Assessing the representation of phonological rules by a production study of non-words in Coratino

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Abstract

Phonological regularities in a given language can be described as a set of formal rules applied to logical expressions (e.g. the value of a distinctive feature) or alternatively as distributional properties emerging from the phonetic substance. An indirect way to assess how phonology is represented in a speaker's mind consists in testing how phonological regularities are transferred to non-words. This is this objective of this study, focusing on Coratino, a dialect from southern Italy spoken in the Apulia region. In Coratino, a complex process of vowel reduction operates, transforming the /i e ɛ u o ɔ a/ system for stressed vowels into a system with a smaller number of vowels for unstressed configurations, characterized by four major properties: (1) all word-initial vowels are maintained, even unstressed; (2) /a/ is never reduced, even unstressed; (3) unstressed vowels /i e ɛ u o ɔ/ are protected against reduction when they are adjacent to a consonant that shares articulation (labiality and velarity for /u o ɔ/ and palatality for /i e ɛ/); (4) when they are reduced, high vowels are reduced to /ɨ/ and mid vowels to /ə/. A production experiment was carried out on 19 speakers of Coratino to test whether these properties were displayed with non-words. The production data display a complex pattern which seems to imply both explicit/formal rules and distributional properties transferred statistically to non-words. Furthermore, the speakers appear to vary considerably in how they perform this task. Altogether, this suggests that both formal rules and distributional principles contribute to the encoding of Coratino phonology in the speaker's mind.

Keywords

Vowel reduction, phonology, internal grammar, rules, Italian dialect, speech production, non-words, cognitive representations

1. Introduction

1.1. The nature of phonological knowledge

The processes by which a speaker generates motor commands and sounds from a lexical item are described in the post-generativist framework (e.g. Chomsky & Halle, 1968; Jackendoff, 2002) by a combination of phonological and phonetic components. Phonological rules enable speakers to relate the deep phonological structure connected to the lexicon, possibly involving morphological processes, to the surface phonological sequence. Phonetic components drive the set of motor commands for producing a coherent sequence of articulatory trajectories and ultimately an acoustic speech utterance corresponding to the surface phonological structure.

Phonological rules may be described in the context of various alternative theoretical frameworks (e.g. generative phonology, Chomsky & Halle, 1968; Optimality Theory, Prince & Smolensky, 1983). The complex interfacing of phonological and phonetic processes has been the topic of a number of debates and papers in the literature. The concept of a clear-cut separation between a phonological module belonging to the grammar, interfaced with a phonetic system unrelated to the grammar, has been progressively replaced by a more nuanced view (Scobbie, 2005; Kingston, 2006; Hamann, 2011) where phonetic principles contribute to constraining and shaping phonological units and rules (e.g. Flemming, 2001; Hayes & Steriade, 2004).

The way linguists describe linguistic processes differs from the knowledge a speaker has of these processes. In line with foundational writings by Chomsky (1965), Jackendoff (2002) introduces the terms "functional mind" and "functional knowledge" to clarify this distinction, making the functional linguistic entities described by linguists different from the neurocognitive processes by which language-users may or may not have access to linguistic knowledge. The present paper is focused on the implicit knowledge speakers have about the phonology of their language. This question is indeed part of the general program of laboratory phonology (Pierrehumbert et al., 2000).

The nature of phonological knowledge and representations is, once again, the topic of years of lively discussions and controversies. The "phonological mind", to quote the term introduced by Berent (2013), can either be described as an algebraic device (Berent et al., 2012; Berent, 2013), operating on discrete variables through algebraic rules (Marcus, 2001), or it can be conceived as a statistical machine, operating on continuous sensori-motor phonetic or discrete phonemic units, exploiting the machinery of connectionism and probabilistic computations (McClelland, 2009). In recent years, exemplar-based models (e.g. Pierrehumbert, 2001; Coleman, 2002), together with "usage-based phonology" (Bybee, 2001), have offered a new framework proposing to derive the whole set of phonetic categorization and phonological computational processes from the emergent properties of statistical distributions of produced and perceived items stored in memory. Of course, the concept we have of the phonological-phonetic interface is of importance here, possibly enabling the phonological mind to adopt phonetic principles for specifying variables, rules and their combinations (e.g. Flemming, 2001; Hayes & Steriade, 2004).

1.2. Vowel reduction in Coratino, a rich field for experimentation

Vowel reduction provides a very interesting field for evaluating phonological knowledge, for two sets of reasons. Firstly, this phenomenon intimately mixes phonological and phonetic processes. Indeed, vowel reduction may be either phonological, consisting in a loss of certain phonological contrasts within a given vowel system, generally associated with prosodically weak positions, e.g. within unstressed syllables (e.g. Steriade, 1994; Barnes, 2006); or vowel reduction may be phonetic, typically corresponding to undershoot phenomena, with trajectories towards the intended vowel not reaching their target and hence leading to a gradient reduction of formant contrast in the vowel space (Lindblom, 1963, 1967). Secondly, phonological vowel reduction, that involves a change of vowel target in a given phonological context, can display a rich phenomenology of consonantal contexts driving or impeding the reduction process. Such potentially complex phonological rules need to be captured in some way as phonological knowledge by the speaker of the corresponding language.

This is indeed the case of Coratino, a southern Italian dialect spoken in the Apulia region, which is the focus of the present study. Within the Coratino vocalic system, the ability of a vowel to function contrastively depends on the stress and positional configuration of the vowel in the word. There are 7 vowel phonemes /i e ɛ u o ɔ a/ in stressed positions. In unstressed positions, initial vowels are maintained, but non-initial vowels are reduced to a centralized configuration, apart from /a/ which is systematically maintained: [fəˈn**u**ccə] "fennel" vs. [fən**ɨ**ˈcɛddə] "dim.[1]"; [ˈl**i**mə] "lime" vs. [lɨˈm**a**] "to lime"; [ˈfɛmənə] "women" vs. [f**ə**məˈnɛddə] "dim."; [ˈr**o**tə] "wheel" vs. [r**ə**ˈtɛddə] "dim.". Nevertheless, this complete phonological reduction does not operate when vowels are "protected" by being adjacent to a consonant that shares articulation such as labiality and velarity for back vowels (/u o ɔ/ "protected" by e.g. /b/ or /g/) and palatality for front vowels (/i e ɛ/ "protected" by e.g. /ɟ/): [ˈl**u**mə] "lamp" vs. [l**u**ˈminə] "dim."; [ˈm**o**llə] "elastic" vs. [m**o**lˈlɛttə] "dim."; [ˈk**u**rvə] "curve" vs. [k**u**rˈvɛttə] "dim."; [ˈf**i**ɟɟə] "girl" vs. [f**i**ɟˈɟɛttə] "dim."; [ˈc**e**sə] "church" vs. [c**e**saˈrɛddə] "dim.". In this case, there is only a partial phonological reduction concerning the contrast between mid-high and mid-low vowels, which is lost. The reduction process has been analyzed in the context of formal phonology in Bucci (2013, 2017) and D'Introno & Weston (2000).

In a recent study published in this journal (Bucci et al., 2018), we attempted to specify in the vowel reduction pattern in this dialect what could be attributed to undershoot phenomena typical of phonetic reduction, and what should really be considered as a loss of phonemic

[1] Abbreviation – dim.: diminutive.

contrast and a change in vowel target, which should be specifically considered as phonological reduction. To this end, we recorded for 10 native Coratino speakers a set of paired utterances where each of the 7 vowels /i e ɛ u o ɔ a/ respectively appeared in a stressed and an unstressed configuration. Stressed configurations were obtained in Coratino words in which the vowel was embedded in the stressed syllable, e.g. /ˈrotə/, "wheel". Unstressed configurations were obtained by adding a diminutive suffix at the end of the word, the suffix taking the stress in Coratino and hence removing it from the syllable containing the target vowel, e.g. /rəˈtɛddə/, "small wheel".

Formants F1 and F2 were systematically measured at the center of the considered vowels, stressed or unstressed. The major objective was to attempt to disentangle phonetic from phonological reduction processes. Phonetic reduction would consist of undershoot phenomena, with decreasing formant contrast keeping vowels distinct (Fig. 1a). Phonological reduction would shift all non-initial non-protected vowels (that is, vowels without the relevant consonantal context protecting them from reduction) except /a/, towards a single schwa target at the center of the vowel space. Initial or protected vowels (that is, vowels protected from phonological reduction by the appropriate consonantal context) would be maintained, apart from the loss of the mid-high vs. mid-low contrast (Fig. 1b).

The average acoustic data for the 10 speakers are displayed on Fig. 2, linearly normalized by constraining for each speaker the mean F1 value for stressed /i/ and /u/ to be 0 and the mean F1 value for stressed /a/ to be 1, and the mean F2 values for stressed /u/ and /i/ to be respectively 0 and 1. All initial vowels appeared as quite stable acoustically, confirming that they are never reduced in Coratino, even in an unstressed configuration. For non-initial unstressed vowels, the acoustic analyses confirmed the phonological reduction process previously described by Bucci (2013, 2017). Indeed, non-initial unstressed protected vowels maintained their vowel quality and just displayed some phonetic reduction with a decrease in formant contrast. For these vowels, the phonological (categorical) vs. phonetic (gradient) nature of the reduction of the mid-high vs. mid-low contrast was less clear, and will not be further considered in the present study. However, there did appear to be a phonological reduction process for non-initial unstressed non-protected vowels with a loss of the front-back contrast shifting all front unrounded and all back rounded vowels towards schwa, /a/ keeping its status of a low central vowel, possibly reduced to /ɐ/. Still, importantly, we discovered an unexpected aspect in the phonological reduction to schwa, since there appeared a small but systematic contrast between high vowels reduced to /ɨ/ and mid-vowels reduced to /ə/, with a statistically significant 75-Hz difference in F1 values between the two groups (see Fig. 2).

Additional analyses of coarticulatory patterns for unstressed non-initial vowels confirmed that the reduction of non-protected vowels to schwa (i.e. towards /ɨ ə/) is phonological. Indeed, these analyses showed that undershoot phenomena, characteristic of phonetic reduction, were actually applied after transformation of the non-protected vowels into schwa. In particular, front unrounded vowels in labial contexts, e.g. /bib/, had lower F2 values than back rounded vowels in dental contexts, e.g. /dud/, which would be quite unlikely on the basis of pure phonetic undershoot phenomena. This was interpreted as a sequence of two processes: firstly, categorical phonological reduction transformed the plain /i/ and /u/ vowels into schwa because they were not protected by the corresponding consonantal context; secondly, coarticulatory effects due to the labial or dental context respectively decreased or increased the actual schwa F2 value because of gradient phonetic undershoot.

In summary, the acoustical analysis of the Coratino vowel system in Bucci et al. (2018) confirmed the following major facts about phonological reduction of unstressed vowels in this dialect, that we consider in the following as four major properties (P) of the Coratino phonological system:

- (P1) Initial vowels are not phonologically reduced;

- (P2) /a/ is not reduced, even in a non-initial configuration and regardless of the consonantal context;
- (P3) Non-initial non-protected vowels are reduced to schwa, while vowels protected by an adjacent consonant sharing place of articulation with the vowel are maintained, possibly with a loss of the mid-high vs. mid-low contrast;
- (P4) There seem to be two targets for phonological reduction of non-protected vowels, respectively a higher target /ɨ/ for the reduction of high vowels /i/ and /u/, and a lower target /ə/ for the reduction of mid vowels /e ɛ o ɔ/.

This is the set of phonological properties that seem to constitute the description of the vowel system in Coratino. The objective of the present study is to evaluate to what extent Coratino speakers have a conscious access to these properties, and how they are represented in the brain. We will now discuss what experimental tools can be exploited for this purpose.

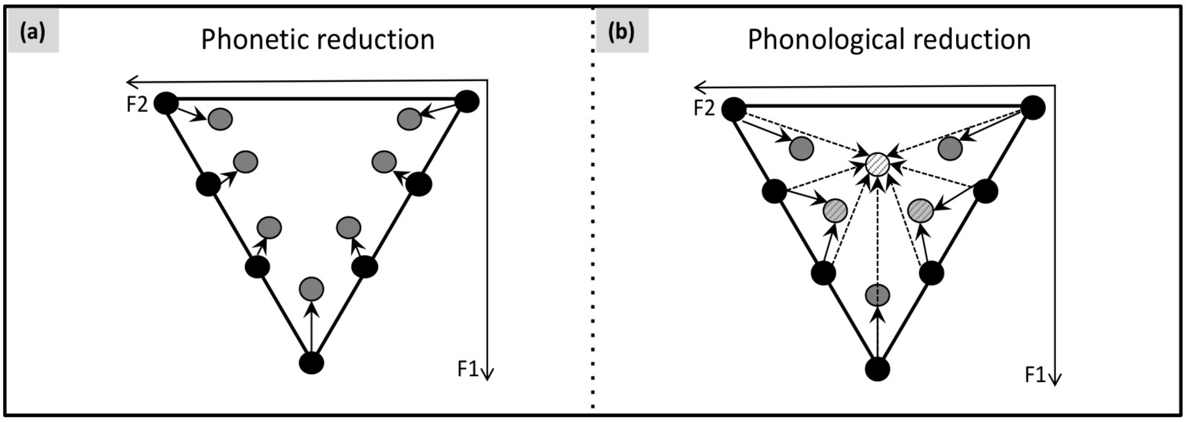

Figure 1 (from Bucci et al., 2018). Schematic predictions comparing the effects of phonetic (a) vs. phonological (b) vowel reduction in Coratino. Qualitative F1 and F2 values have no exact meaning. Arrows represent vowel reduction from the stressed to the unstressed configuration. Black disks display non-reduced vowels in a stressed configuration. In (a) and (b), grey non-hatched disks display unstressed vowels with phonetic reduction. In (b), plain arrows display the reduction of mid-high towards mid-low unstressed initial or protected vowels, and dotted arrows towards the white hatched disk display the reduction of all unstressed non-initial non-protected vowels to schwa. From Bucci et al., 2018, Fig. 2.

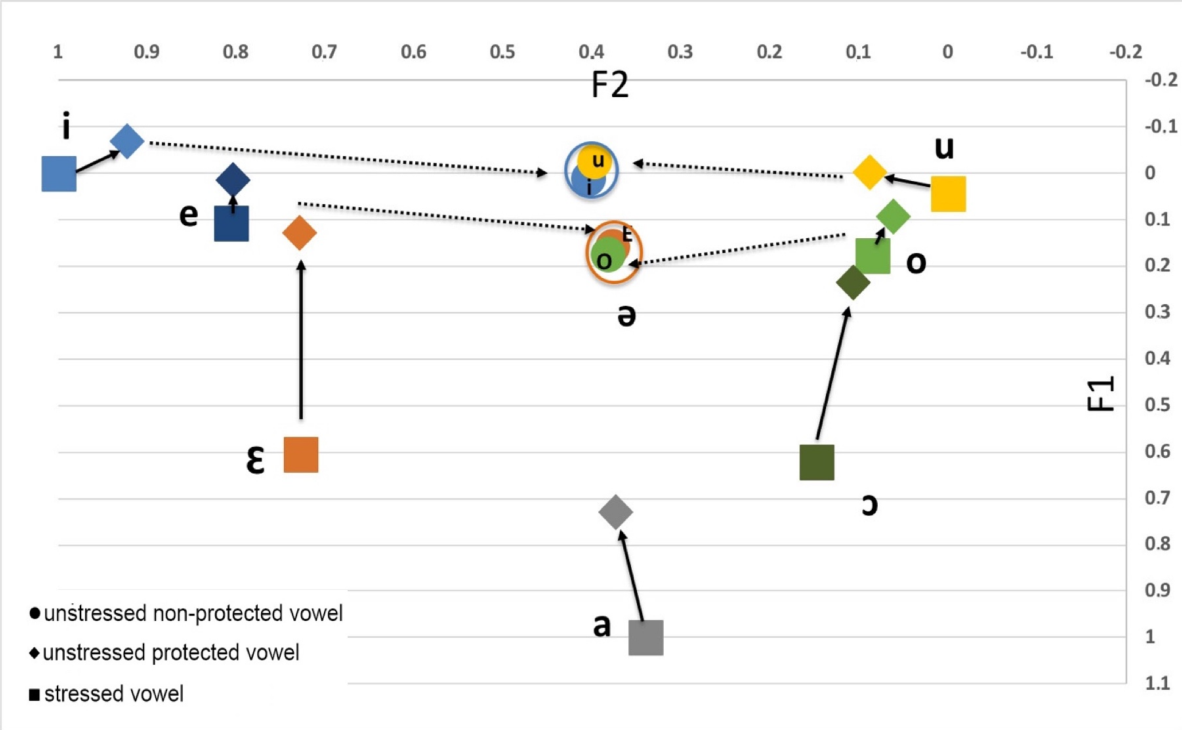

Figure 2 – Average normalized formant values over all utterances and all speakers, for stressed (initial or not), unstressed initial or protected and unstressed non-initial non-protected vowels. The two circles in the schwa region delimit the two sub-areas respectively corresponding to the schwas coming from high vs. medium vowels (mid-vowels summarized by the symbols E for /e ɛ/ and O for /o ɔ/). From Bucci et al., 2018, Fig. 4.

1. 3. Nonce-word formation as a paradigm for assessing phonological knowledge

A rather classical and much used paradigm in the study of the mental representations of linguistic knowledge consists in using non-words in various kinds of experimental tasks. Non-words can be a way to disentangle the linguistic rules from the linguistic material on which they have been learned. The underlying assumption is that if rules are learned in an “algebraic” way independent of the examples they were learned from, they should be applied to new material provided by nonce words. However, if the rules are just the emergent product of a set of learned distributions, then the distributions are in some sense "part" of the rule, and the individual items from which the rule was learned are likely to be processed more efficiently than unknown material that is not part of the learning set, that is nonce words.

Nonce words were first used to establish acceptability ratings by Greenberg & Jenkins (1964), who attempted to determine quantitative ratings of the acceptability of consonant sequences in syllable onset in American English. Over the years, this was followed by a large number of studies exploiting quantitative ratings on nonce words for assessing phonotactic knowledge (e.g. Vitevich et al., 1997; Treiman et al., 2000; Bailey & Hahn, 2001; Albright, 2007) or the status of phonological rules, e.g. the Obligatory Contour Principle (Berent & Shimron 1997; Berent et al., 2001) or rule organization in optimality theory (Coleman & Pierrehumbert, 1997; Hammond, 2004).

Other studies involve non-word repetition, a classical tool in the study of language development (e.g. Munson & Beckman, 2005; Coady & Evans, 2008). It is classically considered to depend on both the acquisition of phonological regularities and on the pattern of similarities between the non-word to be uttered and the words in the lexicon. Thus, Gathercole (1995) shows that non-words with high "wordlikeliness", that is with a high degree of similarity to existing words, are influenced by the specific properties of these words in the lexicon, while non-words with low "wordlikeliness" are rather produced in a phonologically regular way.

Finally, since the princeps "wug" study by Berko (1958), production of non-words is also tested without repetition, in grammatical tasks in which the form of a given word must be produced from another form (e.g. conjugate a non-existing verb to assess the way speakers apply their knowledge of morphological generalizations on such nonce verbs). This has generated various applications in phonology or morphology (see reviews in Bybee & McClelland, 2005; Albright & Hayes, 2011), including the study of various kinds of morpho-phonological alternations concerning e.g. consonant reduction (Albright & Hayes, 2003), gemination (Kawahara, 2013), voicing (Ernestus & Baayen, 2003), tone sandhi (Zhang et al., 2006), diphthongization (Albright et al., 2001) or vowel reduction (Chociej, 2011).

The question we ask in this study is how the complex rules driving vowel reduction in Coratino operate on non-words. This involves asking Coratino speakers to apply diminutives to nonce-words with stressed vowels becoming unstressed in the process of generating diminutive forms, and evaluating whether properties P1 to P4 apply on the corresponding utterances. The debate between the "algebraic mind" as defined e.g. by Berent (2013) and the "statistical mind" corresponding to various views about emerging rules in the connectionist paradigm (e.g. McClelland, 2009) or the exemplarist framework (e.g. Bybee, 2001; Pierrehumbert, 2001, 2006) leads to clearly distinct predictions.

If phonology consists in a set of hard-coded formal rules – whatever the formalization in phonological theory – then we can predict that these rules should transfer from words to non-words. Hence, the properties P1, P2, P3 and P4 should entirely apply to the nonce words in the experiment. However, if phonology rather consists in a set of emergent principles associated with the distribution of word phonological content in memory, then transfer from words to non-words would rather occur in the form of a general process driven by the similarities between phonemic sequences associated with words and non-words. Under this assumption, similar trends would be obtained for non-words as for words, for the four properties and for all speakers, though possibly in a fuzzier and less systematic way.

Finally, it can also be assumed that speakers could consider the exercise as a non-linguistic game and apply to these items the diminutive process without any vowel transformation, considering in some sense that since the non-words presented to them are not part of a lexicon, they are not concerned by phonological principles at all. Indeed, while the paradigm of generating a non-word transformation of some kind has already been exploited with success on morphology, it has never been used, to our knowledge, directly on the application of a set of phonological rules.

In sum, we have two sets of theoretical expectations: either categorial and complete use of the properties P1 to P4, or gradient use of the properties depending on the uttered item and its relationships with the lexicon. And we have an underlying question which concerns how the speakers will achieve the task and whether they will display any phonological reduction at all.

To assess the way reduction rules are represented by Coratino speakers, a corpus of non-words was created, representative of the cases of maintenance and reduction in unstressed position. This corpus was submitted to 19 native speakers. Their productions were perceptually and acoustically analyzed to annotate the cases of maintenance and reduction of the relevant vowels and the associate formant values, in order to assess properties P1, P2, P3 and P4.

2. Method

2.1. *Participants*

The data for this study were collected in fieldwork in Corato, on 19 native speakers aged from 18 to 65 years (mean age 31; 14 men and 5 women). All the participants were born in Corato, live there and speak the dialect daily. They have different socio-cultural profiles (peasants, smallholders, workers, nurses, retirees, traders, students and unemployed). All speakers use dialectal Italian on a daily basis in addition to Coratino. Dialectal Italian is a mixture of Standard Italian – in which there is no reduction to schwa – with Coratino. Importantly, this mixture respects the same reduction rules as Coratino.

None of the participants was aware of the aim of the study. Moreover, none of them had any training in phonetics or phonology.

2.2. *Corpus*

We first created a corpus of non-words consisting in 70 roots – “radicals” in the following (see Appendix 1). Each radical included a target vowel set in penultimate position making it stressed in Coratino. The participants’ task, presented in detail in the next section, consisted in adding a suffix to the radical, rendering the target vowel unstressed. This enabled us to evaluate how the target vowel was produced in an unstressed configuration.

From among the seven plain vowels in Coratino, we considered the five vowels /i e u o a/, discarding the mid-low vowels and hence the mid-high vs. mid-low contrast from the study. The radicals were composed of three types of bi- or tri-syllabic structures (all ending with schwa) with different positions of the test vowel in the structure, in order to vary the target syllable position. The five vowels were systematically incorporated in each kind of structure. The target stressed vowel in the radical could be:

- at the initial position (Appendix 1a): ˈ**V**Tə (V the target vowel within /i e u o a/, T a voiced or voiceless dental plosive /d/ or /t/, hence 10 items);
- in the first syllable in a non-initial position (Appendix 1b): ˈC**V**də (with C a plosive within labials /p b/, dentals /t d/ and palatals /c ɟ/, hence 30 items);
- in the second syllable (Appendix 1c): taˈC**V**də (with C a plosive within velars (/k g/), dentals /t d/ and palatals /c ɟ/, hence 30 items).

The corpus therefore covered all situations of interest: vowel /a/ vs. other high or mid-high vowels; initial vs. non-initial vowels; and three types of left consonantal contexts, respectively palatal contexts, protective for the front but not for the back series, labial or velar contexts protective for the back but not for the front series, and dental contexts, not protective for either series – dental contexts being also systematically selected to the right of the target vowel. Labials and velars, which are supposed to play the same role in respect to protection in Coratino, were respectively selected for bi-syllabic and tri-syllabic items. Notice that this corpus was set up so that conditions were both balanced and varied, in order to provide a sufficient number of samples for each of the four tested properties, and also to ensure a certain degree of variability making it more difficult for the speakers to predict the stimuli and to provide stereotypic responses. Care was also taken to keep the test at an acceptable length for the participants.

2.3. *Task*

The 70 nonce radicals of the corpus were first recorded by a native speaker of Coratino, carefully producing stress on the penultimate target vowel. They were then prepared in a random order, and presented auditorily to each participant. The participant's task was to listen to each stimulus and then to directly produce a new item (without repeating the nonce radical) by adding the diminutive suffix (-ˈɛddə) at the end of the radical. For example, the speaker heard [taˈgudə] and then was asked to produce /taˈgudə/+suffix, for example [taguˈdɛddə]. Only one utterance was considered for each item, with no possibility of correcting or modifying the production, and in case of hesitation, the item was rejected.

Since suffixes are always stressed in Coratino, the task was expected to result in removing the accent from the studied vowel in the radical, making it unstressed. This task hence enabled the reduction/non-reduction process to be grasped, by assessing whether the studied vowel, once unstressed, underwent reduction or resisted and continued to be produced as a plain vowel. We made the following predictions for the set of 70 radicals (see Appendix 1):

- 32 items were expected to display reduction, since they included non-initial non-/a/ vowels with non-protective adjacent consonantal contexts (e.g. /ˈd̲**u**d̲ə̲/ supposedly providing /d**ə̲**ˈdɛttə/);
- 38 items were expected to resist reduction and remain unchanged, for any of the following reasons: (i) because of an adjacent consonantal context sharing place of articulation with the target vowel: labiality or velarity for back rounded vowels /u o/

and palatality for front vowels /i e/, e.g. /ˈ**po**də/ → /p**o**ˈdɛttə/ or /ˈc**i**də/ → /c**i**ˈdɛttə/, 16 items altogether); (ii) because they contained the vowel /a/ (12 items); (iii) because they contained a vowel in an initial position (10 items).

In a rare number of cases, the participant happened to produce a vowel in the suffixed item that was neither the plain vowel of the radical, nor a schwa (be it [ɨ] or [ə]): for example, the participant heard /taˈgadə/ and produced [tagiˈdɛdde] instead of [tagaˈdɛddə]. In some other cases the participant erroneously applied the diminutive: for example, the participant heard /ˈbudə/ and produced [ˈbudəˈdɛdde] instead of [buˈdɛdde]. These productions were rejected from further analyses.

For 3 speakers, recordings were made in a quiet room of each participant's home. Two recording sessions were held at the city's cultural association (Pro Loco) for 11 speakers and in a quiet room at a public library in the city for 5 speakers. Recordings were made with the built-in unidirectional microphone, in mono mode, of a digital recorder (Zoom H2) placed on a tripod about 30 cm from the participant, and sampled at 44,100 Hz. In some cases, the recordings of productions were corrupted by an external noise (e.g. a cough or another person in the room intervening at the same time as the speaker generated the non-word). In these cases, the item was rejected.

Altogether, rejections based on incorrect production or noisy items amounted to 11% of the expected productions. We will now detail the processing of the valid items.

2.4. *Vowel coding*

All further analyses are based on the general assumption that speakers may have produced phonologically reduced patterns, in which the stressed vowel in the nonce radical is transformed into schwa in the unstressed configuration in the uttered suffixed item. Therefore, each valid item was coded according to this criterion, i.e. reduced to schwa vs. non-reduced. Coding was made in two steps: a perceptual evaluation followed by an acoustic check.

2.5. *Perceptual evaluation*

The automatic classification of vowels in context is known to be a complex task, particularly in unstressed configurations where coarticulation and reduction phenomena play a large role in specifying the vowel attributes. The acoustic data in Bucci et al. (2018) confirm the difficulty of fully separating vowel classes, including vowels reduced to schwa, with 100% certainty. We therefore decided to perform a first labelling stage based on the expertise of trained phoneticians, since such expertise allows all fine spectro-temporal details of the acoustic trajectories to be grouped coherently into phonological classes.

We first checked that all target vowels, produced in the suffixed item, were indeed unstressed. Then perceptual evaluation, i.e. deciding whether there is maintenance or reduction of the penultimate vowel of the radical, was assigned to three phoneticians, native speakers of French, who were familiar with the task of phonetically transcribing Romance languages. Importantly, none of these phoneticians were expert in Coratino, so none of them knew what the expectations and predictions were concerning this material.

The first two transcribers evaluated the whole corpus, their task being to evaluate each item and specify whether the production of the (radical+suffix) non-word contained a full vowel within /i u e o a/ or a reduced vowel /ə//. The task was therefore specified in phonological terms, and reduction at this stage was summarized as "reduced to schwa", without introducing the possibility of differences in F1 values between a "higher" and a "lower" schwa. The results of the two evaluators were compared and when there was a mismatch, the item was presented to the third evaluator who took the final decision. Mismatches occurred for 9% of the cases, largely due to palatal contexts (for half of these mismatch cases, the other half being distributed mainly between dental and velar cases) and with front vowels in two thirds of the mismatch cases.

2.6. *Acoustic analyses*

After this perceptual evaluation, all valid items were subjected to acoustical analysis. The stimuli were manually segmented individually by the Audacity software (http://audacityteam.org/). They were then annotated with the Praat software (Boersma & Weenink, 2018). On each item, we manually identified three events: 1) the beginning of the vowel, i.e. the beginning of the formant transition from the previous consonant to the vowel target, 2) the beginning of the formant transition from the vowel to the next consonant and 3) the center of the vowel, defined as occurring at the point of time halfway between events 1) and 2). The values of the first two formants F1 and F2 of these schwa vowels were estimated at the vowel center (position 3) with Praat default settings for formant analysis (i.e. LPC analysis applied on 25-ms windows with 5 formants below 5500 Hz for all speakers, both male and female).

Systematic analysis of (F1, F2) values then enabled us to check the coherence of perceptual evaluation. To this end, we referred to the phonological analysis in Fig. 1 and to the typical phonetic realizations of Coratino vowels in Fig. 2. We first defined 5 classes corresponding to the plain vowels /i e u o a/, and for each speaker we attributed the formant values of each item to the corresponding vowel class when phoneticians had considered the item vowel as non-reduced. Concerning vowels labelled as schwa by the phoneticians, we did not at this stage separate this class into separate groups based on height differences – this was done in a further analysis that will be described later. But we did consider phonetic coarticulation effects on schwa, abundantly displayed in Bucci et al. (2018). A first qualitative inspection of formant values showed that labial and dental contexts did not lead to strong modifications of acoustic values, but palatal contexts led to clear fronting of the produced schwa, with a strong F2 increase. Hence, we separated the vowels labelled as schwa by the phoneticians into two groups, respectively schwa (with labial or dental contexts) and palatal schwa.

This led to the creation of separate plots for each speaker with formant values in the (F1, F2) space grouped in 7 categories [i e u o a ə ʲə] (see Fig. 3). Careful analysis of these plots led us to marginally modify the phoneticians' decisions when a vowel was clearly attributed to the wrong class in terms of the coherence of vowel formants. These modifications occurred for less than 3% of the items. They corresponded mainly to back vowels in a palatal context, reduced to a fronted schwa, that had been mistakenly taken as a plain front vowel. In Fig. 3 we report two typical examples. The first (Fig. 3a) presents a number of reduced vowels, schwas or palatal schwas. The second (Fig. 3b) corresponds to a speaker who produced no phonological reduction at all. Overall, the formant distributions for the 19 speakers confirm the coding provided by the phoneticians, and validate the further analyses about phonological reduction in the studied nonce-words.

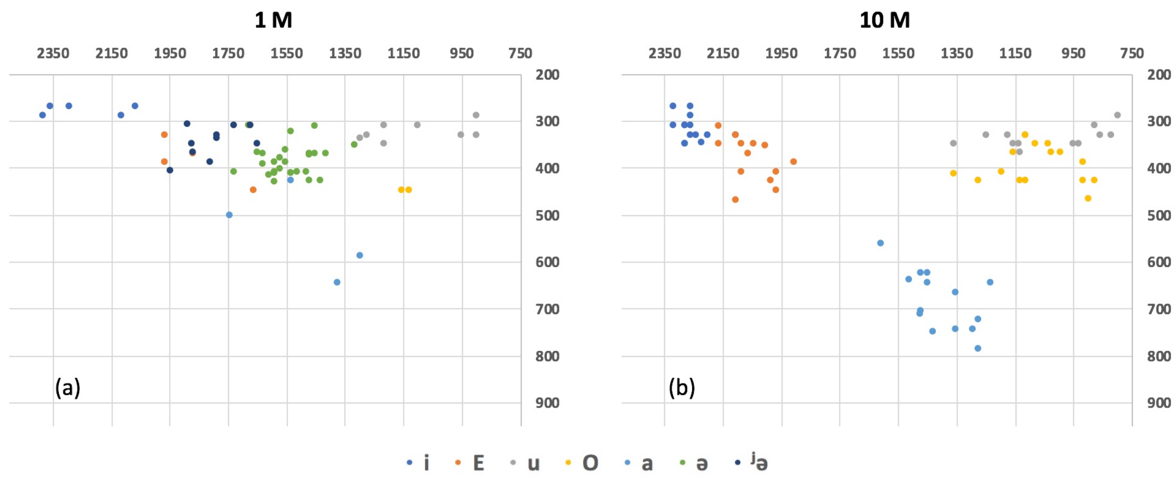

Figure 3 – Formant values for all items grouped in 7 classes (see text), for two representative speakers. (a) Speaker 1 (male) with clear phonological reduction. (b) Speaker 10 (male) with no phonological reduction at all.

2.7. *Hypotheses and statistical analyses*

Statistical analyses were guided by the four properties presented in Section 1. Importantly, the distribution of vowels concerning the first three properties does not enable a joint evaluation. Indeed, the task is driven by 3 main factors, namely vowel (/i e u o a/), position (initial or not) and protection (protected or not). However, the distribution over the 3 factors is not complete since protection does not concern /a/ nor initial vowels. We therefore separated the analysis of the vowel and position effects from the analysis of protection for non-initial non-/a/ vowels.

2.7.1. Effect of position and vowel (P1 & P2)

The first analysis concerned properties P1 and P2. P1 states that initial vowels never reduce. The corresponding hypothesis is that initial vowels reduce less than non-initial ones. P2 states that vowel /a/ never reduces while all other vowels may reduce to schwa when they are not protected by their consonantal context. The corresponding hypothesis is that among /i e u o a/, /a/ provides fewer cases of reduction than the other vowels.

These two hypotheses were evaluated by applying a logistic regression with random effects, to model the probability of a binary response variable, i.e. "reduced" vs. "non-reduced", in a repeated measures paradigm considering the fixed factors "vowel" (with 5 values: /i e u o a/), "position" (initial or not), and their interaction, including two random factors, "speaker" and "item" (with 70 items uttered by 19 speakers). The random logistic regression was performed using the *glmer*() function of the *lme4* package of the R software, version 3.2.0 (R Development Core Team, 2016).

Selection of the appropriate model was based on log-likelihood differences between models, assessed with a Chi-square test with a degree of freedom equal to the difference in the number of parameters, and with the criterion of p-value lower than 0.05. The effect of introducing random slopes was analyzed first, and then the fixed effects were studied by a descendant analysis with the *anova* function in R. To judge the performance of the final model, we used the area under the ROC (Receiver Operating Characteristic) curve, which takes values between 0 and 1, using the *AUC* (Area Under Curve) package of the R software (see Saporta, 2011).

Once the final model had been obtained, if necessary, multiple comparison tests were applied using the method presented in Hothorn et al. (2008), with the *glht* function of the *multcomp* package of the R software. This method ensures that the first-order risk associated with taking all decisions simultaneously does not exceed a threshold that is set in advance (0.05) by adjusting the p-values.

2.7.2. Consonantal protection

The second analysis concerned P3, which states that non-low vowels /i e u o/ resist reduction when they are protected by the appropriate consonantal context, and are reduced otherwise. The corresponding hypothesis is that protected vowels are associated with fewer cases of reduction than non-protected ones, considering only non-initial vowels. To check whether reduction might depend on the corresponding vowel, we described the 4 vowels involved by their two phonological contrasts, corresponding to the height and front/back dimensions. Furthermore, to assess whether the phonotactic structure of the 70 items in the corpus could play a role in reduction, we also introduced two additional factors in the analysis, namely the number of syllables in the item (2 or 3) and the voiced vs. unvoiced nature of the left consonantal context. Therefore, altogether, the consonantal protection hypothesis was evaluated by applying a logistic regression with random effects, to model the probability of a binary response variable, i.e. “reduced” vs. “non-reduced”, in a repeated measures paradigm including two random factors, “speaker” and “item” (with only 48 items per speaker, removing initial and /a/ vowels) and testing the influence of the fixed factors “protection” (protected or not), “vowel height” (high or mid high), “vowel place” (back or front), “syllables” (bi-syllabic or tri-syllabic items), “voicing” (voiced or unvoiced left consonantal context) and their interaction.

Once again, we used the likelihood ratio test. The effect of introducing random slopes was analyzed first, and then the influence of fixed effects was studied, this time by an ascendant analysis, because of the number of factors. Finally, we checked the area under the ROC curve with *AUC* and we carried out multiple comparison tests with *glht* when appropriate.

2.7.3. Two targets for reduction

Finally, to assess whether there can indeed be two targets for schwa, we evaluated the presence of possible differences for the F1 values for reduced configurations respectively provided by high /i u/ vs. mid /e o/ vowels in the radical. This evaluation was performed only on the configurations that were “correctly reduced”, that is for which the speaker actually reduced a configuration with a vowel not protected by its consonantal context. However, we consider that the missing values are not due to the experimental setup (the modalities of the factor have no impact on the probability of giving an answer). Similarly, we consider that the missing values are not due to the value of F1 (e.g. not due to the fact that they would be too high or too low to be recorded). Finally, we do not consider that the data are censored (that is, we do not consider that a response would have been recorded if we had waited longer). In other words, we consider for statistical analysis that the missing values are completely random.

To assess the existence of two targets for reduction, we evaluated the existence of significant differences in F1 between reduced utterances coming respectively from high /i u/ vs. mid /e o/ vowels in the radical. This was done by a linear statistical model with a random factor, "speaker", added to the fixed factor "height" of the original stressed vowel with two values, high vs. mid, carried out with the *lme* function in the *nlme* package in the R software.

Notice that no normalization was applied to the F1 values, since normalization is difficult to apply without access to stressed items, which provide a more reliable estimation of maximal and minimal F1 values (see Section 1.2 and Fig. 2). However, the introduction of the "speaker" random factor actually provides a normalization by the mean of all utterances for the corresponding speaker.

Once again, we employed the likelihood ratio test. The effect of introducing random slopes was analyzed first, and then the influence of fixed effects was studied. Once the appropriate model was selected, the difference between the two modalities of the fixed effect if significant was evaluated, as previously, with the *glht* function of the *multcomp* package in R.

3. Results

We shall now describe the results in relation to the three statistical tests presented in Section 2.7.

3.1 *Effect of position and vowel*

The data concerning the effect of position are quite clear. It appears that all speakers maintained all vowels (including /a/) in all tested items (100% of cases), when the target vowel was in an initial position. Therefore, there is no reduction of initial vowels by the Coratino speakers of the present study, whatever the vowel, the nonword context and the speaker.

Because of this complete separation effect of position, a joint statistical analysis of "position" and "vowel" was impossible, and the first statistical analysis focused on the effect of vowel. The analysis showed that inter-individual variability is significant, with changes in random slopes from one modality to another of the "vowel" factor ($\chi^2(4)=59.7$, $p<0.0001$). The "vowel" factor does not significantly influence reduction ($\chi^2(4)=8.1$, $p=0.1$). Altogether, the selected model only involves "item" and "vowel|speaker" random slopes as random effects, and only one intercept as fixed factor. The area under curve (AUC) is 0.95, which shows that the model performed well.

The probabilities of non-reduction per vowel are displayed in Fig. 4. They show that the probability of non-reduction for vowel /a/ is high, as expected. Still, it is less than 100%, and actually lower than the probability for /u/, and overall, no difference between vowels is significant (which is confirmed when one looks at all comparisons between pairs of vowels leading to p-values larger than 0.2, see Table 1).

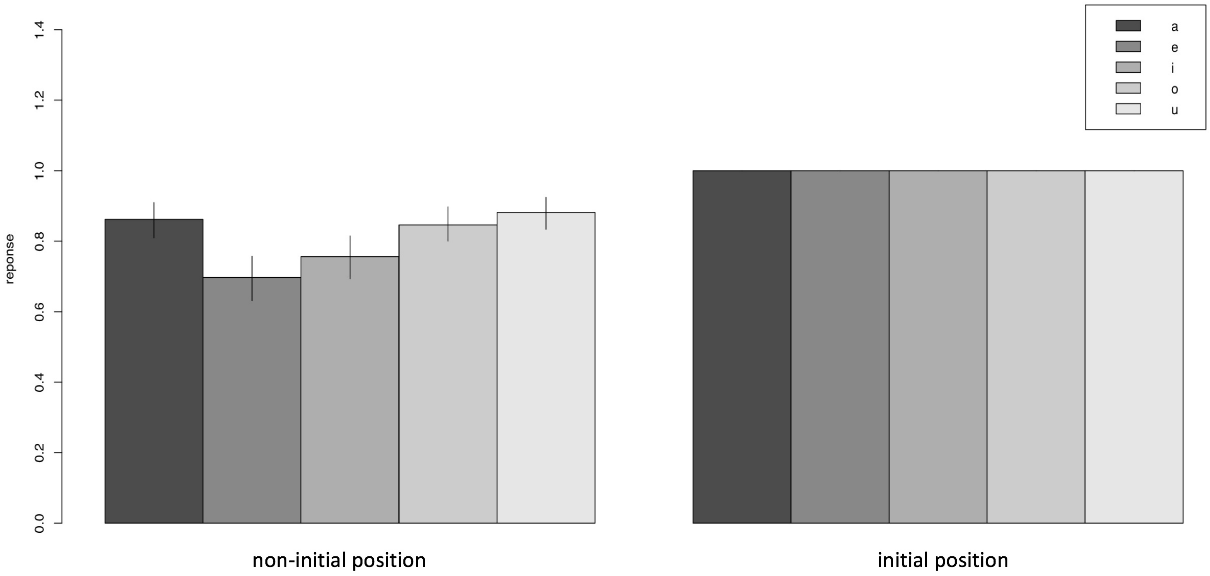

Figure 4 – Percentage of non-reduction for the 5 vowels in a non-initial (left) or initial (right) position, averaged over the 19 speakers.

Table 1 – Analysis of differences in reduction probabilities between vowels in a non-initial position.

For each tested hypothesis (first column) the "estim" column provides the difference between the regression coefficients in the model. The "SE" column displays standard deviations. The "z value" column provides the value of the test statistics. The final column "Pr(>|z|)" gives the corresponding p-value. All p-values are larger than 0.05.

	estim	SE	z value	Pr(>|z|)
e - a	-1.5187	0.7863	-1.931	0.286
i - a	0.5960	1.3868	0.430	0.992
o - a	-0.5540	0.7795	-0.711	0.951
u - a	0.2650	0.9027	0.294	0.998
i - e	2.1148	1.1969	1.767	0.377
o - e	0.9647	0.7353	1.312	0.669
u - e	1.7837	0.8799	2.027	0.239
o - i	-1.1500	1.3358	-0.861	0.905
u - i	-0.3311	1.4040	-0.236	0.999
u - o	0.8190	0.8125	1.008	0.843

3.2 *Consonantal protection*

First, the analysis of random effects shows that inter-individual variability changes with random slope variations from one modality of the front-back factor to the other ($\chi^2(2)$ = 39.62, p<0.0001). Focusing then on the ascendant selection of fixed effects, at the end of this process there remain only the "protection" ($\chi^2(1)$=6.73, p=0.0094) and "syllables" factors ($\chi^2(1)$=12.55, p=0.0003) with no interaction. Hence, altogether, the selected model includes "protection" and "syllables" as fixed factors, and "item" and "front-back|speaker" random slopes as random effects. The AUC value of 0.93 is still satisfactory. The comparison between protected and non-protected conditions is significant, z=2.99, p=0.0055, the proportion of non-reduction in protected items being significantly higher than in non-protected ones (86% vs. 76%). The comparison between bi-syllabic and tri-syllabic conditions is also significant, z=3.66, p=0.00056, with no interaction between the two factors involved, "protection" and "syllables". It appears that the overall proportion of non-reduction is higher for bi-syllabic ˈC**V**də than for tri-syllabic taˈCVTə items (respectively 86% vs. 74%). No other fixed factor appears to play a significant role in the analysis, with hence no difference between vowels nor between voiced vs. unvoiced contexts.

Though the effect of protection appears significant overall, speakers seem to behave rather differently in the task. To make this clear, we display in Fig. 5 the proportion of reduction for non-protected and for protected vowels, for each of the 19 speakers. The test proposed for evaluating property P3 consists in evaluating whether, overall, speakers are above the diagonal, which is indeed the case. The perfect phonological fit to property P3 is represented in the Figure by the plain circle at the top left, with reduction for all non-protected items, and no reduction for any protected item. This shows that the property is respected only as a trend, but it is far from being complete. It also shows that speakers are highly variable, with some speakers maintaining all vowels in nonce words, and others reducing items rather randomly (along the diagonal) whatever their status relative to protection. It can also be seen that one speaker, displayed by a circled cross in the figure, has a strong tendency to maintain protected vowels (proportion 0.69) and to reduce non-protected ones (proportion 0.84).

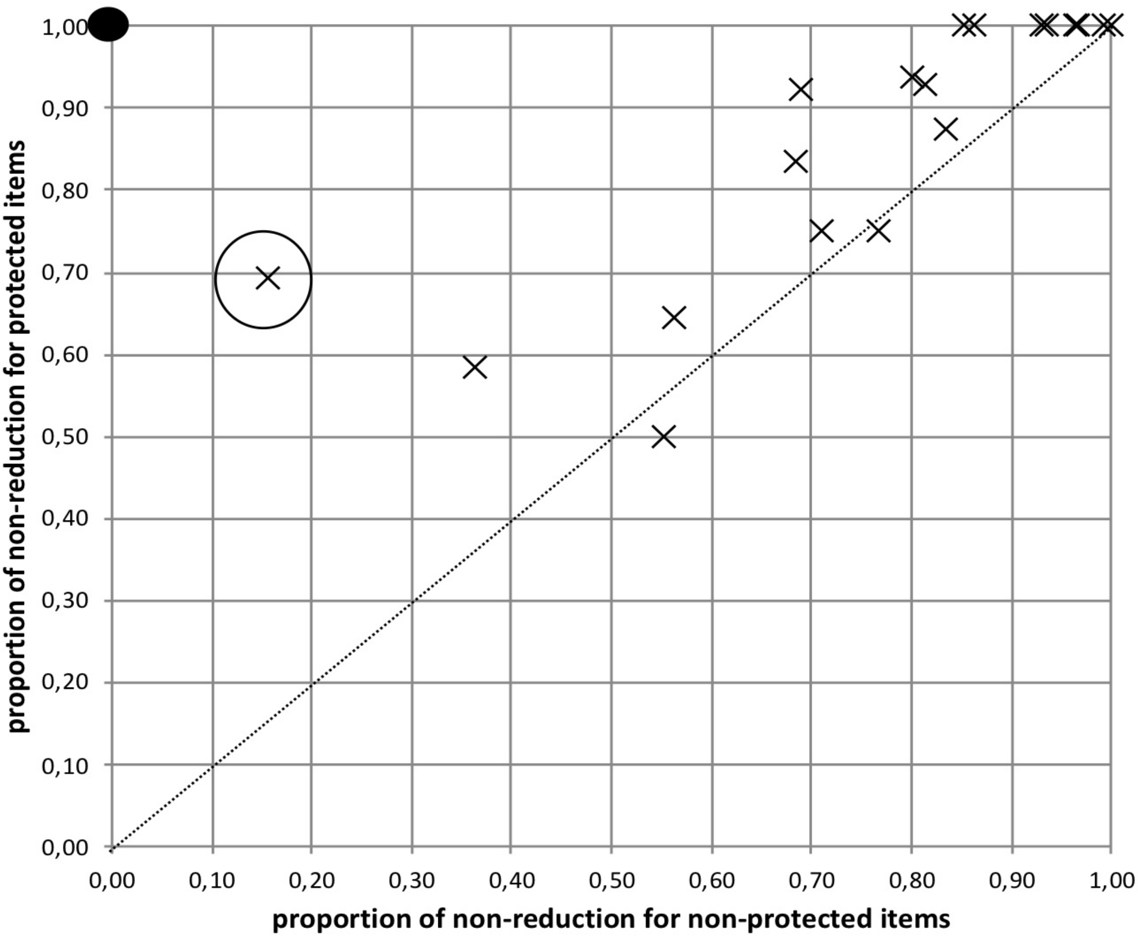

Figure 5 – Percentage of non-reduction for the protected vs. non-protected items, averaged over non-initial vowels /i e u o/ and over the 19 speakers.

3.3. *Two targets for reduction*

The last analysis revealed changes in individual variability (varying random slopes) from one modality of the "height" factor to the other: $\chi^2(1)=4.5$, p=0.03. Importantly, the "height" factor appears to significantly influence the F1 value ($\chi^2(1)$= 15.77, p<0.0001). Hence the selected model comprises "height" as fixed factor and "height|speaker" random slopes. Fig. 6 displays the mean values of F1 for schwas associated with high vs. mid vowels. It appears that the values are significantly different, with a lower value for the reduction target for high vowels (mean 343 Hz) compared to the value for mid-high vowels (mean 408 Hz): z=4.98, *p*<0.0001.

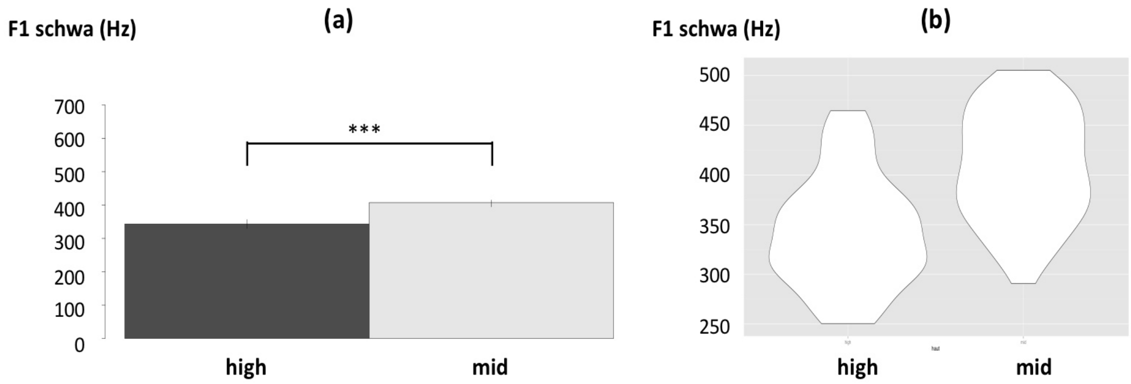

Figure 6 – Distribution of F1 values for schwas respectively associated with high vs. mid-high vowels. (a) Vertical bars provide 95% bootstrap confidence intervals for means. The difference of F1 values between the two groups is highly significant, as displayed by the three stars (p<0.0001). (b) Distribution of F1 values for schwas respectively associated with high vs. mid-high vowels.

4. Discussion

The analysis of productions of Coratino speakers in the nonce-word generation paradigm applied to vowel reduction processes displays a rich and complex pattern of results, that we will consider in relation to three questions, namely: (i) What do these data tell us about the nonce-word generation paradigm itself? (ii) What do they tell us about the representation of phonological rules in a speaker's mind? and (iii) What do they tell us about the vowel system and the vowel reduction process in Coratino?

4.1. The nonce-word paradigm applied to the vowel reduction process

As discussed in Section 1.3 in the Introduction, the paradigm of nonce-word production from a given existing word has been used to assess various kinds of phonological alternations, though rarely with vowel reduction (though see Chociej, 2011) and also seldom with such a rich pattern of reduction phenomena as in Coratino. Hence the importance of discussing how speakers in the present study behaved in this paradigm.

A first important observation is that speakers did perform the task straightforwardly and, more importantly, that they did display reduction and a certain tendency to follow the principles of phonological rules (e.g. P1, P3, P4, see next section) in their productions. Hence it seems that the nonce-word generation paradigm could shed interesting light in the study of the representation of phonological rules in a given language.

Still, it is striking that the amount of phonological vowel reduction is much lower than envisioned. Indeed, while initial vowels were never reduced in agreement with P1, as will be discussed in the next section, non-initial vowels display a relatively low level of reduction. Grouping together all vowels including /a/ and all consonantal contexts, whether protective or not, 82% of the produced items display a maintained plain vowel (see Fig. 4, left) while predictions based on P2 and P3 would have led to an overall level of maintenance of only 49% (since, by construction, 2/3 of the high or mid vowels should have been reduced, see Appendix 1 and Section 2.2).

Analyzing variation among speakers in more detail (Fig. 5), it appears that 2 speakers did not display any reduction at all for either protected or non-protected items. These speakers might be assumed to have considered the paradigm as simply a word game in which a nonce radical had to be completed automatically with a diminutive without applying any rules of language to the generated item. For these speakers the generation paradigm failed to elicit phonological processes at all.

The other speakers did display some amount of reduction – with hints that phonological rules intervened in the reduction process, as will be discussed later – though with a large amount of inter-speaker variability, from speakers who maintained the vowel almost systematically, to one speaker who seems to have played the phonological game almost perfectly. We tried to find possible explanations of this specific behavior in one single speaker. This participant happens to be young (19) but there are several other participants in the same age range who showed no tendency to display the same kind of reduction pattern. We must admit that we have no strong hypothesis to offer at this stage to explain why the participants' behavior is so variable in the studied paradigm.

Altogether, this suggests that the nonce-word generation paradigm applied to phonological/phonetic phenomena can provide interesting patterns, with however, in the present case, rather large inter-individual variability and a limited ability to fully engage phonological principles.

4.2. The representation of phonological rules in the minds of Coratino speakers

While keeping in mind the caveats raised in the previous section about the imperfect ability of the nonce-word generative paradigm to fully engage the phonological system in the speakers' productions, we will now discuss the results of the statistical analyses of these productions in reference to the "algebraic" vs. "statistical" models of phonological representations in the speaker's "phonological mind". Let us first summarize the major findings in Section 3:

- Concerning the status of initial position (property P1), initial vowels in non-words are never reduced, even in a non-stressed configuration;

- Concerning the robustness of /a/ (property P2), it appears that /a/ is well maintained for most speakers, with an overall 12% reduction averaged over all speakers. However, there is no statistically significant trend that /a/ is more robust than other vowels in unstressed non-initial configurations in non-words;
- Concerning consonantal protection for non-initial vowels (property P3), there is significant evidence of a transfer to non-words. Moreover, there appears to be a considerable amount of inter-individual variability, since one speaker clearly behaves differently from the others and displays a strong tendency for consonantal protection in non-words;
- Concerning the existence of two targets for reduction (property P4), the trend observed for words (Bucci et al., 2018) is transferred to non-words, with a clearly significant difference between F1 values for the [ɨ] target for high vowels (around 340 Hz) and for the [ə] target for mid-vowels (around 410 Hz).

Let us now review the assumptions we proposed in Section 1.3 concerning the possible transfer of phonological regularities from words to non-words. If phonological regularities in words are the consequence of hard-coded formal rules ("Formal-Rule Hypothesis", *FRH* hereafter), then these rules could be completely transferred to non-words (which corresponds to the ideal case displayed by a filled circle in Fig. 5), or transferred differently depending on rules, speakers and even items. If, instead, phonological regularities are emergent properties of the distribution of items in the lexicon ("Emergent Property Hypothesis", *EPH* hereafter), the transfer of these properties from words to non-words would operate through similarities between phonemic sequences associated with those words and non-words. A given non-word would be produced in relation with the production of "similar" words, hence similar trends would be obtained for non-words and for words for all speakers, though possibly in a fuzzier and less systematic way.

Let us now analyze each of the four experimental results obtained in Section 3, in reference to these different assumptions.

(P1) – The processing of initial vowels is actually compatible with both *FRH* and *EPH*. Indeed, it could be assumed that participants have learned a phonological rule stating that initial vowels in Coratino are always maintained regardless of the stress value and that this rule is perfectly transferred to non-words (*FRH*); or that the distribution of initial vowels in Coratino is so clear that it has been entirely transferred to non-words because proximity computations provide non-ambiguous outputs (*EPH*). It could also be posited that Coratino speakers just do not reduce vowels at all in non-words, but we can already discard this hypothesis, considering the pattern for non-initial vowels, that we will now analyze in more detail.

(P2) – The result of the test of /a/ robustness is negative: there is no statistically significant overall trend that /a/ is less reduced than other vowels. This is incompatible with a strict application of *FRH*, in which a formal rule about /a/ maintenance would be systematically transferred to non-words. Fig. 4 rather suggests that there is an overall trend that a certain number of items are reduced, about 18% altogether, averaged over all unstressed non-initial configurations and over the 19 speakers. Additional analysis of variability related to item structure displayed rather large differences between bi- vs. tri-syllabic items. The greater maintenance of ˈC**V**də structures could be due to distributional properties, considering their proximity with ˈ**V**də structures in which the vowel is protected by its status of radical-initial. We have no explanation for the difference between front and back vowels, since data about the distribution of corresponding structures in words in Coratino are not available.

(P3) – The pattern of data about consonantal protection goes in a different direction. Indeed, there is a significant trend for consonantal protection in non-words at the group level, though consonantal protection is far from complete for all speakers. This is at odds with a strong version of *FRH* that would propose a perfect transfer from words to non-words. It is more in line with a distributional framework *EPH*, possibly based on distributional properties of the presented nonce-radicals. Still, the inter-speaker variability is puzzling. Indeed, it is unclear why distributions would vary so much among speakers. A striking case of inter-speaker variability concerns the circled speaker in Fig. 5 who seems to apply the consonantal protection rule fairly consistently. Altogether, the pattern in Fig. 5, with some speakers reducing no item, others reducing a rather large proportion of items (up to 50% for one speaker) and one speaker respecting the consonantal protection rule fairly well, seems to suggest that the speakers are able to take into account the rule concerning consonantal protection, though in a non-deterministic way, varying among speakers.

(P4) – The fourth property concerning the existence of two targets for reduction seems fairly well respected. It provides a confirmation of the existence of different targets for the reduction of high vs. mid vowels, highlighted in Bucci et al. (2018). It appears that this property also applies to non-words. Interestingly, this property is difficult to interpret in the *EPH* context. It can be envisioned that the existence of two targets is encoded in a distributional way, but it is less clear how this could be transferred to non-words. Indeed, what would be transferred from the words? It cannot simply be the diminutive form of the word, since these diminutive forms do not have an intrinsic structure that shows whether the complete form contained a high or a mid-vowel. Thus, the existence of two targets for reduction in non-words suggests that speakers have the knowledge, explicit (rule-encoded) or implicit (distributional), of a "relationship" between two morphemes, the radical and the suffixed radical.

Therefore, altogether, the pattern of reduction behaviors is somewhat complex, property-dependent and variable among speakers. Some aspects are fairly compatible with the transfer of formal rules, e.g. the status of initial vowels, or the pattern of reduction towards two different targets. Others are rather in line with distributional properties transferred towards non-words on the basis of phonemic similarities, e.g. the difference between bi-syllabic and tri-syllabic items. It is difficult to explain the wide variability between speakers by a purely distributional approach, since it seems unlikely that distributional patterns are so different from one speaker to another. It rather suggests that participants base their behavior, at least in part, on certain rules that they have acquired for words, and that they transfer these rules in a variable way to non-words. This variability could have been driven by speakers conceiving the task as a non-linguistic game rather than a real language task, as is possibly evidenced by the fact that some speakers did not produce any reduction at all throughout the experiment.

4.3. Back to the vowel system in Coratino

Finally, the present data can be related to the vowel system and the phonological reduction process in Coratino. Firstly, they clearly confirm that initial vowels are never reduced, even in unstressed configurations (P1). It is actually quite common to find a greater number of vocalic contrasts in initial syllables (see reviews in Barnes, 2002; Flemming, 2005). This is often considered as related to a domain-initial boundary marking cue reflecting the importance of the initial syllable in the lexical access process (see e.g. Beckman, 1998; Flemming, 2005), though it can also be conceived as the trace of past or present initial stress, making initial positions, even unstressed, part of the stressed domain (Barnes, 2002). The status of initial configurations has been modelled by Bucci (2013) as syllabic space providing a branching structure making vowels non-reduced, in the framework of government phonology (Kaye et al., 1990) and CVCV phonology (Scheer, 2004).

The description of the consonantal protection process (P3) is partly supported by the present data. Even if the role of consonant protection is gradient and far from complete in non-word generation, the trend is indeed significant and even quite large in one speaker. This strongly suggests that there is indeed a protection rule in Coratino – however it may be represented in the speakers' minds, as discussed previously. This supports the phonological analyses of this process as they have been developed in e.g. Bucci (2013, 2017) in the nonlinear phonology framework, proposing that consonantal protection provides the target vowels with branching structures in the skeleton. Branching structures would enable the vowel to resist reduction, following the proposal by Honeybone (2005) that segments sharing an articulation feature are protected from lenitions. The fact that consonant protection appears in the present study as a statistical trend rather than a systematic rule for most speakers could suggest that P3 is in fact a phonotactic preference for some CV associations due to a diachronic pattern that is no longer active in the present state of Coratino. However, it appears that loanwords in Coratino systematically follow the protection rule (e.g. [ˈv**ɛ**spə] "vespa" becomes [v**ə**ˈspɛttə] "dim." in a non-protected case, and [təlәˈf**o**nə] "phone" becomes [tələf**o**ˈninə] "dim." in a protected case), which rather supports the view that P3 is indeed a synchronic rule, even if it is only weakly transferred to nonce words in the present study.

The status of the low level /a/ is less clear, with no confirmation of its greater robustness in the present data. On the other hand, the data in Fig. 6 provide a strong and striking confirmation of the quite unexpected discovery, in Bucci et al. (2018), that there are actually two targets for reduction in Coratino, /ɨ/ for the reduction of high vowels and /ə/ for the reduction of mid vowels. Taken together, these two seemingly inverse findings – a negative one about P2 and a positive one about P4 – could be jointly accounted for in the new phonological analysis developed by Bucci et al. (submitted). The authors propose that the reduction process could be considered as a loss of the front/back contrast (and the correlated unrounded/rounded contrast) with a maintenance of the height features in Coratino. They provide a phonological analysis of this new conception, that corresponds to the final phonetic analysis in Bucci et al. (2018) suggesting that reduction actually reduces the 7-vowel system /i e ɛ o ɔ u a/ for stressed configurations to a 3-vowel system /ɨ ə a/ for unstressed configurations, possibly involving some amount of reduction for /a/ towards the centralized central /ɐ/.

Altogether, the present data hence provide support for this adapted description of the structure and properties of the vowel system in Coratino.

5. Conclusion

The analysis of the production of non-words by 19 native Coratino speakers provides enlightening information on the way they represent and exploit phonological principles associated with vowel reduction in their dialect. It suggests that the nonce-word generative paradigm could be applied to the study of the cognitive representation of phonological rules, though with some clear limitations. It shows that speakers display different behaviors in respect to each of the four basic properties of vowel reduction. Possible evidence for the use of explicit/formal rules is provided by data on vowel maintenance in initial position of an utterance, by the use of two targets /ɨ/ and /ə/ for vowel reduction, and by the specific behavior of one speaker concerning consonantal protection. However, evidence for behaviors guided by distributional properties learnt on words and transferred in a statistical way to non-words may also be found in various aspects of the reduction process, particularly concerning the role of consonant context.

This study hence suggests that both sets of processes are likely to intervene in the behavior of Coratino speakers for vowel reduction on non-words. Importantly, these data on the way the four major properties of vowel reduction in Coratino, phonetically described and phonologically analyzed in previous studies, transfer, to a certain extent, to non-words, provide confirmation and precisions on the nature of these properties in the phonology of Coratino.

Statement of Ethics

• Participants (or their parents or guardians) gave their written informed consent.

• The study protocol was approved by the research institute's committee on human research.

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Jonathan Bucci defined the experimental protocol, participated in the data acquisition sessions in Corato, did the acoustical analyses and participated in the writing process. Paolo Lorusso organized the data acquisition process in Corato and participated in the acquisition sessions. Mirko Grimaldi supervised the data acquisition process in Corato and participated in the final writing process. Silvain Gerber did the statistical analyses. Jean-Luc Schwartz supervised the definition of the protocol and the analysis process and participated in the writing process.

References

Albright, A. (2007). Gradient Phonological Acceptability As a Grammatical Effect, ms., MIT. (http://web.mit.edu/albright/www/papers/Albright-GrammaticalGradience.pdf)

Albright, A., Andrade, A.E., & Hayes, B. (2001). Segmental environments of Spanish diphthongization. In A. Albright, & T. Cho (Eds.), UCLA Working Papers in Linguistics, Number 7: Papers in Phonology 5, pp. 117–151.

Albright, A., & Hayes, B. (2003). Rules vs. analogy in English past tenses: a computational/experimental study. Cognition, 90, 119–161. doi:10.1016/S0010-0277(03)00146-X

Albright, A., & Hayes, B. (2011). Learning and learnability in phonology. In J. Goldsmith, J. Riggle, & A. Yu (Eds.) Handbook of Phonological Theory (pp. 661–690). Blackwell/Wiley.

Bailey, T.M., & Hahn, U. (2001). Determinants of wordlikeness: Phonotactics or lexical neighborhoods? Journal of Memory and Language, 44(4), 568-591. doi:10.1006/jmla.2000.2756

Barnes, J. (2002). Positional neutralization: a phonologization approach to typological patterns. PhD dissertation, University of California, Berkeley.

Barnes, J. (2006). Strength and weakness at the interface: positional neutralization in phonetics and phonology. Berlin & New York: Mouton de Gruyter.

Beckman, J. (1998). Positional Faithfulness. Amherst, University of Massachusetts.

Berent, I. (2013). The phonological mind. Trends in Cognitive Sciences, 17(7), 319-327. doi:10.1016/j.tics.2013.05.004

Boersma, P., & Weenink, D. (2018). Praat: doing phonetics by computer [Computer program]. from http://www.praat.org/

Berent, I., & Shimron, J. (1997). The representation of Hebrew words: Evidence from the Obligatory Contour Principle. Cognition, 64, 39–72. doi:10.1016/S0010-0277(97)00016-4

Berent, I., Everett, D.L., & Shimron, J. (2001). Do phonological representations specify variables. Evidence from the obligatory contour principle. Cognitive Psychology, 42, 1–60.

Bucci, J. (2013). Voyelles longues virtuelles et réduction vocalique en coratin. Canadian Journal of Linguistics/Revue Canadienne de Linguistique, 58(3), 397–414. doi:10.1017/S0008413100002632

Bucci, J. (2017). L'alternance des voyelles moyennes en coratin : une analyse basée sur la théorie des éléments. Canadian Journal of Linguistics/Revue Canadienne de Linguistique, 63, 1–24. doi:10.1017/cnj.2017.22

Bucci, J., Perrier, P., Gerber, S., & Schwartz, J.L. (2018). Vowel Reduction in Coratino (South Italy): Phonological and Phonetic Perspectives. Phonetica. doi:10.1159/000490947.

Bucci, J., Scheer, T., & Schwartz, J.L. (submitted): Phonological analysis of a system with two targets for vowel reduction in Coratino, The Linguistic Review.

Bybee, J. (2001). Phonology and Language Use. Cambridge: Cambridge University Press. doi:10.1017/CBO9780511612886

Bybee, J., & McClelland, J. (2005). Alternatives to the combinatorial paradigm of linguistic theory based on domain general principles of human cognition. The Linguistic Review, 22, 381–410. doi: 10.1515/tlir.2005.22.2-4.381

Chociej, J. (2011). Phonological grey areas: The case of polish vowel-zero alternations. Unpublished dissertation. http://individual.utoronto.ca/chociej/Files/UToronto-GP2-Chociej.pdf

Chomsky, N. (1965). Aspects of the theory of syntax. Cambridge, MA: MIT Press.

Chomsky, N., & Halle, M. (1968). The sound pattern of English. New York, Harper and Row.

Coady, J.A., & Evans, J.L. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments (SLI). International Journal of Language & Communication Disorders, 43, 1–40. doi: 10.1080/13682820601116485

Coleman, J. (2002). Phonetic representations in the mental lexicon. In J. Durand, & B. Laks (Eds.), Phonetics, Phonology, and Cognition (pp 96-130). Oxford: Oxford University Press.

Coleman, J., & Pierrehumbert, J. (1997). Stochastic phonological grammars and acceptability.

D'Introno, F., & Weston, R. M. (2000). Vowel Alternation, Vowel Consonant Assimilation and OCP Effects in a Barese Dialect. In L. Repetti (Ed.), Phonological Theory and the Dialects of Italy (pp. 89–110). Amsterdam: Benjamins.

Ernestus, M., & Baayen, R.H. (2003). Predicting the unpredictable: Interpreting neutralized segments in Dutch. Language, 79, 5–38.

Flemming, E. (2001). Scalar and categorical phenomena in a unified model of phonetics and phonology. Phonology, 18(1), 7-44.

Flemming, E. (2005). A phonetically-based model of phonological vowel reduction. Manuscript. Cambridge: MIT.

Gathercole, S.E. (1995). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. Memory & Cognition, 23(1), 83–94. doi:10.3758/BF03210559

Hamann, S. (2011). The phonetics-phonology interface. In N. Kula, B. Botma, & K, Nasukawa (Eds.), Continuum Companion to Phonology (pp. 202–224). London: Continuum.

Hammond, M. (2004). Gradience, phonotactics, and the lexicon in English phonology. International Journal of English Studies 4, 1–24.

Hayes, B., & Steriade, D. (2004): Introduction: The phonetic bases of phonological markedness. In B. Hayes, R. Kirchner, & D. Steriade, (Eds.) Phonetically based phonology (pp. 1-33). Cambridge: Cambridge University Press.

Honeybone, P. (2005). Sharing makes us stronger. In P. Carr, J. Durand & C. Ewen (Eds.) Headhood, elements, specification and contrastivity: Phonological papers in honour of John Anderson (pp. 167–192). Amsterdam: John Benjamins.

Hothorn, T., Franck Bertz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. Biometrical Journal, 50, 346–363.

Jackendoff, R. (2002). Foundations of language: Brain, meaning, grammar, evolution. USA: Oxford University Press.

Kaye, J., Lowenstamm, J., & Vergnaud, J. R. (1990). Constituent structure and government in phonology. Phonology, 7(1), 193–231.

Kawahara, S. (2013). Emphatic gemination in Japanese mimetic words: a wug-test with auditory stimuli. Language Sciences, 40, 24–35.

Kingston, J. (2006). The phonetics phonology interface; In P. de Lacy (Ed.) The Cambridge Handbook of Phonology (pp. 401–434). Cambridge: Cambridge University Press.

Lindblom, B. (1963). Spectrographic study of vowel reduction. The journal of the Acoustical society of America, 35(11), 1773–1781.

Lindblom, B. (1967). Vowel duration and a model of lip mandible coordination. Speech Transmission Laboratory Quarterly Progress Status Report, 4, 1–29.

Marcus, G. (2001). The algebraic mind: Integrating connectionism and cognitive science. Cambridge: MIT Press.

McClelland, J.L. (2009). Phonology and perception: a cognitive scientist's perspective. In P. Boersma, & S. Hamann (Eds.) Phonology in Perception (pp. 293–314). Mouton De Gruyter.

Munson, B., Edwards, J., & Beckman, M.E. (2005). Phonological knowledge in typical and atypical speech-sound development. Topics in Language Disorders, 25(3), 190–206. doi:10.1097/00011363-200507000-00003

Pierrehumbert, J. (2001). Exemplar dynamics: word frequency, lenition and contrast. In J. Bybee, & P. Hopper (Eds.), Frequency and the Emergence of Linguistic Structure (pp. 137–157). Amsterdam: Benjamins.

Pierrehumbert, J., Beckman, M.E., & Ladd, D.R. (2000). Conceptual foundations of phonology as a laboratory science. In N. Burton-Roberts, P. Carr, & G. Docherty (Eds.). Phonological knowledge: Its nature and status (pp. 273–303). Cambridge: Cambridge University Press.

Prince, A., & Smolensky, P. (2004). Optimality theory: Constraint interaction in generative phonology. Oxford: Wiley-Blackwell.

Treiman, R., Kessler, B., Knewasser, S., Tincoff, R., & Bowman, M. (1996). English speakers' sensitivity to phonotactic patterns. In M. Broe, & J. Pierrehumbert (Eds.) Papers in Laboratory Phonology V (pp. 269-282). Cambridge, UK: Cambridge University Press.

R Development Core Team. (2008). R: a language and environment for statistical computing. Vienna, R Foundation for Statistical Computing. http://www.R-project.org.

Saporta, G. (2011). Probabilités, analyse des données et statistique. Paris : Editions TECHNIP, 622 p.

Scheer, T. (2004). A lateral theory of phonology: What is CVCV, and why should it be? (Vol. 1). Berlin: Walter de Gruyter.

Scobbie, J.M. (2005). Interface and Overlap in Phonetics and Phonology. In G, Ramchand. & C, Reiss (Eds.), The Oxford Handbook of Linguistic Interfaces (pp. 17–52). Oxford: Oxford University Press.

Steriade, D. (1994). Positional neutralization and the expression of contrast. ms., UCLA.

Treiman, R., & Barry, C. (2000). Dialect and authography: Some differences between American and British spellers. Journal of Experimental Psychology: Learning, Memory, and Cognition, 26(6), 1423–1430.

Vitevitch, M.S., Luce, P.A., Charles-Luce, J., Kemmerer, D. (1997). Phonotactics and syllable stress: Implications for the processing of spoken nonsense words. Language and Speech, 40(1), 47–62.

Zhang, J., Lai,Y., & Turnbull-Sailor, C. (2006). Wug-testing the "tone circle" in Taiwanese. In D. Baumer, D. Montero, & M. Scanlon (Eds.), Proceedings of the 25th West Coast Conference on Formal Linguistics (pp. 453–461). Cascadilla Proceedings Project, Somerville, MA.

Appendix 1

(a) ˈVTə structure:

/ˈutə/	/ˈudə/
/ˈotə/	/ˈodə/
/ˈetə/	/ˈedə/
/ˈitə/	/ˈidə/
/ˈatə/	/ˈade/

(b) ˈCVdə structure:

/ˈpudə/	/ˈbudə/	/ˈtudə/	/ˈdudə/	/ˈcudə/	/ˈɟudə/
/ˈpodə/	/ˈbodə/	/ˈtodə/	/ˈdodə/	/ˈcodə/	/ˈɟodə/
/ˈpedə/	/ˈbedə/	/ˈtedə/	/ˈdedə/	/ˈcedə/	/ˈɟedə/
/ˈpidə/	/ˈbidə/	/ˈtidə/	/ˈdidə/	/ˈcidə/	/ˈɟidə/
/ˈpadə/	/ˈbade/	/ˈtade/	/ˈdade/	/ˈcade/	/ˈɟade/

(c) TaˈCVdə structure:

/taˈtudə/	/taˈdudə/	/taˈkudə/	/taˈgudə/	/taˈcudə/	/taˈɟudə/
/taˈtodə/	/taˈdodə/	/taˈkodə/	/taˈgodə/	/taˈcodə/	/taˈɟodə/
/taˈtedə/	/taˈdedə/	/taˈkedə/	/taˈgedə/	/taˈcedə/	/taˈɟedə/
/taˈtidə/	/taˈdidə/	/taˈkidə/	/taˈgidə/	/taˈcidə/	/taˈɟidə/
/taˈtade/	/taˈdade/	/taˈkade/	/taˈgade/	/taˈcade/	/taˈɟade/

The underlined items are contexts where reduction should not occur, while for the other items it should occur, according to the phonological properties of reduction for words in Coratino.