A Cross-linguistic Model of the Acquisition of Inflectional Morphology in English and Modern Greek

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Abstract

We present a connectionist model of a general system for producing inflected words. The Multiple Inflection Generator (MIG) combines elements of several previous models (e.g., association between phonological representations of stem and inflection form: Rumelhart & McClelland, 1986; multiple inflections for a grammatical class: Hoeffner & McClelland, 1993; lexical-semantic input: Joanisse & Seidenberg, 1999; multiple grammatical classes: Plunkett & Juola, 1999). MIG assumes that the goal of the morphological component of the language system is to output a phonological form appropriate to the grammatical context in which the word appears. Our aim was to demonstrate that the model is able to capture developmental patterns in the acquisition of morphology in two different languages: one with a simple morphological system (English), and one characterized by rich morphology and absence of default forms (Modern Greek).

Keywords: Inflectional Morphology; Cross-linguistic Language Acquisition; Neural Network Modeling

Introduction

The Rumelhart and McClelland (1986) model for the acquisition of past tense was extremely influential and spawned new models on morphological acquisition. The model had several drawbacks. First, it is unlikely that the language system would have a specific component for one inflection type within one grammatical class. Second, the model did not simulate all the error patterns that children exhibit in development, notably the presence of unmarked forms. Third, the generalization of inflectional rules to unusual novel inputs was somewhat poor. More widely, it remains to be seen whether an architecture appropriate for modeling morphological acquisition in one language can readily extend to other languages that may have quite different inflectional paradigms. In this article, we present a model that is generalized to all inflectional types within a language (English) and show how the same architecture can be generalized to a different language with a richer inflectional structure (Modern Greek).

Our approach assumes that the language system comprises functional components and that at least one of the components is involved in conditioning the phonological properties of words during output so that their forms are appropriate to the grammatical context in the sentence in which they will appear. The goal was to simulate qualitative developmental patterns in the acquisition of English and Modern Greek, including the order of acquisition across inflection types and proportions of error types across development.

Previous connectionist models of morphology

Rumelhart and McClelland's (1986) model of the acquisition of the English past-tense was the first to apply the principles of Parallel Distributed Processing in the domain of inflectional morphology. This influential model showed that a two-layered feed-forward neural network architecture could learn mappings between phonological representations (Wickelfeature representations) of stems and corresponding past tense forms of English verbs. The model also simulated a wide range of phenomena reported in empirical studies of the acquisition of morphology, such as frequency effects and the U-shaped learning curve for the acquisition of irregulars (Brown, 1973).

This model demonstrated that an explicit representation of rules was not necessary for the acquisition of morphology. Instead, rule-like behavior was an emergent property of the learning system and reflected statistical regularities in the mappings of the training set. Rumelhart and McClelland challenged the existing 'symbolic' view, which proposed the dual-route account for morphological development (Pinker, 1984). According to this account, two separate mechanisms were involved in the learning of morphology. A rule-based system supported the learning of regular mappings, while a rote-memory system supported the learning of irregular mappings. The so-called 'past tense debate' emerged within the field of language acquisition.

Criticisms against the connectionist approach (e.g., Pinker & Prince, 1988) ranged from those pointing out implementational issues (e.g., the psycholinguistic implausibility of Wickelfeature representations) to those questioning the ability of the connectionist framework to address certain aspects of language acquisition (e.g., generalization). Subsequent connectionist studies addressed many of these criticisms by proposing more detailed models: Plunkett and Marchman (1993) refined the general principles of the model of Rumelhart and McClelland (1986) in a three-layered feed-forward architecture which employed more realistic phonological representations;

other studies incorporated lexical-semantics in the connectionist architecture to address dissociations in the learning of regular and irregular verbs (e.g., Joanisse & Seidenberg, 1999); Plunkett and Juola (1999) studied the acquisition of noun plural and verb past tense in a single connectionist network, while Hoeffner and McClelland (1993) considered multiple verb inflections. Finally, other work demonstrated that implementing a developmental deficit in connectionist architectures could simulate the acquisition of morphology in atypical language development. (e.g., Hoeffner & McClelland, 1993; Joanisse, 2004; Thomas & Karmiloff-Smith, 2003).

Acquisition of inflectional morphology in English

English inflectional morphology is characterized by its simplicity, manifested by the extensive use of default (base or uninflected) forms. For example, noun inflection does not consider gender and does not distinguish between the nominative and the accusative case. Psycholinguistic studies of inflectional morphology in English often focus on the domain of the past tense. This paradigm is of particular theoretical interest because it is quasi-regular. The majority of verbs form their past tenses through stem-suffixation (e.g., walk / walked). A rule determines the appropriate allomorphic suffix (/t/, /d/, or /^d/)) based on the last phoneme of the stem. However, a significant number of verbs form their past tenses irregularly (e.g., swim / swam, hit / hit, go / went).

Early studies on child language (e.g., Berko, 1958; Brown, 1973; de Villiers & de Villiers, 1973) established that different inflections in English are acquired in a consistent order along development. For example, the progressive of the verbs is acquired earlier than the past tense. Other studies addressed the profile of individual inflections in greater detail. For example, van der Lely & Ullman (2001) showed that accuracy rates are greater for regular than for irregular inflections. Accuracy also depends on type and token frequency. Frequency effects are more pronounced in irregular inflections (the so-called frequency by regularity interaction). Finally, children are efficient in generalizing the rule to novel forms (e.g., wug / wugged).

Morphological development is characterized by developmental error patterns. For example, children often produce base forms in contexts in which grammatical marking is obligatory (e.g., *He *come* home / He comes home). This type of error is referred to variously as a *no-mark error*, *no-change error* or *omission error*. Rice, Wexler, and Cleave (1993) suggested that omission errors define an early stage in language development, in which morphological marking is not applied consistently on the base forms. They termed this stage as the Optional Infinitive (OI) stage. Zero-mark errors occur in greater percentages in irregular inflections (e.g., Matthews & Theakston, 2006; van der Lely & Ullman, 2001).

Another prototypical error pattern is *over-regularization* or *over-generalization.* This type of error refers to the (incorrect) application of a rule on irregular stems (e.g., **thinked* / thought). Overregularization errors appear later in development than omission errors (Brown, 1973). As a result, in Brown's stage II (age range: 28-36 months, MLU range: 2.0-2.5) a sudden drop in the production of correct irregular forms was observed. This phenomenon is often described in terms of a U-shaped learning curve of irregulars. Overregularization errors are sometimes taken as evidence for the productive use of rules in child language (Marcus, 2000). Finally, a related error type is the *blend error* or *double-marked error* (e.g., Kuczaj, 1978). These errors refer to cases in which children apply a rule to an irregularly inflected form (e.g., **wented* / went).

Acquisition of inflectional morphology in Modern Greek

Modern Greek is a language with a rich morphological system. As Stephany (1997) describes, there are no default forms of words in Modern Greek. Instead, many different grammatical features are fused in single word forms. For example, nouns have grammatical gender, and are inflected with respect to case and number. Verbs are inflected with respect to person, tense, aspect and voice.

Modern Greek also presents different conjugational classes in nominal and verbal inflections, challenging the dichotomy between regular and irregular inflectional categories. For example, studies on the perfective past tense (e.g., Stavrakaki & Clahsen, 2001) describe three classes of verbs with respect to the marking of the perfective aspect. The 'sigmatic' class is the major class of verbs. The perfective past tense forms in this class are characterized by the addition of the aspectual marker /s/ ('sigma' in Greek) to the stem (e.g. pez-o / e-pek-s-a, play / played - 1st person singular). The addition of the aspectual marker may invoke phonologically predictable changes to the stems. A second class of verbs does not employ the aspectual marker /s/, and presents unpredictable modifications of the stem (e.g., plen-o / e-plin-a, wash / washed - 1st person singular). Finally, a third class of verbs have idiosyncratic perfective past tenses forms (e.g., tro-o / e-fag-a, eat / eaten - 1st person singular).

Stephany (1997) studied the production data of three children. Based on these data she suggested an order for the acquisition of different grammatical inflections and different grammatical features in Modern Greek. For example, tense is acquired earlier than aspect. Rare nominal conjugational categories are acquired late in development. As default forms are missing in Modern Greek, it has been suggested that the Optional Infinitive stage is realized by production of certain frequent forms in inappropriate contexts. Stephany (1997) observed that children undergo an early stage of development (up to 3 years old) in which they produce a lot of 3rd singular forms instead of the correct verbal inflections. Thus, 3rd singular forms could be considered an analogue of root infinitives in English (Varlokosta, Vainikka & Rohrbacher, 1998). Finally, with regard to the perfective past tense, Stavrakaki

and Clahsen (2009) found that the sigmatic rule is over-generalized in verbs belonging to non-sigmatic categories. The sigmatic rule is also preferred for the production of past tenses of novel verbs.

Simulations

Design

Our aim was to increase the generality of the original past tense model across inflection types, grammatical classes, and across languages. We began by combining elements of previous connectionist models of morphology (e.g., multiple grammatical classes: Plunkett & Juola, 1999; multiple inflections for a grammatical class: Hoeffner & McClelland, 1993; lexical-semantic input: Joanisse & Seidenberg, 1999) to implement a generalized inflectional system. The Multiple Inflectional Generator (MIG) considered three grammatical classes (nouns, verbs, and adjectives) and multiple inflections for each grammatical class (e.g., nouns: base forms, plurals, and possessives). The aim of MIG was to output a phonological form appropriate to the grammatical context in which the word appeared.

Following Plunkett and Marchman (1993), we constructed two training sets based on artificial languages that reflected the basic features of the morphological systems of English and Modern Greek. We performed two sets of simulations. In the first set of simulations, MIG was trained using the English training set. In the other, MIG was trained on the Modern Greek training set. In each condition, we contrasted the learning profile of MIG to corresponding data from empirical studies on the acquisition of morphology outlined above. For reasons of space, from the full set of behaviors exhibited by the model, we concentrate on reporting results from past tense. The goal was to replicate the following empirical effects: For English: (i) the relative acquisition of regular and irregular verbs; (ii) the frequency by regularity interaction in accuracy; (iii) the Optional Infinitive stage; (iv) the greater incidence of unmarked stem errors for irregulars; (v) the relative incidence of over-generalization and blend errors; (vi) generalization to novel stems. For Modern Greek: (i) the relative acquisition of sigmatic and non-sigmatic categories; ii) the production of 3rd singular forms as analogue of the Optional Infinitive stage; iii) the over-generalization of the sigmatic rule in verbs belonging to non-sigmatic categories; (iv) the generalization of the sigmatic rule to novel stems.

Architecture

The MIG employed a three-layered feed-forward neural network architecture. Four sources of information (cues) were presented in the input layer (Figure 1). (1) Input Phonology (95 units) encoded the phonological properties of the base forms using a five-slot scheme parallel to the that used in Plunkett & Marchman (1991, 1993). Each slot could encode a phoneme based on a distributed code of 19 binary articulatory features (Thomas & Karmiloff-Smith, 2003). The articulatory features (e.g., sonorant, consonantal, voiced, rounded) corresponded to standard linguistic categorizations (Fromkin & Rodman, 1988). The Input Phonology layer used only the first three slots to encode the phonological structure of monosyllabic words. (2) Following Joanisse and Seidenberg (1999), Lexical Semantics (1600 units) were used to provide localist representations of the meaning of each base form. (3) Grammatical Category (3 units) provided part-of-speech information. (4) Target Inflection (10 units) provided information on the type of inflection the network should consider (e.g., for verbs: base, past tense, 3rd singular or progressive).

The network was required to produce a phonological representation of the appropriate inflected form in the output layer (Output Phonology). The Output Phonology layer employed 95 units to implement a five-slot scheme. The last two slots were used to encode inflectional suffixes. In order to address morphology in Modern Greek, limited changes were introduced to the initial architecture solely to capture differences in the morphological structure of Modern Greek. In particular, the Target Inflection cue was expanded to include: gender, number and case information for nouns; gender, number, case, and grade information for adjectives; tense, aspect and person information for verbs. Additionally, Input Phonology provided phonological representations of word stems, without considering any inflectional suffixes and affixes. Finally, the Input and Output Phonology layers employed a twelve-slot scheme to incorporate morphological affixes, suffixes and disyllabic stems.

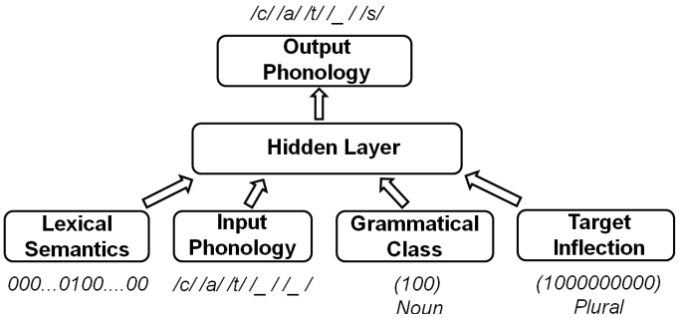

Figure 1: The architecture of MIG with an example of input-output mappings (here, to output the plural noun *cats*)

Training Sets

English Training Set. The training set for English was constructed based on measurements of type frequencies of different grammatical categories, different inflections or allomorphic subcategories of the same inflection. These measurements were derived from the tagged Brown corpus (Francis & Kucera, 1999) via computational linguistics methods. The NLTK open source software (http://www.nltk.org, accessed May 2010) was used for processing the Brown corpus. Frequencies of different grammatical categories and different inflection types were based on the counts of different tags in the corpus. Fre-

quencies of the allomorphic categories (e.g., /t/, /d/, /^d/ past tenses) were obtained using algorithms that identified the last phoneme of the stems.

The training set consisted of 1,600 words and 5,200 inflections based on those words (word-to-inflection ratio: ~0.3). The 1,600 words were artificial monosyllabic phoneme strings (800 verbs, 400 nouns, and 400 adjectives) which followed one of three templates (CCV, VCC and CVC; see Plunkett & Marchman, 1993). Ten different inflections were considered for the English training set (nouns: base form, plural, possessive; verbs: base form, progressive, 3rd singular, past tense; adjectives: base form, comparative, superlative). The inflected forms incorporated two additional phonemes for the inflectional suffixes. Combining words with their different possible inflections, the English training set comprised 5,200 stem / inflected form mappings. A simplified two-level scale of token frequency (Thomas & Karmiloff-Smith; 2003) was implemented by scaling the weight changes computed by the Back-propagation of Error algorithm (Rumelhart, Hinton, & Williams, 1986) after the presentation of each mapping. For arbitrary mappings (e.g., go / went) the weight changes were multiplied by 9 for tokens of high-frequency and 6 for tokens of low-frequency. For all other mappings, the weight changes were multiplied by 3 for high-frequency tokens, and 1 for low-frequency tokens.

A generalization set of 1,600 novel types and the corresponding 5,200 tokens was also created. It consisted of three subsets of stems with differing degrees of similarity to the stems of the training set. Items for the first subset of the generalization set were created by changing the first phoneme of existing stems. Items for the second subset were generated by changing the first two phonemes of the existing stems. In both cases a consonant was replaced by another consonant and a vowel with another vowel to conform to the phonotactics imposed by the three templates used for the training set. Items in the third subset were generated by changing the first two phonemes of existing stems in a way that violated the phonotactics of the artificial language.

Modern Greek Training Set. For the Modern Greek training set, type frequencies of different inflections and different conjugational categories were based on descriptions of Stephany (1997) or sampling of the Hellenic National Corpus of the Institute of Speech and Language Processing (ISLP, http://hnc.ilsp.gr/en/, accessed May 2010). In the absence of any other constraints, type frequencies were made parallel to type frequencies of the English training set. The Modern Greek training set consisted of 1600 types and 26,400 tokens (type to token ratio: ~0.06). The 1,600 types were a vocabulary of 800 verbs, 400 nouns and 400 adjectives. Items were dissyllabic, and conformed to the phonotactics of Modern Greek. Nouns were inflected in the nominative, the genitive and the accusative case of the singular and plural number. Verbs were inflected with respect to person (1st, 2nd, and 3rd), number (singular, plural) and tense (present, perfective past, imperfective past). Adjectives were inflected with respect to gender, case and number in the plain, comparative, and superlative grade. The Modern Greek training set consisted of a total of 26,400 mappings (tokens). A generalization set of 1,600 novel types and the corresponding 26,400 types was also constructed. Items for the generalization set were generated by changing the phonemes of the first syllable of the stem of items of training set.

Procedure

Networks were trained for 400 epochs, using the Back-propagation of Error algorithm (Rumelhart, Hinton, & Williams, 1986). The length of training was selected to ensure that the networks achieved final ceiling levels of performance. Based on piloting, the following parameters were used in both English and Greek versions of the model: 75 hidden units, learning rate 0.01, momentum 0. Results were averaged over 10 replications with different random seeds. Training was not incremental but used the full training set throughout, with one caveat: in each epoch, the network was exposed to a random 30% of the total inflected forms, corresponding to the number of different words in the training set.

Results

Network output was evaluated using a variant of the Nearest Neighborhood algorithm. The output activation for each slot was made equal to its nearest neighbor in the Euclidean space of the phonemes, so that continuous activations were converted to phonemic strings. The string was then assessed against pre-defined categories, based on patterns presented in empirical investigations of children's productivity (e.g., 'correct', 'omission errors', 'over-generalization errors', 'blend errors', 'other'). In this section we present initial results from the two simulations, demonstrating the viability of the more general model.

Simulation 1: English Training Set

The simulation results were parallel to the acquisition profile of the English past tense in several ways. Accuracy rates were higher for regulars than for irregulars. Type frequency effects were more pronounced for irregulars. MIG reproduced an OI stage, characterized by high percentages of omission errors for both regulars and irregulars. The rates of no-mark errors were higher for irregulars than for regulars. MIG also simulated overgeneralization errors and blend errors. Finally, the past tense rule was efficiently generalized in novel items with accuracy rates of 88%, 86%, and 43% for novel stems most to least similar to stems in the training set. Importantly, for the latter, accuracy levels went up to 83% when errors in the reproduced stem were ignored. That is, while the network sometimes struggled to output very strange, phonotactically illegal novel stems, it nevertheless showed a high level of accuracy in outputting an appropriate past tense morpheme. It was able to do so because the Verb gram-

matical class unit and Past Tense target inflection units could form strong connections to the inflectional morpheme region of the output layer. In some respects, this is equivalent to an implementation of a 'rule' for past tense formation (Marcus, 2001). In this way, the MIG improves on the rule induction ability shown by the original Rumelhart and McClelland model.

Figures 2 and 3 contrast the developmental trajectory of MIG for the first 100 epochs of training with corresponding cross-sectional behavioral data from van der Lely and Ullman (2001) for 6-8 year old children, for regular and irregular past tense formation. As training was performed in a non-incremental fashion, we do not take the very early stages of training to be psychologically realistic (see Plunkett & Marchman, 1993). To evaluate the modeling results in light of the empirical data, we identified a window in the training time of the model (epochs 20-70) in which the accuracy rates of the model in the regular past tense were matched to those reported in the developmental study of van der Lely and Ullman (2001). In this time window, the rates of the main error patterns in the simulation results present qualitative similarities to the rates in the empirical data. Once more, compared to the Rumelhart and McClelland model, MIG now combines simulation of correct performance with error patterns.

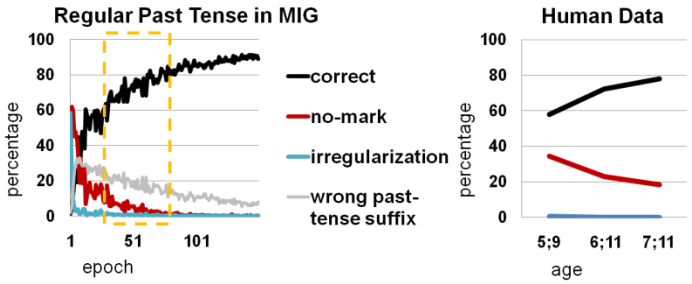

Figure 2: Regular past-tense acquisition in MIG compared to empirical data on from van der Lely & Ullman (2001)

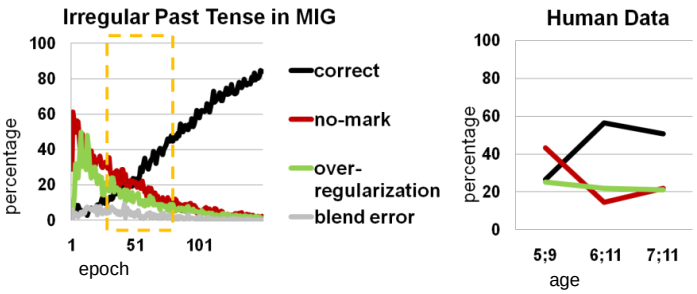

Figure 3: Irregular past-tense acquisition in MIG compared to empirical data on from van der Lely & Ullman (2001)

Simulation 2: Modern Greek Training Set

MIG was also able to learn the complex mappings of the Greek training set. For the perfective past tense, accuracy rates were higher for the sigmatic class than the other conjugational classes. The sigmatic rule was generalized efficiently to novel items (accuracy rates for generalization: 71%).

The model also captured the major developmental error patterns. It simulated an early phase in which 3rd singular forms were produced in inappropriate contexts, which Varlakosta et al. (1998) identified as a marker of the Optional Infinitive stage. It also captured the pattern of overgeneralization of the sigmatic rule in non-sigmatic conjugational classes. Both of these error patterns are depicted in Figure 4, which compares the learning profile of MIG in the 2nd person singular non-sigmatic category (e.g., plen-o / e-plin-es, wash / washed) and corresponding data by Stavrakaki and Clahsen (2009).

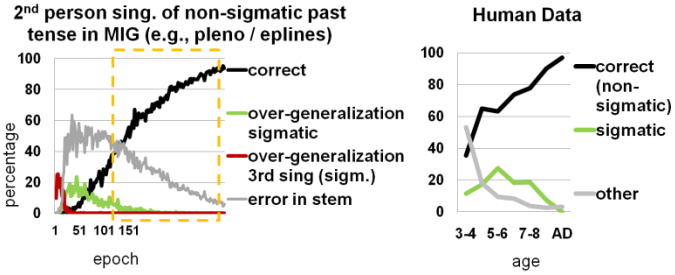

Figure 4: Non-sigmatic perfective past tense in MIG and empirical data from Stavrakaki & Clahsen (2009)

Conclusions

Connectionist approaches to the acquisition of morphology have faced four challenges: to simulate developmental error patterns as well as accuracy levels; to demonstrate that associative systems can generalize inflectional rules to unusual novel stems; to show that architectures can be general across inflection types and grammatical classes, rather than focusing on narrow inflectional paradigms; and to show that architectures can be general across languages, even though those languages may place very different demands on acquisition due to the complexity of their morphology.

In this paper, we introduced the Multiple Inflection Generator. The model is novel in that phonological output forms are conditioned to be appropriate to their grammatical context by the integration of multiple input cues. These input cues include the phonological form of the stem, lexical-semantics, grammatical class, and target inflection information. Cues are relied on differentially depending on the mappings of various inflectional forms (see, e.g., Joanisse & Seidenberg, 1998, for the greater reliance of irregular verbs on lexical-semantic information, also shown by our model).

Focusing on the past tense, we showed how the MIG reproduced error patterns as well as accuracy levels. Notably, in both English and Modern Greek, an Optional Infinitive stage was observed, even though the character of that stage is different in each language (unmarked stems vs. 3rd person singular). Generalization rates of the past tense rule were high for novel stems, even for phonotactically illegal stems. MIG captured the order of emergence of different inflection types for different grammatical classes. And it was able to capture developmental patterns for two languages of different morphological complexity.

These results are only preliminary. More detailed work is required to establish quantitative fits both within and between languages. However, our initial findings demonstrate the viability of a more general, cross-linguistic model of the acquisition of inflectional morphology.

Acknowledgments

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References

Berko, J. (*1958*). The child's learning of English morphology. *Word, 14*, 150-177.

Brown, R. (1973). *A first language: The early stages.* London: George Allen & Unwin Ltd.

Clahsen, H., & J. Dalalakis (1999). Tense and agreement in Greek SLI: A case study. *Essex Research Reports in Linguistics, 24,* 1-25.

de Villiers, J.G., & de Villiers, P.A. (1985). Acquisition of English. In D. Slobin (Ed.), *The crosslinguistic study of language acquisition: Vol. 1. The data* (pp. 27-140). Hillsdale, NJ: Lawrence Erlbaum.

Francis, W.N., & Kucera, H. (1979). *Manual of Information to Accompany a Standard Sample of Present-day Edited American English , for Use with Digital Computers.* Original ed. 1964, revised 1971, revised and augmented 1979. Department of Linguistics, Brown University, Providence, R.I.

Hoeffner, J. H., & McClelland, J. L. (1993). Can a perceptual processing deficit explain the impairment of inflectional morphology in developmental dysphasia? A computational investigation. In E. V. Clark (Ed.*), Proceedings of the 25th Child Language Research Forum.* Palo Alto, CA: Stanford University Press.

Joanisse, M.F. (2004) Specific language impairments in children: Phonology, semantics and the English past tense. *Current Directions in Psychological Science, 13,* 156-160.

Joanisse, M.F., & Seidenberg, M.S. (1999). Impairments in verb morphology following brain injury: A connectionist model. *Proceedings of the National Academy of Science USA, 96,* 7592-7597.

Kuczaj, S.A. (*1977*). The acquisition of regular and irregular past tense forms. *Journal of Verbal Learning and Verbal Behavior*, 16, 589-600.

Matthews, D. E., & Theakston, A. L.(2006) 'Errors of omission in English-speaking children's production of plurals and the past Tense: The effects of frequency, phonology, and competition', *Cognitive Science: A Multidisciplinary Journal, 30: 6*, 1027 — 1052.

Marcus, G. F. (2000). Children's Overregularization and Its Implications for Cognition. In P. Broeder, & J. Murre (eds). *Models of Language Acquisition: Inductive and deductive approaches.* Oxford: Oxford University Press, pp 154-176.

Marcus, G.F. (2001). *The Algebraic Mind: Integrating Connectionism and Cognitive Science (Learning, Development, and Conceptual Change),* Cambridge, MA: MIT Press.

Pinker, S. (1984). *Language learnability and language development*. Cambridge, MA: Harvard University Press.

Pinker, S., & Prince, A. (1988). On language and connectionism: Analysis of a parallel distributed processing model of language acquisition. *Cognition*, *28*, 73–193

Plunkett, K., & Juola, P. (1999). A connectionist model of English past tense and plural morphology. *Cognitive Science, 23,* 463-490.

Plunkett, K., & Marchman, V. (1991). U-shaped learning and frequency effects in a multi-layered perceptron: Implications for child language acquisition. Cognition, 38, 1-60.

Plunkett, K., & Marchman, V. (1993). From rote learning to system building: Acquiring verb morphology in children and connectionist nets. *Cognition, 48,* 21-69.

Rice, M.L. (2000). Grammatical symptoms of specific language impairment. In: D.V.M. Bishop & L.B. Leonard (Eds.), *Speech and Language Impairments in Children: Causes, characteristics, intervention and outcome* (pp.17-34). Hove, England: Psychology Press.

Rumelhart, D. E., Hinton, G. E., & Williams, R.J. (1986). Learning internal representations by error propagation. In D. E. Rumelhart, J. L. McClelland and The PDP Research Group, *Parallel distributed processing: Explorations in the microstructure of cognition. Volume 1: Foundations* (pp. 318–362). Cambridge, MA: MIT Press.

Rumelhart, D. E. & McClelland, J. L. (1986). On learning the past tense of English verbs. In J. L. McClelland, D. E. Rumelhart and PDP Research Group (Eds), *Parallel distributed processing: Volume 2: Psychological and Biological models.* (pp. 216-271). Cambridge, MA: MIT Press.

Stavrakaki, S. & Clahsen, H. (2009). The perfective past tense in Greek child language. *Journal of Child Language*, *36*, 113-42.

Stephany, U. (1997). The Acquisition of Greek. In: Slobin, D. I. (ed.). *The cross-linguistic study of language acquisition 4* (pp.183-333).Hillsdale, NJ: Erlbaum.

Thomas, M.S.C. & Karmiloff-Smith, A. (2003). Modelling language acquisition in atypical phenotypes. *Psychological Review, 110, 4,* 647-682.

van der Lely, H. K. J., & Ullman, M. (2001). Past tense morphology in specifically language impaired children and normally developing children. *Language and Cognitive Processes, 16,* 177-217.

Varlokosta, S., Vainikka, A., & Rohrbacher, B. (1998). Functional projections, markedness, and ‚root infinitives' in early child Greek. *The Linguistic Review* 15:187-207.