Neural Tracking of Implicit vs Explicit Phonotactic Learning

Enes Avcu, Ryan Rhodes and Arild Hestvik
University of Delaware

Artificial grammar learning (AGL) studies have been widely used for testing the learnability of phonological patterns. It has been shown at the behavioral level that learners can extract adjacent and non-adjacent dependencies with relatively short training (Finley, 2017). Less is known about how lab-learned patterns are encoded at the neurophysiological level (cf. Domahs et al., 2009; Moore-Cantwell et al., 2018). Our aim was to examine the neurophysiological correlates of implicit and explicit learning of a non-adjacent phonotactic pattern. The "implicit" group merely repeated grammatical exemplars without any explicit instruction, while the "explicit" group had the rule explained. While recording EEG, participants were presented with words that were either well-formed or ill-formed according to the rule. We found that both groups performed behaviorally with accuracy levels indicating knowledge of the rule. However, only the implicit learning group exhibited an ERP response modulated by well-formedness, which we interpret as reflecting prediction errors. These results show that implicit, but not explicit, learning engages neurophysiological mechanisms that lead to prediction models at the neural level and suggests that implicit lab-learning experiments tap into the kind of unconscious, automatic learning that is characteristic of natural language acquisition.

Methods. We ran an artificial grammar learning experiment with two learning conditions (implicit vs explicit), testing the learnability of a simple phonotactic pattern – a non-adjacent sibilant harmony pattern attested in Navajo.

Stimuli. All training and test stimuli consisted of two syllables of the form of CV.CV, with sibilants ([s, ʃ]) as the first and second consonants. All words were either "harmonic" (both sibilants identical) or "disharmonic" (mixed [s] and [ʃ]). The duration of each phoneme was strictly controlled at 100ms, making each word 400ms long, and the violation at 200ms.

Procedure. 45 monolingual American English speakers participated, divided into two groups (N=24 and 21). The procedure for the implicit-learning group consisted of two phases: training and testing. The training phase differed for the two groups. For the explicit-learning group, the rule was explained: "s and ʃ cannot appear in the same word". Explicit-learning participants were then presented with all the harmonic and disharmonic words and instructed to press a button in response to each stimulus to categorize them. Feedback was given for correct and incorrect responses. Implicit-learning participants instead listened only to harmonic words and were instructed to repeat each word orally. Implicit-learning participants were not told the rule and received no feedback. In the testing phase, participants in both groups were instructed to listen to a sequence of words and categorize each word as "part of the language" (i.e. novel harmonic) or "not part of the language" (novel disharmonic) that they had been exposed to during training. Participants were tested in an auditory oddball paradigm, with 80% harmonic and 20% disharmonic words. The groups differed only in training (explicit vs implicit)[1].

Data Recording and Analysis. Hits (a disharmonic word was presented, and the participant reported it as disharmonic) and *false alarms* (a harmonic word was presented, but the participant reported it as a disharmonic word) were used to calculate *d'*, a measure of the participant's sensitivity to the rule. Learning was then modeled as having a *d'* greater than 0. EEG was recorded with a HydroCel 128 electrode net (Electrical Geodesics). The P3 measurements were taken from the rare-minus-frequent difference waves measured at frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4) electrode sites. ERPs were computed for two-time windows: a stimulus-locked P3 (400 to 700ms after the stimulus onset), and a response-locked P3 (-200 to -100ms before the behavioral response), following Luck

[1] Testing phase was the same for both groups, except the implicit group had 300 trials compared to 1200 in explicit group.

(2009). Analysis of variance (ANOVA) included factors of the region (frontal, central, parietal) and harmony (harmonic, disharmonic words).

Results. Behavioral results showed that the implicit group detected disharmonic words with a mean sensitivity (d') of 0.558, while the explicit group's sensitivity was 1.666. The difference between groups was significant: $t(43)=3.68$, $p<.001$, $1-\beta=.976$. The implicit group's mean accuracy was 0.66 (SD=.13), while explicit group's mean accuracy was 0.80 (SD=.14), which also showed a significant group difference ($p=.002$, $1-\beta=.949$). Electrophysiological results for the stim-locked and resp-locked P3 of the implicit group showed a significant region effect and harmony effect (all p values <.005). This indicates that the brain detected the rule violation at exactly 200ms, resulting in a P3 peak at 500ms (300ms after the violation). As for the explicit group, both stim-locked and resp-locked P3 showed a significant region effect ($p<.001$), but NOT a harmony effect (p values >.05). This means that the explicit group's detection of the rule violation was not reflected in P3. Furthermore, we found a significant lateralized readiness potential (LRP) in both groups, which reflects the response selection process.

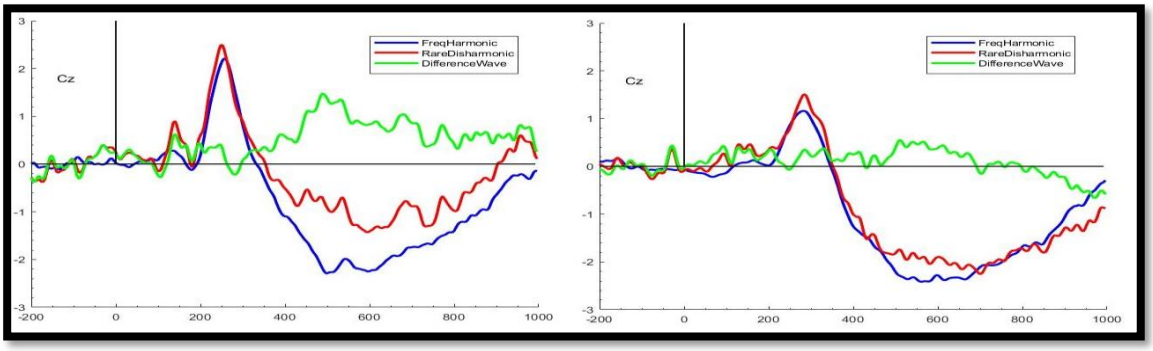

Fig. 1. Stimulus-locked grand average ERP waveforms: clear harmony effect reflected in P3 difference waveform in implicit (left panel) but not in explicit group (right panel). All stimuli elicited a clear auditory evoked potential (AEP).

Discussion and Conclusion. Behaviorally, both the explicit and implicit groups learned the non-adjacent phonotactic pattern, with the explicit group performing much better than the implicit group, reflected in both *d'* and accuracy. However, the two groups differed in their measured brain responses. The implicit learners showed a predicted P3 modulation to rule violation, while the explicit learners showed no modulation, despite the presence of a robust AEP and LRP in both groups. We interpret these results to indicate that implicit and explicit learning leads to different types of neural encoding of the acquired phonotactic rule. This interpretation is in line with Moreton et al. (2017)'s distinction between cue-based (implicit) and rule-based (explicit) models; the former is more like typical phonotactic learning whereas the latter is classic visual category learning which depends on frontal-striatal circuits (Ashby and Maddox, 2005) that may not be reflected on an EEG. Moreover, our results fit with the observation that first language acquisition is implicit and leads to long-term neural encoding, whereas adult 2nd language acquisition, based on explicit learning, leads to a fundamentally weaker knowledge state. We conclude that lab-based learning experiments mimic naturalistic long-term implicit language learning.

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Perception of Mandarin Tone 3 and Tone 4: Effects of Syllable Position and Focus

Chao Han, Yue Yuan, Irene Vogel
University of Delaware

Words in connected speech undergo modifications not observed in isolation. For example, the acoustic properties of different elements may be reduced when their identity is retrievable on the basis of contextual cues in the speech stream[1]. It can thus be expected that if these cues are removed, the weaker acoustic cues will result in confusion. Since the meaning of a Mandarin word depends crucially on its tone, if the tones are not clearly produced, there is the potential for a good deal of ambiguity, with the same syllable having multiple meanings. Mandarin speakers do not, however, experience more trouble understanding connected speech than speakers of other languages, suggesting either that the tones are always clearly articulated and/or that the context provides adequate information to overcome any reduction in the clarity of the tone production.

We investigate the two possibilities by testing the perceptual distinction between Tones 3 and 4 (T3 and T4), previously reported to cause some difficulty for listenters[2]. In fact, both tones have a similar initial falling trajectory, the crucial difference residing in the rise after the fall in T3, but not T4. Since other prosodic conditions (i.e., syllable position[3] and focus[4]) have been found to affect the acoustic manifestation of tones, we also test whether they affect the perception of the tones. As our findings show, there is considerable perceptual confusability between T3 and T4, and this is, moreover, influenced by both syllable position and focus.

In a three-alternative forced choice perception task, 6 Mandarin-speaking participants heard syllables extracted from 3-syllable words produced by 10 Mandarin speakers (4F) in short dialogues, with the target in a Focus or Non-Focus condition. Tonal co-articulation and sandhi were controlled for by having syllables with congruent tones adjacent to the target syllables. The participants heard 72 CV syllables with each of /i, u, a/ bearing T3 and T4, and 36 distractors with T1 or T2, drawn from each the three syllable positions, in both focus conditions. Each syllable was repeated twice, and the participants selected one of 3 characters corresponding to the same CV syllable (e.g., /bi/) with T3, T4 and either T1 or T2.

The initial results of the 6 participants listening to syllables produced by three of the speakers showed an overall accuracy of 50% for T3 and 77% for T4 (chance = 33%). T3 was incorrectly perceived as T4 40% of the time, but as T1 or T2 only 10% of the time. T4 was perceived incorrectly as T3 only 9% of the time, and as T1 or T2 14% of the time. Since T3 was frequently perceived as T4 (but not vice versa), it appears that the fall at the beginning of both tones is what the participants most readily detected.

The asymmetry of the T3 and T4 errors indicates a bias in favor of T4, so we calculated d-prime scores for each tone as a function of syllable position and focus (Figure 1). As can be seen, when the bias is compensated for, the sensitivity to the two tones is quite similar.

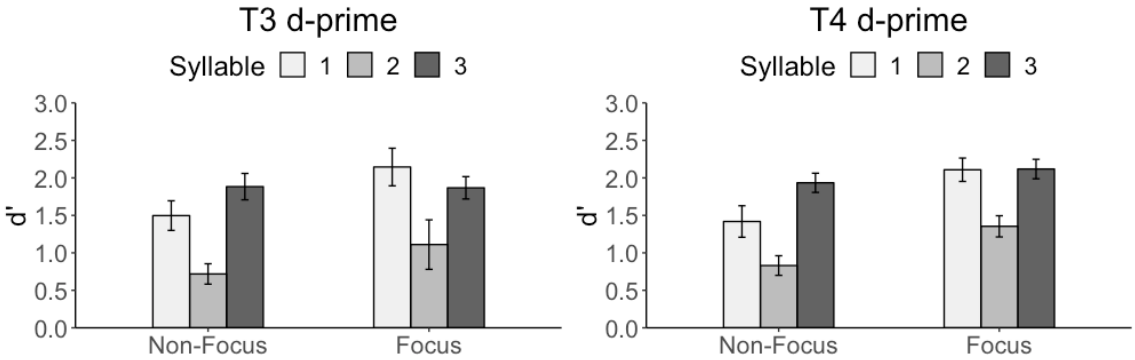

Figure 1: D-prime for T3 and T4 as a function of focus and syllable position.

A two-way ANOVA reveals that the sensitivity to both tones was affected by syllable position (*p*s < .001). Post-hoc tests showed that the sensitivity is significantly lower in the 2nd syllable than in the other two (*p*s < .05), suggesting that the acoustic cues that distinguish the tones are least salient in the word-medial position. In terms of redundancy, this suggests that context may provide the most assistance to the recognition of the second syllable in a tri-syllabic word, despite potentially weaker tone cues. Moreover, the fact that the Focus Condition increased the sensitivity value for T4 ($p = .01$), but not T3, suggests that the acoustic properties cuing focus enhance the clarity of T4, while the same is not true for T3.

Additional insight is provided by examination of the acoustic properties of the syllables extracted from the recorded corpus of all ten speakers (although the present findings are based only on three of the speakers). We ran the Binary Logistic Regression Analyses (BLRAs) with measurements for duration, F0, energy, vowel centralization, and several properties associated with non-modal phonation (given the reported creakiness associated with T3) to reveal to what extent T3 is distinguished from T4 using all of the properties in each syllable position and focus condition, as well as to what extent a property found to be significant contributes to the classification (Table 1).

Table 1. BLRAs: Classification Rates for T3 vs. T4 by Syllable and Focus Condition.

Syllable	Focus Condition	Overall Classification	Top 2 Individual Classifiers
1	Non-Focused	82%	HNR (68%), Enr (63%)
	Focused	90%	F0 (84%), $\Delta F0_{3\text{-}1}$ (71%)
2	Non-Focused	84%	HNR (73%), Enr (70%)
	Focused	89%	F0 (79%), Enr (75%)
3	Non-Focused	89%	HNR (79%), F0 (74%)
	Focused	93%	F0 (83%), Enr (76%)

The overall classifications are all quite robust, and there is a slight increase in the Focus Condition, consistent with its greater perceptual sensitivity. The main cue to the distinction - without focus enhancement - in all three syllables is the phonation property, Harmonic-to-Noise Ratio (HNR). This is followed by Energy (Enr) in Syllables 1 and 2, but F0 in Syllable 3, consistent with observations that T3 is often creaky, leading to reduced energy, and also with a drop in F0 in word-final position. The top classifier in the Focus condition in all syllables is F0, consistent with observations that focus increases the overall pitch range in Mandarin[4], and this, in turn, would further enhance the falling contour of T4. What is not observed, however, is a weaker classification rate in the middle syllable, although the perceptual sensitivity to the tonal contrast is weakest in this position. It may be that the difference is due, at least in part, to the fact that words from only 3 speakers were used in the current analysis, and/or to the fact that the d' calculations included all tones, while the BLRAs specifically tested T3 vs. T4, possibilities that warrant examination with additional data.

References

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Phonemes or Allophones? The phonological status of [tʃ, dʒ] in Brazilian Portuguese

Andressa Toni

Background: This study analyzes the phonological status of [tʃ, dʒ] in Brazilian Portuguese (BP) by focusing on psycholinguistic cues, since the contextual distribution of these phones is becoming opaque in the language. Post-alveolar affricates are usually analyzed as underlying /t, d/ alveolar stops that undergo palatalization in BP (Cagliari, 1997; Cristófaro-Silva, 2003). The alveolar stop palatalization process is a rule that applies when /t/ or /d/ are adjacent to a high front vowel in the word domain – but the process direction and the nature of the triggering high front vowel are variable along the Brazilian dialects. In the dialect spoken in São Paulo city both an underlying /i/ and the phonetic [ɪ] (derived from an unstressed mid-high /e/) can trigger palatalization when after a /t, d/ onset, whereas in some South dialects like the one spoken in Curitiba only an underlying /i/ can trigger palatalization *(cf. a, b on Table 1)*. The most permissive dialects for palatalization are spoken in Northeast cities like Aracaju, where the glide [j] and the nasal vowel [ĩ] can trigger palatalization even when before the alveolar stops (*cf. c, d*). On the other hand, the strictest dialects are spoken in cities like Florianópolis, where no vowels can trigger palatalization. Table 1 below exemplifies these characteristics, comparing possible palatalization contexts across dialects in examples a-d; examples e-h show contexts blocked for all dialects:

Context	**_ [i, ɪ]**	**_ [i]**	**_ [i, ɪ]; [j, ĩ] _**	*****	**Gloss**
Dialect	*São Paulo*	*Curitiba*	*Aracaju*	*Florianópolis*	
a. **ti**a	[ˈ**tʃi**a]	[ˈ**tʃi**a]	[ˈ**tʃi**a]	[ˈ**ti**a]	'aunt'
b. tape**te**	[taˈpe.**tʃɪ**]	[taˈpe.**tɪ**]	[taˈpe.**tʃɪ**]	[taˈpe.**tɪ**]	'rug'
c. do**id**o	[ˈdo**j.d**ʊ]	[ˈdo**j.d**ʊ]	[ˈdo**j.dʒ**ʊ]	[ˈdo**j.d**ʊ]	'crazy'
d. l**ind**o	[ˈl**ĩ.d**ʊ]	[ˈl**ĩ.d**ʊ]	[ˈl**ĩ.dʒ**ʊ]	[ˈl**ĩ.d**ʊ]	'beautiful'
e. **tri**go	[ˈ**tɾi**.gʊ]	[ˈ**tɾi**.gʊ]	[ˈ**tɾi**.gʊ]	[ˈ**tɾi**.gʊ]	'wheat'
f. m**it**o	[ˈm**i.t**ʊ]	[ˈm**i.t**ʊ]	[ˈm**i.t**ʊ]	[ˈm**i.t**ʊ]	'myth'
g. **ded**o	[ˈ**de.d**ʊ]	[ˈ**de.d**ʊ]	[ˈ**de.d**ʊ]	[ˈ**de.d**ʊ]	'finger'
h. **tet**o	[ˈ**tɛ.t**ʊ]	[ˈ**tɛ.t**ʊ]	[ˈ**tɛ.t**ʊ]	[ˈ**tɛ.t**ʊ]	'roof'

Table 1: Palatalization contexts in BP

Contextual opacity: We observe that /t, d/ can be phonetically realized as [t, d] or optionally as the conditioned allophones [tʃ, dʒ] in BP. However, unconditioned [tʃV, dʒV] patterns have been observed in some common words in all dialects of the language, like *tchau* [ˈtʃaw] 'bye', and in new words and slangs (*tchutchuca* [tʃuˈtʃu.kɐ] 'pretty woman (slang)'). Total assimilation of the high front vowel in unstressed diphthongs can also lead to the surface of opaque [tʃV, dʒV] patterns, like in *sí**tio*** [ˈsi.**tʃʊ**] 'ranch', *mé**dia*** [ˈmɛ.**dʒɐ**] 'mean value'. Some of the [tʃV, dʒV] patterns can even form minimal pairs with [tV, dV] (regardless their reduced number), as in *tal* [ˈtaw] 'such like' versus *tchau* [ˈtʃaw] 'bye'; *TAM* [ˈtãⁿ] 'name of an air flight company' versus *Tchan* [ˈtʃãⁿ] 'name of a musical group'. Considering these unconditioned occurrences of [tʃ, dʒ], authors like Cristófaro-Silva (2006) argue for the phonemic status of [tʃ, dʒ] based on the opaque distribution of these phones. For authors like Cagliari (2009), the allophonic nature of BP affricates would only be noticed by the child with proper school education, when children realize that [tV, tʃi] and [dV, dʒi] should be written with the same letters, T or D (although some dictionaried words have TCH representing [tʃ], as in *tchau* 'bye', *atchim!* 'achoo!'). **Proposal:** In order to verify if the affricate segments maintain their allophonic status in BP, the present study analyzes data from three sources: i) a priming procedure testing if word-final [t] and [tʃ] auditory primes would equally affect the recovery time of word-final /t/ pictures stimuli; ii) a longitudinal study observing the developmental path of [tʃ, dʒ] segments in data from three Brazilian children; and iii) data from

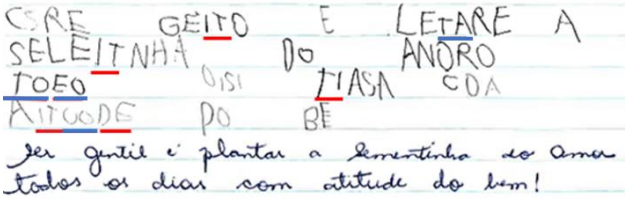
the literacy development of one of the children from the longitudinal study. Data from São Paulo's dialect were analyzed. The predictions made for both allophonic and phonemic status of the affricates are summarized on the following table. Results are discussed below:

	Priming	**Segmental development**	**Literacy development**
Allophones	Stops would prime both stops and affricate stimuli	Stops would be the primary substitutes of affricate sounds	T, D would represent both [t, tʃ] and [d, dʒ] sounds
Phonemes	Stops would prime only stop stimuli	Stops or fricatives could equally substitute affricate sounds	TCH, DJ (or others) would represent [tʃ, dʒ] sounds

Priming test: 9 adults, 6 reading children and 10 preschoolers were tested on an auditory-picture priming procedure with 4 prime conditions: final [tʃɪ] (priming [ˈnɔɾ.**tʃɪ**] 'North' for stimuli /fɔɾ**te**/ 'strong'); final [tɪ] ([ʒẽ^{n}.**tɪ**] 'people' for /den**te**/ 'tooth'); final [tV] ([ɪsˈpa.**dɐ**] 'sword' for /eska**da**/ 'stairs'); no prime ([gaˈha.**fɐ**] 'bottle' for /pɾezen**te**/ 'gift'). /te/-ending stimuli was expected to be palatalized in the participants responses. The goal of the test was to observe if both [tɪ] and [tʃɪ] would equally prime the /te/-ending stimuli palatalized to [tʃɪ]. We also examined if [tɪ] and [tʃɪ] would have similar priming effects as the unambiguous [tV] contexts. For all groups, recovery times were not significantly different for primes [tɪ], [tʃɪ] and [tV], but were significantly different when compared to the no prime condition (Mean values: *Adults*: [tɪ] 1.05s; [tʃɪ] 1.027s; [tV] 0.88s; no prime 1.44s; *Reading children*: [tɪ] 1.33s; [tʃɪ] 1.47s; [tV] 1.07s; no prime 1.84s; *Preschoolers*: [tɪ] 1.49s; [tʃɪ] 1.35s; [tV] 1.18s; no prime 1.67s). As [tɪ] was expected to prime [tʃɪ]-ending stimuli only if both were allophones from the same phoneme, and as both [tɪ] and [tʃɪ] were not significantly different than [tV] contexts, these results suggest an allophonic status for the affricates in São Paulo's dialect.

Segmental development: Biweekly data from three children were analyzed from their first intended affricate target through [tʃ, dʒ] acquisition (Lz: 1;7-3;3 y.o.; Am: 1;10-3;0 y.o.; Ar: 1;8-2;9 y.o.). Palatalization in /te, de/ were acquired only after /ti, di/. Palatalization contexts were mostly articulated as the actual targets [tʃ, dʒ] (72%), or as alveolar stops /t, d/ (21%, *presen**te*** [peˈzẽ.**tɪ**] 'gift'), and in a less degree as fricatives (***di**nheiro* [**zi**ˈɲe.ɾʊ] 'money'; *quen**te*** [ˈkẽ**ʃ**] 'hot'), alveolar affricates [ts, dz] (***ti**tia* [**tsi**ˈtʃiɐ] 'aunt'), and velar stops (*ves**ti**do* [vɪsˈ**ki**.dʊ] 'dress'). The preference for substituting affricates with stops (instead of equally considering both fricatives and stops as substitute candidates) points to a phonological relationship between /t, d/ and [tʃ, dʒ].

Literacy development: Ar.'s notebooks from the first grade of elementary school were analyzed. As the child failed the first grade, we were able to examine two years of literacy development. All occurrences of T and D were collected and analyzed for their accuracy and substitution patterns. The goal was to observe if [tʃ, dʒ] would be initially written differently than [t, d]. 2,262 occurrences of T, D were collected on the corpus, 498 of them in contexts suitable to palatalization. No occurrences of TCH or other ways of representing affricates were observed. Similar errors occurred in both contexts in comparable proportions ([ˈda.**dʊ**] > DA**D**; [foˈge.**tʃɪ**] > FOGUE**T**). Therefore, orthographic means also could not differentiate [t, d] and [tʃ, dʒ]. Hence, the examined data sign for the allophonic status of alveolar stops and post-alveolar affricates in Brazilian Portuguese.



"Being kind is to grow the little seed of love everyday with good gestures"

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I'm Sorry but Time Travel Isn't Real: Against counterfeeding from the past

Samuel Andersson, Yale University, samuel.andersson@yale.edu

Introduction Wilson (2006) has shown that Optimality Theory with Candidate Chains (OT-CC; McCarthy 2007) can represent so-called counterfeeding from the past (CFFTP), a type of paradox which violates the condition that rule ordering must be transitive. Wolf (2010) argues that several genuine examples of CFFTP are found in the world's languages, thereby seriously challenging parallel phonological theories, as well as serial alternatives which respect transitivity of ordering. I show that all known cases of CFFTP in Wolf (2010) are either unconvincing, or analyzable in rule-based phonology. In one claimed case of CFFTP, syllable structure is involved. In order to avoid a paradox, the data must be recast in purely segmental terms. This is an especially welcome result for Substance-Free Rule-Based Phonology (Bale and Reiss 2018, Hale and Reiss 2008, 2011, among others), where it has been independently suggested that syllables are not part of phonological representations (Samuels 2009).

Counterfeeding from the past An example from Wolf (2010) will serve to illustrate CFFTP and the apparent time travel involved. Samothraki Greek (data from Newton 1972, Kaisse 1975) has rules of r-deletion (intervocalically), mid vowel raising (before /a, o/ among other environments), and glide formation (in hiatus contexts). The rules seem to apply in this order, with r-deletion preceding raising, and raising preceding glide formation:

UR	/méra/	UR	/palé-os/
r-deletion	méa	raising	palíos
raising	mía	glide formation	paljós
SR	[mía]	SR	[paljós]
Translation	'day'	Translation	'old'

Interestingly, glide formation fails to apply to the output of raising if and only if r-deletion applied earlier in the derivation. Without this restriction, [mía] 'day' should become *[mjá]. The lack of glide formation is not caused by phonotactics: [mjá] is attested with the meaning 'one, feminine' from underlying /mía/. Glide formation is thus in a sense counterfed by the r-deletion earlier in the derivational history, leading to the name counterfeeding from the past.

In more abstract terms, with rules A, B, and C, CFFTP occurs when A precedes B, and B precedes C, but A never precedes C even in the derivations where this is expected. This could be accounted for by a different rule ordering C << A << B (where << means 'precedes'), but this violates transitivity: if A << B and B << C, only the order A << B << C is predicted.

Previous explanations OT-CC can account for CFFTP by using precedence (PREC) constraints. Let A' be the faithfulness constraint violated by application of rule A, and C' the correpsonding constraint for C. With the constraint PREC(C', A'), we are penalizing derivations where C' is violated later in the derivational chain than A'. Ranking PREC(C', A') high will produce the desired result: C underapplies if and only if A has applied (see Wilson 2006, Wolf 2010 for details and tableaux; see also Odden 2008 for a demonstration that CFFTP is possible in Sympathy Theory; McCarthy 1999). Sayeed (2016) has since shown that CFFTP can be accounted for in transitivity-respecting rule-based grammars, but only by introducing ad hoc rules, otherwise unattested segments in the language, and Duke of York derivations. Below I will show that much more plausible solutions to the problem of CFFTP are available.

A reassessment In some cases CFFTP can be given a straightforward rule-based analysis. For Samothraki Greek, we apply r-deletion last. Raising now precedes r-deletion, which seems problematic since r-deletion feeds raising. However, we can incorporate an optional r into the

environment of raising, anticipating future applications of deletion. Mid vowel raising was thought to be triggered by following a and o, but we can change raising so that it is triggered by (r)a and (r)o instead. Glide formation then fails to apply to the output of raising since there is no hiatus: the underlying /r/ has not yet been deleted. A derivation for 'day' is shown below (/palé-os/ 'old' is as above):

UR	/méra/
raising / _ (r)a, (r)o	míra
glide formation / _V	------
r-deletion / V_V	mía
SR	[mía]

Wolf's (2010) CFFTP survey reveals no convincing examples of CFFTP which cannot be reanalyzed. In Luiseño, Munro and Benson (1973) cite forms where the rules are applied in a non-paradoxical order, and Kroeber and Grace (1960) cite many classes of exceptions to the relevant 'postlexical' rules. For Attic-Ionic Greek (Adams 1972), the rules involved are not learnable from the synchronically-available input (Sayeed 2016).[1] For Yup'ik a paradox only arises if we attempt to combine ɣ- and ʁ-deletion into one rule, something which is actively argued against for independent reasons by Wolf's reference for this language (Underhill 1976). The final case is Bedouin Hijazi Arabic (Al-Mozainy 1981), which I reanalyze below.

Flat phonology In Bedouin Hijazi Arabic (BHA; Al-Mozainy 1981), CFFTP involves a vowel syncope rule applying in open syllables. However, this rule is paradoxically ordered with respect to resyllabification. If we apply the same reasoning as for Samothraki Greek above, we must reorder the syncope rule: although it applies in open syllables, it must now precede the syllabification algorithm. This paradox can only be resolved if the syncope rule directly encodes, in segmental terms, what counts as an open syllable in BHA. Despite the complex surface consonant clusters of BHA, the syncope rule can be rewritten using nothing more than the ( ) optionality brackets which were already necessary for Samothraki Greek:

i, u → Ø / _(#)(C)(#)V

This type of rule, familiar from pre-syllabic phonological theories (Chomsky and Halle 1968), is precisely what would be expected in Substance-Free Rule-Based Phonology. Within this theory, it has recently been suggested that phonology is flat rather than hierarchical (Samuels 2009), and thus cannot make reference to syllables.

Conclusion Counterfeeding from the past presents difficulties for many theories of phonology by challenging the assumption that process ordering is transitive. Many claimed cases of CFFTP are not convincing examples of a paradox. I have shown how rule-based theories can resolve the remaining paradoxes by using optionality brackets. There are thus no convincing exampes of CFFTP. In some cases, the reanalyses have wider implications, and I have argued that Bedouin Hijazi Arabic behaves exactly as expected if phonology does not make reference to syllables, as in some versions of Substance-Free Rule-Based Phonology.

Selected references Al-Mozainy, H. Q. (1981). *Vowel Alternations in a Bedouin Hijazi Arabic Dialect: Abstractness and stress*. PhD: University of Texas at Austin. Kaisse, E. (1975). A violation of transitivity in Modern Greek. In R. E. Grossman, L. J. San, & T. J. Vance (Eds.), *Papers from the Eleventh Regional Meeting of the Chicago Linguistic Society* (pp. 329–339). Chicago: CLS. Samuels, B. (2009). *The Structure of Phonological Theory*. PhD: Harvard. Sayeed, O. (2016). *Phonological time travel: "counterfeeding from the future."* Paper presented at the LAGB 2016, University of York. Wilson, C. (2006). *Counterfeeding from the past*. Ms. Los Angeles, CA: UCLA. Wolf, M. (2010). *On the existence of counterfeeding from the past*. 84th LSA, Baltimore.

1 Moreover, the paradoxically-ordered rule can only be stated using several arcane notational conventions which have seldom been used outside of the infamous Main Stress Rule in SPE (Chomsky and Halle 1968).