough to discern this morphological priming effect. In addition, based on an analysis of a smaller amount of the current data, it is argued that the data collected might had been too small to reveal a significant effect of regularity on past tense formation.

An unexpected result of the experiment reported here was the high error rate. Although the primary measurement was response times, errors were also collected. The results of the error analysis did not reveal any significant effect of regularity. However, inflectional entropy, a different factor of complexity, explained those results. Inflectional entropy describes the uniformity of the distribution of the inflected forms within a verbal paradigm. The higher the inflectional entropy of a paradigm is, the more similar the items of that paradigm are, and consequently the more difficult it is to produce the target item. The results of this experiment show that the higher the inflectional entropy of a verbal paradigm in Greek is, the higher the probability of error.

The effect of inflectional entropy on the language abilities of impaired populations has been hardly studied so far. Since inflectional entropy was shown to have a significant effect on the performance of healthy people, a reanalysis of the data by Terzi et al. (2005) was conducted to investigate the effect of inflectional entropy on the Greek past tense formation by PD patients. The analysis revealed no statistically significant effects. In an analysis of only a small part of the current data on healthy people, mentioned earlier in this discussion, the significant effect of inflectional entropy on error rates also disappeared. Based on the results of that reanalysis, we conclude that possible methodological flaws of the Terzi et al. study do not allow us to accurately test if inflectional entropy has the same effect on the past tense formation for PD patients as for healthy people. Future research could address this issue by conducting a larger scale experiment with more participants as well as a greater inflectional entropy range.

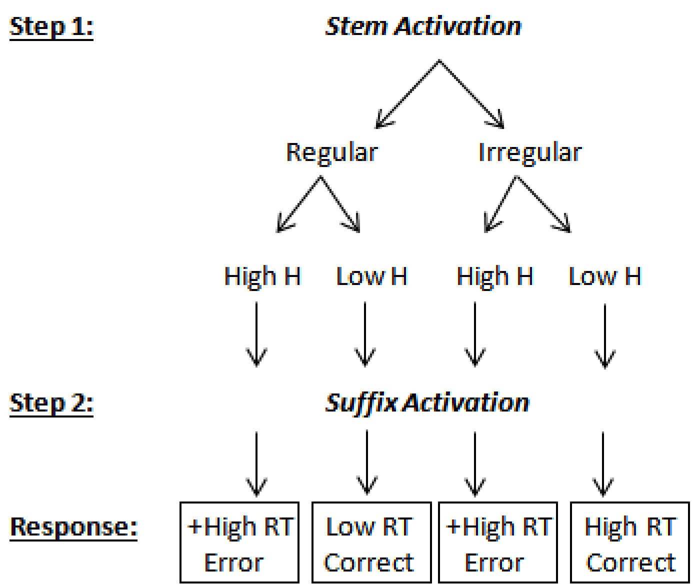
Inflectional entropy can be seen as an index of complexity of lexical access to activate lexical items. If the complexity is higher, it should be reflected both in the RTs as well as in the errors. Inflectional entropy in the present study has been shown to have a significant effect on the errors but not on the RTs. Recall, though, that the RTs analyzed here are only the RTs for the correct answers. When the RTs of the correct answers were compared against the RTs for the erroneous answers, the latter were shown to be significantly higher than the former. Recall also that the erroneous answers were those with higher levels of inflectional entropy. Since the higher RTs are related to errors and errors are related to higher inflectional entropies, it is inferred that the higher inflectional entropies are related to the higher RTs of the erroneous answers. The RTs of the correct answers though were not significantly affected by inflectional entropy. The task was probably not sensitive enough to detect such an effect for healthy people.

What this study provided us with so far is evidence that both regularity and inflectional entropy are factors of complexity that affect past tense formation in Greek. However, we cannot talk about two different factors of complexity, both affecting the data, without trying to understand how they interact. In what follows, I formulate a hypothesis for verb production that would allow both regularity and inflectional entropy to act as expected, given what we already know about these two different factors of complexity. Regularity defines whether a verb follows particular rules for its formation or not. Depending on the regularity condition of the verb, the relevant memory systems are activated. Inflectional entropy describes the uniformity of the distribution of the inflected forms within a verbal paradigm.

When Kostić (1991) first mentioned individual information values of nouns, he focused on the suffix of the nouns. The suffix of a noun is simply a morpheme. Kostić calculates the information values of this morpheme, namely the suffix, and refers to it as the individual information value of the inflected form. Since the stem is the same for all the items in a noun paradigm, what differs and what distinguishes the various inflected forms is the suffix.

Now consider verbs. So far, inflectional entropy of a verb's paradigm has been presented as a property that concerns fully formed items. Following Kostić's reasoning though, we can assume that the stem and the number and person suffix of a Greek verb can be treated separately, even when the factor in hand is inflectional entropy (and not regularity). This would result in two inflectional entropy values: the inflectional entropy of the stem and the inflectional entropy of the suffix. All verbs, irrespectively of their regularity condition, share the same suffixes. For instance, the 6 different suffixes for the 6 different persons in present tense in Greek are used both for regular and irregular verbs. Consequently, the inflectional entropy of the person and number suffix is expected to be the same for all Greek verbs. However, the inflectional entropy of the stem is expected to differ among the various verbs. Some verbs have more stems than others and their frequencies and syntactic functions differ. What determines the difference in the inflectional entropy values of verbs, then, is the inflectional entropy of their stem. If this hypothesis is valid, then the results of this study are summarized and explained in Figure 5.

Figure 5: A model of Past tense formation in Greek, integrating both regularity and inflectional entropy



The formation of past tense in Greek in this scenario consists of two steps. Step 1 is the activation of the stem, and Step 2 is the activation of the suffix. Both regular and irregular verbs are distinguished into high inflectional entropy (High H) and low inflectional entropy (Low H) verbs. Both inflectional entropy and regularity affect the complexity of the process at Step 1, but their effect is only realized after Step 2, at which point the person and number suffix is attached to the stem and the final form is produced.

In Step 1, when the stem is activated, regularity determines whether there will be a morphological priming effect that will later affect the response latency. More specifically, regular past tense forms that share the same stem with their present tense forms should be produced faster than irregular past tense forms that have a different stem than their present tense forms. Then, still in Step 1, inflectional entropy has its own effect on the stem activation. If a verb - either regular or irregular - has high inflectional entropy (i.e. uniform distribution of probabilities and therefore higher uncertainty) the possibility of making an error is higher than in the case of a verb with low inflectional entropy. In case of error, the system is expected to have given its best before failing. In other words, all the available time for producing that item must have been used, thus causing higher RTs (+High RT) for the erroneous answers than for the correct answers, irrespectively of the item's regularity condition. Hence, in the cases where there is high inflectional entropy and an error is produced, we assume that the effect of inflectional entropy overwrites the effect of regularity. If the inflectional entropy of the verb is low (i.e. easy to detect among the other members of its paradigm), the possibility of having a correct answer is significantly higher. The response latencies of the correct answers will differ, depending on the regularity condition of the verb. Producing the past tense form of a regular verb with low inflectional entropy will provide a correct answer in a shorter period of time (Low RT) than producing the past tense form of an irregular verb with low inflectional entropy (High RT).

From this, at Step 2, the number and person suffix is activated and attached to the stem. The person and number suffix will carry its own inflectional entropy value, but, it will, nonetheless, be the same for all verbs, irrespectively from their regularity condition. Therefore, the activation of the suffix is expected to have the same effect on all four types of stems (Regular-High Entropy, Regular-Low Entropy, Irregular-High Entropy, Regular-Low Entropy). Since the effect of the activation of the suffix is factored out, the response will reflect the effects of regularity and inflectional entropy on the stem, as described before.

It is important to note that there are two important assumptions for this model to work as described. The first is that there is a way to calculate the inflectional entropy values of the stem and the suffix separately. The second is that there is indeed a wide range of entropies for both regular and irregular verbs that would allow this distinction between low and high inflectional entropy verbs. Calculating the inflectional entropy of the stem and the suffix separately, though, requires extensive work, which is left for future research.

9. Conclusion

In this study, I have investigated the effect of regularity and inflectional entropy on the production of Greek regular and irregular verbs. Both regularity and inflectional entropy have been shown to have a significant effect on the formation of past tense by healthy Greek people, but each of them seems to reveal this effect on a different type of measurement. Regularity has an effect on the response latencies, due to a morphological priming effect. More specifically, the past tense formation of irregular verbs causes higher RTs than the past tense formation of regular verbs. Inflectional entropy has an effect on the error rate, with high inflectional entropy verbs having a higher error probability than low inflectional entropy verbs.

A previous study (Terzi et al., 2005) on the effect of regularity on past tense formation in Greek failed to detect the aforementioned effect. A possible explanation would be that the measurement used in that study, namely error rates, was not sensitive enough to detect this effect. A reanalysis of the data of that study for an effect of entropy on past tense formation by PD patients also failed to reveal a significant effect. Further analyses revealed that the amount of collected data plays a crucial role in the detection of such effects, at least for healthy populations. For PD patients no conclusions can be drawn, since the amount of available data is not enough to reveal if entropy has a different effect for that particular population.

The model of past tense formation in Greek presented in the previous section suggests a way to integrate both main effects that this study reports. Based on Kostić's (1991) original approach to individual information values, it is hypothesized that the inflectional entropy of a verbal paradigm can be distinguished into two different inflectional entropy values: the inflectional entropy value of the stem and the inflectional entropy value of the suffix. In order to test this hypothesis, we need to calculate these two types of inflectional entropy separately. This would enable us to further explore the impact of inflectional entropy on language production, as well as comprehension, in a greater detail. So far, we are not able to calculate the inflectional entropy of the stem separately from the suffix, but future research will try to address this possibility.

In conclusion, the current study contributes to our understanding of the complexity of past tense formation, while providing further data for the past tense formation in a relatively understudied language, Greek. This is the first study, at least to my knowledge, providing evidence that the past tense formation of Greek irregular verbs is more difficult than that of regular verbs. In addition to this, the results of this study provide a more realistic picture of how different factors of complexity, in this case regularity and inflectional entropy, can interact. The model of past tense formation for Greek suggested here should be further investigated and validated with cross-linguistic research. Treating the different factors of complexity separately and focusing on particular languages does not help in formulating an accurate theory of lexical access, the ultimate goal of this line of research.

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Appendix A: The Experimental Items

With regular verbs

1. *Kaϑe mera, i pirates tripane ta kivotia.*
   Every day, the pirates pierce the boxes.
   'Every day, the pirates pierce the boxes.'

   Hϑes, gia mia stigmi, i pirates [ ] ta kivotia.
   Yesterday, for one moment, the pirates [ ] the boxes.
   'Yesterday, for a moment, the pirates [ ] the boxes.'

2. *Kaϑe mera, i ksenagos efharisti ton odigo.*
   Every day, the guide thanks the driver.
   'Every day, the guide thanks the driver.'

   Hϑes, gia mia stigmi, i ksenagos [ ] ton odigo.
   Yesterday, for one moment, the guide [ ] the driver.
   'Yesterday, for one moment, the guide [ ] the driver.'

3. *Kaϑe mera, i astegi ftene tus plusius.*
   Every day, the homeless blame the rich.
   'Every day, the homeless people blame the rich people.'

   Hϑes, gia mia stigmi, i astegi [ ] tus plusius.
   Yesterday, for one moment, the homeless [ ] the rich.
   'Yesterday, for a moment, the homeless people [ ] the rich people.'

4. *Kaϑe mera, i pehtries linun tis askisis.*
   Every day, the players solve the exercise.
   'Every day, the players solve the exercise.'

   Hϑes, gia mia stigmi, i pehtries [ ] tis askisis.
   Yesterday, for one moment, the players [ ] the exercise.
   'Yesterday, for a moment, the players [ ] the exercise.'

5. *Kaϑe mera, o politis gemizi ti vitrina.*
   Every day, the seller fills the shop window.
   'Every day, the seller fills the shop window.'

   Hϑes gia mia stigmi, o politis [ ] ti vitrina.
   Yesterday, for one moment, the seller [ ] the window shop.
   'Yesterday, for a moment, the seller [ ] the window shop. '

6. *Kaϑe mera, o prigkipas kapnizi to tsigaro.*
   Every day, the prince smokes the cigarette.
   'Every day, the prince smokes the cigarette.'

Hϑes, gia mia stigmi, o prigkipas [ ] to tsigaro.
Yesterday, for one moment, the prince [ ] the cigarette.
'Yesterday, for a moment, the prince [ ] the cigarette.'

7. *Kaϑe mera i ksaderfi halai tin pleksuda.*
Every day, the cousin breaks down the braid.
'Every day, the cousin undoes the braid.'

Hϑes, gia mia stigmi, i ksaderfi [ ] tin pleksuda.
Yesterday, for one moment, the cousin [ ] the braid.
'Yesterday, for a moment, the cousin [ ] the braid.'

8. *Kaϑe mera, i ipurgos trehi sto grafio.*
Every day, the minister runs to office.
'Every day, the minister rushes to the office.'

Hϑes, gia mia stigmi, i ipurgos [ ] sto grafio.
Yesterday, for one moment, the minister [ ] to office.
'Yesterday, for a moment, the minister [ ] to the office.'

9. *Kaϑe mera, i ginekes kuvalane tis valitses.*
Every day, the women carry the suitcases.
'Every day, the women carry the luggage.'

Hϑes, gia mia stigmi, i ginekes [ ] tis valitses.
Yesterday, for one moment, the women [ ] the suitcases.
'Yesterday, for a moment, the women [ ] the luggage.'

10. *Kaϑe mera, o furnaris plaϑi ta kuluria.*
Every day, the baker makes the buns.
'Every day, the baker makes the buns.'

Hϑes, gia mia stigmi, o furnaris [ ] ta kuluria.
Yesterday, for one moment, the baker [ ] the buns.
'Yesterday, for a moment, the baker [ ] the buns.'

11. *Kaϑe mera, i eggoni magirevi ton trahana.*
Every day, the granddaughter cooks the trahana.
'Every day, the granddaughter cooks the trahana.'

Hϑes, gia mia stigmi, i eggoni [ ] ton trahana.
Yesterday, for one moment, the granddaughter [ ] the trahana.
'Yesterday, for a moment, the granddaughter [ ] the trahana.'

12. *Kaϑe mera, i mitera aploni ta ruha.*
Every day, the mother spreads the clothes.
'Every day, the mother hangs up the laundry.'

Hϑes, gia mia stigmi, i mitera [ ] ti mbugada.
Yesterday, for one moment, the mother [ ] the clothes.
'Yesterday, for a moment, the mother [ ] the laundry.'

13. *Kaϑe mera, o mbakalis pulai ta lahana.*
Every day, the grocer sells the cabbages.
'Every day, the grocer sells the cabbages.'

Hϑes, gia mia stigmi, o mbakalis [ ] ta lahana.
Yesterday, for one moment, the grocer [ ] the cabbages.
'Yesterday, for a moment, the grocer [ ] the cabbages.'

14. *Kaϑe mera, i giagiades potizun ta luludia.*
Every day, the grandmothers water the flowers.
'Every day, the grandmothers water the flowers.'

Hϑes, gia mia stigmi, i giagiades [ ] ta luludia.
Yesterday, for one moment, the grandmothers [ ] the flowers.
'Yesterday, for a moment, the grandmothers [ ] the flowers.'

15. *Kaϑe mera, i monahes ravune ta mandilia.*
Every day, the nuns sew the handkerchiefs.
'Every day, the nuns sew the handkerchiefs.'

Hϑes, gia mia stigmi, i monahes [ ] ta mandilia.
Yesterday, for one moment, the nuns [ ] the handkerchiefs.
'Yesterday, for a moment, the nuns [ ] the handkerchiefs.'

16. *Kaϑe mera, i magires grafun ti sintagi.*
Every day, the cooks write the recipe.
'Every day, the cooks write down the recipe.'

Hϑes, gia mia stigmi, i magires [ ] ti sindagi.
Yesterday, for one moment, the cooks [ ] the recipe.
'Yesterday, for a moment, the cooks [ ] the recipe.'

17. *Kaϑe mera, i stratigi ipsonun ti simea.*
Every day, the generals raise the flag.
'Every day, the generals raise the flag.'

Hϑes, gia mia stigmi, i stratigi [ ] ti simea.
Yesterday, for one moment, the generals [ ] the flag.
'Yesterday, for a moment, the generals [ ] the flag.'

18. *Kaϑe mera, i ergates ktizun tin epavli.*
Every day, the workers build the villa.
'Every day, the workers build the villa.'

Hϑes, gia mia stigmi, i ergates [ ] tin epavli.
Yesterday, for one moment, the workers [ ] the villa.
'Yesterday, for a moment, the workers [ ] the villa.'

19. *Kaϑe mera, i anipsia kovi ta karota.*
Every day, the niece cuts the carrots.
'Every day, the niece chops the carrots.'

Hϑes, gia mia stigmi, i anipsia [ ] ta karota.
Yesterday, for one moment, the niece [ ] the carrots.
'Yesterday, for a moment, the niece [ ] the carrots.'

20. *Kaϑe mera, i fitites diavazun to vivlio.*
Every day, the students read the book.
'Every day, the students read the book.'

Hϑes, gia mia stigmi, i fitites [ ] to vivlio.
Yesterday, for one moment, the students [ ] the book.
'Yesterday, for a moment, the students [ ] the book.'

21. *Kaϑe mera, i gkarsones psinun tus kafedes.*
Every day, the waitresses bake the coffees.
'Every day, the waitresses make the coffees.'

Hϑes, gia mia stigmi, i gkarsones [ ] tus kafedes.
Yesterday, for one moment, the waitresses [ ] the coffees.
'Yesterday, for a moment, the waitresses [ ] the coffees.'

22. *Kaϑe mera, i magises ndinun ta idola.*
Every day, the witches dress the idols.
'Every day, the witches dress the idols.

Hϑes, gia mia stigmi, i magises [ ] ta idola.
Yesterday, for one moment, the witches [ ] the idols.
'Yesterday, for a moment, the witches [ ] the idols. '

23. *Kaϑe mera, o mbogiatzis vafi to ktirio.*
Every day, the painter paints the building.
'Every day, the painter paints the building.'

Hϑes, gia mia stigmi, o mbogiatzis [ ] to ktirio.
Yesterday, for one moment, the painter [ ] the building.
‘Yesterday, for a moment, the painter [ ] the building.'

24. *Kaϑe mera, o taksitzis akui ta tragudia.*
Every day, the taxi driver listens the songs.
'Every day, the taxi driver listens to the songs.'

Hϑes, gia mia stigmi, o taksitzis [ ] ta tragudia.
Yesterday, for one moment, the taxi driver [ ] the songs.
‘Yesterday, for a moment, the taxi driver [ ] to the songs.

With irregular verbs

1. *Kaϑe mera, i kopela kondeni ta manikia.*
   Every day, the girl shortens the sleeves.
   'Every day, the girl shortens the sleeves.'

   Hϑes, gia mia stigmi, i kopela [ ] ta manikia.
   Yesterday, for one moment, the girl [ ] the sleeves.
   'Yesterday, for a moment, the girl [ ] the sleeves'

2. *Kaϑe mera, o skopeftis petiheni ta varelia.*
   Every day, the marksman shoots the barrels.
   'Every day, the marksman shoots the barrels.'

   Hϑes, gia mia stigmi, o skopeftis [ ] ta varelia.
   Yestrday, for one moment, the marksman [ ] the barrels.
   'Yesterday, for a moment, the marksman [ ] the barrels.'

3. *Kaϑe mera, o pilotos gerni to kefali.*
   Every day, the pilot leans the head.'
   Every day, the pilot leans the head.'

   Hϑes, gia mia stigmi, o pilotos [ ] to kefali.
   Yesterday, for one moment, the pilot [ ] the head.
   'Yesterday, for a moment, the pilot [ ] the head.'

4. *Kaϑe mera, i modistra ifeni to forema.*
   Every day, the seamstress weaves the dress.
   'Every day, the seamstress makes the dress.’

   Hϑes, gia mia stigmi, i modistra [ ] to forema.
   Yesterday, for one moment, the seamstress [ ] the dress.
   'Yesterday, for a moment, the seamstress [ ] the dress.'

5. *Kaϑe mera, i voiϑos kani to programa.*
   Every day, the assistant makes the schedule.
   'Every day, the assistant makes the schedule.’

   Hϑes, gia mia stigmi, i voiϑos [ ] to programa.
   Yesterday, for one moment, the assistant [ ] the schedule.
   'Yesterday, for a moment, the assistant [ ] the schedule.'

6. *Kaϑe mera, i maϑites erhonde sto sholio.*
Every day, the students come to school.
'Every day, the students come to the school.'

Hϑes, gia mia stigmi, i maϑites [ ] sto sholio.
Yesterday for one moment, the students [ ] to school.
'Yesterday, for a moment, the students [ ] to the school.'

7. *Kaϑe mera, i gitones vgenun sto mbalkoni.*
Every day, the neighbors go out to balcony.
'Every day, the neighbors go out onto the balcony.'

Hϑes, gia mia stigmi, i gitones [ ] sto mbalkoni.
Yesterday, for one moment, the neighbors [ ] to balcony.
'Yesterday, for a moment, the neighbors [ ] onto the balcony.'

8. *Kaϑe mera, i psarades mbenun sti ϑalasa.*
Every day, the fishermen enter to sea.
'Every day, the fishermen go in the sea.'

Hϑes, gia mia stigmi, i psarades [ ] sti ϑalasa.
Yesterday, for one moment, the fishermen [ ] to sea.
'Yesterday, for a moment, the fishermen [ ] the sea.'

9. *Kaϑe mera, i liturgos fevgi me amaksi.*
Every day, the officer leaves with car.
'Every day, the officer leaves by car.'

Hϑes, gia mia stigma i liturgos [ ] me amaksi.
Yesterday, for one moment, the officer [ ] with car.
'Yesterday, for a moment, the officer [ ] by car.'

10. *Kaϑe mera, i georgi spernun to sitari.*
Every day the farmers sow the wheat.
'Every day, the farmers sow the wheat.'

Hϑes, gia mia stigmi, i georgi [ ] to sitari.
Yesterday, for one moment, the farmers [ ] the wheat.
'Yesterday, for a moment, the farmers [ ] the wheat.'

11. *Kaϑe mera, i daskales pernun tis ekϑesis.*
Every day, the teachers take the essays.
'Every day, the teachers collect the essays.'

Hϑes, gia mia stigmi, i daskales [ ] tis ekϑesis.
Yesterday, for one moment, the teachers [ ] the essays.
'Yesterday, for a moment, the teachers [ ] the essays.'

12. *Kaϑe mera, i ieris lene tin prosefhi.*
Every day, the priests say the prayer.
'Every day, the priests say the prayer.'

Hϑes, gia mia stigmi, i ieris [ ] tin prosefhi.
Yesterday, for one moment, the priests [ ] the prayer.
'Yesterday, for a moment, the priests [ ] the prayer.'

13. *Kaϑe mera, o hasapis gderni ta katsikia.*
Every day, the butcher skins the goats.
'Every day, the butcher skins the goats.'

Hϑes, gia mia stigmi, o hasapis [ ] ta katsikia.
Yesterday, for one moment, the butcher [ ] the goat kids.
'Yesterday, for a moment, the butcher [ ] the goat kids.

14. *Kaϑe mera, o emboros ferni tis konserves.*
Every day, the merchant brings the cans.
'Every day, the merchant brings the canned food'

Hϑes, gia mia stigmi, o emboros [ ] tis konserves.
Yesterday, for one moment, the merchant [ ] the cans.
'Yesterday, for a moment, the merchant [ ] the canned food.'

15. *Kaϑe mera, i aderfes lamvanun to minima.*
Every day, the sisters receive the message.
'Every day, the sisters receive the message.'

Hϑes, gia mia stigmi, i aderfes [ ] to minima.
Yesterday, for one moment, the sisters [ ] the message.
'Yesterday, for a moment, the sisters [ ] a message.'

16. *Kaϑe mera, i dukisa maϑeni to piima.*
Every day, the duchess learns the poem.
'Every day, the duchess learns the poem.'

Hϑes, gia mia stigmi, i dukisa [ ] to piima.
Yesterday, for one moment, the duchess [ ] the poem.
'Yesterday, for a moment, the duchess [ ] the poem.'

17. *Kaϑe mera, i asϑenis pini to siropi.*
Every day, the patient drinks the syrup.
'Every day, the patient takes the syrup.'

Hϑes, gia mia stigmi, i asϑenis [ ] to siropi.
Yesterday, for one moment, the patient [ ] the syrup.
'Yesterday, for a moment, the patient [ ] the syrup.'

18. *Kaϑe mera, i gliptries vazun to simadi.*
Every day, the sculptors put the mark.
'Every day, the sculptors mark it.'

Hϑes, gia mia stigmi, i gliptries [ ] to simadi.
Yesterday, for one moment, the sculptors [ ] the mark.
'Yesterday, for a moment, the sculptors [ ] it.'

19. *Kaϑe mera, i giatrenes trone tis salates.*
Every day, the doctors eat the salads.
'Every day, the doctors eat the salads.'

Hϑes, gia mia stigmi, i giatrenes [ ] tis salates.
Yesterday, for one moment, the doctors [ ] the salads.
'Yesterday, for a moment, the doctors [ ] the salads.'

20. *Kaϑe mera, i simvuli vlepun tis idisis.*
Every day, the counselors see the news.
'Every day, the counselors watch the news.'

Hϑes, gia mia stigmi, i simvuli [ ] tis idisis.
Yesterday, for one moment, the counselors [ ] the news.
'Yesterday, for a moment, the counselors [ ] the news.'

21. *Kaϑe mera i dirties vriskun to ϑisavro.*
Every day, the divers find the treasure.
'Every day, the divers find the treasure.'

Hϑes, gia mia stigmi, i dirties [ ] to ϑisavro.
Yesterday, for one moment, the divers [ ] the treasure.
'Yesterday, for a moment, the divers [ ] the treasure.'

22. *Kaϑe mera i kuniades zestenun ta fagita.*
Every day, the sisters-in –law warm up the foods.
'Every day, the sisters-in -law warm up the foods.'

Hϑes, gia mia stigmi, i kuniades [ ] ta fagita.
Yesterday, for one moment, the sisters-in-law [ ] the foods.
'Yesterday, for a moment, the sisters-in-law [ ] the foods.'

23. *Kaϑe mera, o lohagos serni ta arvila.*
Every day, the captain drags the boots.
'Every day, the captain drags the boots.'

Hϑes, gia mia stigmi, o lohagos [ ] ta arvila.
Yesterday, for one moment, the captain [ ] the boots.
'Yesterday, for a moment, the captain [ ] the boots.'

24. *Kaϑe mera, o lantzeris pleni ta potiria.*
Every day, the dishwasher washes the glasses.
'Every day, the dishwasher washes the glasses.'

Hϑes, gia mia stimi, o lantzeris [ ] ta potiria.
Yesterday, for one moment, the dishwasher [ ] the glasses.
'Yesterday, for a moment, the dishwasher [ ] the glasses.'

Appendix B: Verbs & Inflectional Entropies

VERBS			INFLECTIONAL ENTROPY (H)
Regular Verbs			
1	*tripo*	‘I pierce'	1.479
2	*efharisto*	‘I thank'	1.878
3	*fteo*	‘I blame’	2.409
4	*lino*	‘I solve’	3.336
5	*γemizo*	‘I fill’	3.344
6	*kapnizo*	‘I smoke’	3.558
7	*halo*	‘I undo’	3.535
8	*treho*	‘I rush’	3.643
9	*kuvalo*	‘I carry’	3.747
10	*plaϑo*	‘I make’	4.007
11	*maγirevo*	‘I cook’	3.898
12	*aplono*	‘I hang up’	4.014
13	*pulo*	‘I sell’	4.208
14	*potizo*	‘I water’	4.096
15	*ravo*	‘I sew’	4.330
16	*γrafo*	‘I write down’	4.208
17	*ipsono*	‘I raise’	4.310
18	*htizo*	‘I build’	4.304
19	*kovo*	‘I chop’	4.389
20	*δiavazo*	‘I read’	4.436
21	*psino*	‘I make' (=bake)	4.490
22	*ndino*	‘I dress’	4.517
23	*vafo*	‘I paint’	4.558
24	*akuo*	‘I listen to’	4.740
Irregular Verbs			
1	*kondeno*	‘I shorten'	2.658
2	*petiheno*	‘I shoot'	2.955
3	*γerno*	‘I lean'	2.999
4	*ifeno*	‘I make' (=weave)	3.229
5	*kano*	‘I make'	3.074
6	*erhome*	‘I come'	3.361
7	*vγeno*	‘I go out'	3.484
8	*mbeno*	‘I go in'	3.572
9	*fevγo*	‘I leave'	3.663
10	*sperno*	‘I sow'	3.807
11	*perno*	‘I collect'	3.746
12	*leγo*	‘I say'	4.035
13	*γδerno*	‘I skin'	3.745
14	*fero*	‘I bring'	3.904
15	*lamvano*	‘I receive'	3.965
16	*maϑeno*	‘I learn	4.011

17	*pino*	‘I take'	4.157
18	*vazo*	‘I mark'	4.101
19	*troγo*	‘I eat'	4.262
20	*vlepo*	‘I watch'	4.319
21	*vrisko*	‘I find'	4.141
22	*zesteno*	‘I warm up'	4.336
23	*serno*	‘I drag'	4.633
24	*pleno*	‘I wash'	4.621