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Why are English Voiced Obstruent Codas Difficult for Mandarin-Speaking Learners? A Bi-Directional OT Account

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Abstract

Employing a bidirectional model of OT, this paper offers a novel analysis of Mandarin learners' acquisition of English codas. It argues that the difficulty of voiced obstruent codas results from their incorrect underlying form established at the beginning stage due to Mandarin phonological and orthographic influence and the reranking of cue constraints which can be made possible only through negative evidence. As cue constraints lie at the interface between phonology and phonetics, the present analysis sheds light on current discussions on interfaces in L2 acquisition. It also provides insights into the role of perception and production in L2 phonology.

English voiced obstruent codas have been found to pose difficulty for Mandarin-speaking learners. For example, Eckman (1981) found the common mistake of schwa epenthesis after voiced obstruent, and Wang (1995) observed the repair strategies of deletion, epenthesis, and devoicing of voiced obstruent. In terms of perception, Flege and Wang (1989) found that Mandarin speakers rely more on burst rather than vocalic duration when perceiving word-final obstruent. In a study on the acquisition sequence of English codas, Broselow and Xu (2004) showed that voiceless obstruent codas are the easiest to acquire, voiced obstruent codas are the most difficult and labial nasal /m/ falls in between.

Two major accounts have been offered to explain Mandarin speakers' particular difficulty with English voiced obstruent codas. Eckman (1981) attributed this to the typological fact that voiced obstruents are more marked in the coda position, therefore difficult to acquire. Working under OT framework, Broselow and Xu (2004) argued that such acquisition difficulty may be caused by perceptual problems. That is, due to the fact that Mandarin does not have a voicing contrast, Mandarin speakers may find it difficult to perceive voiced obstruents in coda position. However, they did not give a systematic account of how perception works in the learners' acquisition process.

In this paper, I take into consideration both the two factors of markedness and perception within a bidirectional model of OT (Boersma, 2009, 2011) and provide a new analysis of Mandarin speakers' acquisition of English codas in order to account for the acquisition sequence as discovered in Broselow and Xu (2004).

MANDARIN AND ENGLISH CODAS

Mandarin has a much more limited range of codas than English. Only coronal nasal /n/ and dorsal nasal /ŋ/ are allowed in Mandarin coda position (Duanmu, 2007). On the contrary, English allows a wide range of consonants in coda, only with the exception of glottal fricative /h/ (McMahon, 2002).

The situation is further complicated by the fact that not all Mandarin consonants are the same as their English counterparts. The most prominent difference lies in obstruents. Phonologically, English has voicing as a distinctive feature whereas Mandarin uses aspiration to distinguish obstruents (Duanmu, 2007). As the minimal pairs in (1) shows, underlyingly, while English has both voiced and voiceless obstruents, Mandarin has aspirated and unaspirated obstruents.

(1) Mandarin obstruents:
bāo /pāu/ 'full' – pāo /pʰāu/ 'toss, dù /tù/ 'degree' – tù /tʰù/ 'rabbit', gū /kū/ 'aunt' – kū /kʰū/ 'cry'

English obstruents:
bee /bi/ - pee /pi/, dip /dɪp/ - tip /tɪp/, goat /gəut/ - coat /kəut/

Acoustic studies have shown that when occurring in word-initial position, the VOT of Mandarin unaspirated obstruents and English voiced obstruents fall in the short lag region while the VOT of Mandarin aspirated obstruents and English voiceless obstruents fall in the long lag region (Chao & Chen, 2008). Therefore, roughly speaking, Mandarin unaspirated /p, t, k/ are correspondent to English voiced /b, d, g/, and Mandarin /p^h, t^h, k^h/ are equivalent to English /p, t, k/. However, this does not mean that the phonetic implementations of obstruents in Mandarin and English are always the same. One big difference is that all Mandarin obstruents are phonetically implemented as voiceless except for in some word-medial positions (Duanmu, 2007).

Given the differences outlined above, in order to master English codas, Mandarin speakers are facing two tasks. First, they need to figure out the phonotactic constraint that obstruents and labial nasal /m/ are allowed in coda position. Besides, they have to know that obstruents are differentiated by voicing rather than aspiration, particularly the phonetic knowledge that English /b, d, g/ can be implemented as voiced sounds word-finally. Therefore, the acquisition of English coda constitutes a phonology-phonetics interface problem for Mandarin-speaking learners.

THEORETICAL FRAMEWORK

Bidirectional OT (Boersma, 2009, 2011)

Different from standard OT (Prince & Smolensky, 1993, 2004) that only has two levels of representations (i.e. underlying form and surface form), Boersma's bidirectional OT has multiple levels of representation. As can be seen in Figure 1, three kinds of representations are assumed in this model: phonological, phonetic, and semantic. Phonological representations are the same as in traditional OT, phonetic representations consist of auditory and articulatory forms, and semantic representations have the levels of morphemes and context. The three types of representations are not standing separately. Phonology and phonetics are connected through auditory and surface forms, and phonology and semantics are related via underlying and morphemic forms. Therefore, this model incorporates the interfaces between phonology and phonetics/morphology.

In accordance with the multiple-level grammar, there are multiple types of constraints (see Figure 1). Besides faithfulness and markedness or structural constraints as proposed in standard OT, there are articulatory constraints, sensorimotor constraints, cue constraints, and lexical constraints. Some constraints only operate on one level of representation while some constraints evaluate the relationship between two levels of representation. For example, cue constraints are concerned with the mapping between auditory and surface forms and hence operate at the phonology-phonetics interface.

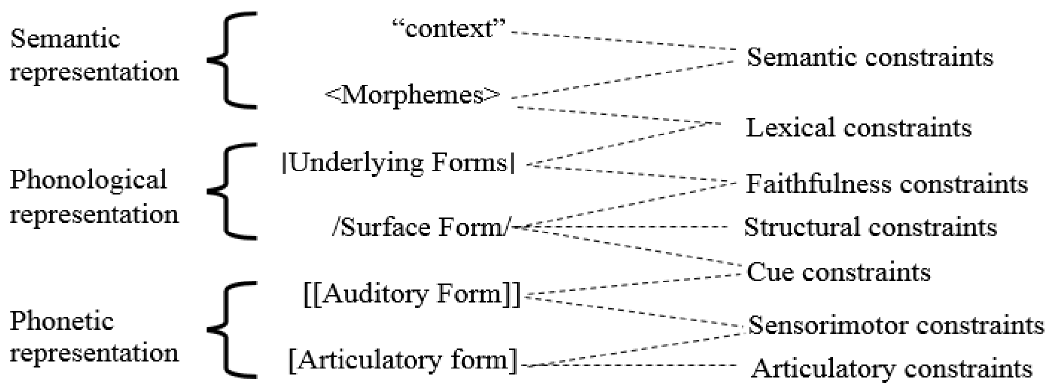

Figure 1. Bidirectional model of OT (Boersma, 2011, p. 34)

Another important characteristic of this model of OT is bidirectionality. It is bidirectional in that it applies to both perception and production. That is, phonological and phonetic perception and production are constrained by the same set of constrains ranked in the same way. Such bidirectionality is also manifested in the operation of constraints. For example, structural constraints can evaluate either the listener's perception of auditory form or the speaker's production of underlying form, i.e. surface form. Similarly, cue constraints not only work on the mapping from auditory to surface form but also the reverse.

Bidirectional OT can operate either serially or in parallel. In both paradigms, listeners start from auditory form to morpheme, and speakers move from morpheme to articulatory form. If the process is serial, there will be intermediate outputs which are independently evaluated by the constraints relating to that particular level. In a parallel process, there is just one output consisting of a set of forms, which is evaluated by all the constraints at one time. This paper follows the parallel paradigm.

From the description above, it can be seen that bidirectional OT is a model incorporating both phonology and phonetics, and both perception and production. As introduced above, Mandarin speakers' acquisition of English coda is a phonology-and-phonetics interface problem, modulated by perception. Therefore, bidirectional OT functions as an excellent vehicle to address this issue.

Gradual Learning Algorithm (Boersma & Hayes, 2001)

The gradual learning algorithm (GLA) is based on Stochastic OT, which assumes that constraints are ranked along a ranking scale on the basis of their specific ranking values. Language acquisition is motivated by errors, that is, the mismatch between the output of learners' current grammar and the perceived input. Each error will only lead to a minor change of the values of relevant constraints. Specifically, the values of those constraints violated by the correct form will be decreased, and the values of those constraints violated by the erroneous form will be increased. The final grammar converges until there are no errors. Since every value adjustment is trivial, the acquisition process is gradual. Although GLA is based on a two-level OT model, the general ideas proposed in the original accounts of GLA are still applicable to the bidirectional model of OT adopted in this paper, as demonstrated in Boersma (2011).

A Heuristic Leaning Mechanism of L2 Phonology

Based on bidirectional OT and GLA as sketched above, I propose a heuristic learning mechanism of L2 phonology in this paper. Following the Full Transfer/Full Access Hypothesis (Schwartz & Sprouse, 1996), I assume that L2 learners' initial constraint ranking in their interlanguage is the same as in their L1. As to the underlying forms of L2 words, given the large amount of written input in instructed SLA, I adopt the view that they are influenced by the written input and their native language orthography (e.g., Bassetti, 2008). For example, when Mandarin speakers see the English word bag, they would represent it as ｜pæk｜ in that Mandarin /p/ and /k/ have the same orthographic forms as English /b/ and /g/.

Both perceptions and production errors induce learning. Perception errors happen if the underlying form mapped from acoustic input is different from the established underlying form. Production errors occur when the produced form is not the same as the correct pronunciation. Boersma (2011) assume that first language learners can automatically detect the variation of their pronunciation from the input. However, I maintain that this will not happen to L2 learners; rather, production errors can only be noticed through negative evidence, either by other people' correction or by their self-monitoring.

CURRENT ANALYSIS

The Acquisition of Voiceless Obstruent Codas and /m/ Codas

At the beginning stage of acquisition, even though their native language does not allow obstruent and labial nasal codas, Mandarin-speaking learners of English can still keep voiceless obstruent and /m/ codas in words' underlying representations due to written input. The underlying form of a voiceless obstruent coda will not be exactly the same as that represented in native English speakers' mental lexicon. Rather, it will be affected by Mandarin orthography and phonology. Specifically, since Mandarin aspirated obstruents /p^h, t^h, k^h/ are spelled the same as English voiceless obstruents /p, t, k/, Mandarin speakers will regard English voiceless obstruents as equivalent to Mandarin aspirated obstruents and represent them as such. For example, the English word neat will have the underlying form ｜nith｜ rather than ｜nit｜ in Mandarin speakers' interlanguage. That is, the obstruent coda is specified for aspiration, but not voicing. Since Mandarin /m/ does not differ from English /m/, it will be represented the same in the interlanguage as in the target language.

Now let's look at how Mandarin speakers' interlanguage grammar develops in response to both perception and production errors with regard to voiceless obstruent and /m/ codas. First, let's focus on perceptual learning. Tableaux in (2) and (3) display the initial ranking in Mandarin speakers' interlanguage, which is the same as in their L1.

As (2) and (3) shows, the structural constraints militating against obstruent codas and /m/ codas as proposed in Broselow & Xu (2004) are ranked higher than faithfulness constraints. The cue constraint */ /[C] prevents a consonantal sound from being unperceived in the surface form and */ə/[ ] prevents an empty sound from being perceived as a schwa. Since Mandarin does not allow obstruent coda and labial nasal coda, I assume the two cue constraints are ranked below the structure constraints.

(2) Mandarin speakers' perceptual learning of English voiceless obstruent codas: stage 1

[[ni:t^h]]	NoObsCoda	NoLabialCoda	*/ /[C]	*/ə/[ ]	Max	Dep
√ /nit^h/|nit^h|	*! →					
☜/ni/|ni|			* ←			
☜/ni.tə/|nitə|				* ←		

(3) Mandarin speakers' perceptual learning of English /m/ codas: stage 1

[[ti:m]]	NoObsCoda	NoLabialCoda	*/ /[C]	*/ə/[ ]	Max	Dep
√ /tim/|tim|		*! →				
☜/ti/|ti|			* ←			
☜/ti.mə/|timə|				* ←		

Due to the high ranking of the structural constraints against codas, Mandarin speakers will always perceive English words with voiceless obstruent and [m] codas as either coda-less (deletion) or followed by a vowel (epenthesis), though they violate */ /[C] and */ə/[ ]. Since the perceived form (as indicated by ☜) is different from the correct one (as indicated by √ in the tableau), the ranking values of relevant constraints will change. Specifically, the ranking value of NoObsCoda will be decreased (as indicated by the forward arrow) because it militates against the correct form. By contrast, the ranking values of */ /[C] and */ə/[ ] will be increased (as indicated by the backward arrow) because they favor the optimal but incorrect form. Note that faithfulness constraints will not change because neither the optimal candidate nor the correct form violates them. After encountering a large number of perception errors, NoObsCoda will be ranked below */ /[d] and */ə/[ ], and the auditory input will be perceived the same as the one stored in the lexicon. Since no perception errors will occur at this later stage, the ranking will not change any more and perceptual learning will be done.

As far as production learning is concerned, the process is similar to perpetual learning, but in a reverse way. Since both perception and production are constrained by the same grammar, the ranking in (2) and (3) also applies to production at the initial stage. As the tableaux in (4) and (5) show, under this ranking Mandarin speakers will either delete the coda or epenthesize a vowel after the coda, which constitutes a production error. If they can notice this error, for example through their teachers' correction, the learning algorithm will adjust the ranking of relevant constraints. In this particular case, NoObsCoda and NoLabialCoda will be demoted along the ranking scale, and Max and Dep will be promoted.

(4) Mandarin speakers' production learning of English voiceless obstruent codas: stage 1

|nit^h|	NoObsCoda	NoLabialCoda	*/ /[C]	*/ə/[ ]	Max	Dep
√ /nit^h/ [[ni:t^h]]	*! →					
☞/ni/[[ni:]]					* ←	
☞/ni.tə/[[ni:tə]]						* ←

(5) Mandarin speakers' production learning of English /m/ codas: stage 1

|tim|	NoObsCoda	NoLabialCoda	*/ /[C]	*/ə/[ ]	Max	Dep
√ /tim/[[ti:m]]		*! →				
☞/ti/[[ti:]]					* ←	
☞/ti.mə/[[ti:mə]]						* ←

Comparing perceptual learning and production learning, it can be seen that both types of learning involve the demotion of NoObsCoda and NoLabialCoda but they have different effects on cue constraints and faithfulness constraints. Perceptual learning induces the change of cue constraints but production learning faithfulness constraints. Considering the fact that L2 learners have a greater amount of positive evidence than negative evidence, it can be expected that cue constraints */ /[C] and */ə/[ ] will be promoted faster than faithfulness constraints. Therefore, / /[C] and */ə/[ ] will outrank NoObsCoda earlier than Max and Dep. When that happens, no perception errors will occur, as argued above, but production errors still persist. These production errors, if noticed by learners, will further motivate the demotion of NoObsCoda and promotion of Max and Dep. When NoObsCoda is ranked below Max and Dep, learners will correctly produce voiceless obstruent codas. The same process also applies to coda /m/.

The Acquisition of Voiced Obstruent Codas

The establishment of the underlying form of English voiced obstruent codas involves the same process as the other two types of codas. Mandarin speakers will underlyingly represent English voiced obstruents /b, d, g/ as Mandarin unaspirated obstruents /p, t, k/ in the coda position because they are spelled the same in English and Mandarin. For instance, the English word need will be represented as ｜nit｜ with ｜t｜ being specified as unaspirated but unspecified for voicing. Note that this underlying form is different from the underlying form of the English word neat ｜nit｜ which has the feature [-voi] for ｜t｜.

The perceptual learning of voiced obstruent codas is similar to that of voiceless obstruent codas, but involves more constraints. As the tableau in (6) shows, besides NoObsCoda, a more specific structural constraint NoVcdObsCoda is involved. Moreover, there are more cue constraints involved, such as the cue constraint */-voi/[lengthened vowel] that bans an obstruent from being perceived as voiced if the preceding vowel has long duration. Because voicing is not contrastive in Mandarin, it is unranked with */+voi/[lengthenedvowel]. */-voi/[periodic] and */+voi/[periodic] are another two relevant constraints which militate against a sound with voicing closure being perceived as having the feature voicing specified. At the beginning stage these cue constraints are not violated by the correct pair of forms /nit/｜nit｜ because /t/ is not specified for voicing. The higher ranking of NoObsCoda and NoVcdObsCoda results in the optimally perceived form being either coda-less or inserted with an illusory vowel. Facing such errors, perceptual learning will begin. As can be expected, after NoObsCoda is demoted below */ /[C], */ə/[ ], the correct form /nit/｜nit｜ will win out. Then the ranking will not incur any perception error and perceptual learning will stop. Note that at this stage of acquisition, NoVcdObsCoda is not demoted because voicing is not specified in the underlying representation and hence the correct form does not violate NoVcdObsCoda. Its effect will become visible in later stages.

(6) Mandarin speakers’ perceptual learning of English voiced obstruent coda: stage 1

[[ni::d]]	NoObs Coda	NoVcd ObsCoda	*/ / [C]	*/ə/[ ]	*/-voi/ [periodic]	*/+voi/ [periodic]	*/-voi/ [lengthened vowel]	*/+voi/ [lengthened vowel]
√ /nit/|nit|	*! →							
☜/ni/|ni|			* ←					
☜/nitə/|ni.tə|				* ←				

The initial stage of production learning of voiced obstruent codas is also very similar to that of voiceless obstruent codas. As can be seen in tableau (7), the optimal output either has the coda deleted or a vowel inserted due to the higher ranking of the constraint requiring no obstruent codas. Such production errors will thus lead to the demotion of NoObsCoda and promotion of Max and Dep.

(7) Mandarin speakers' production learning of English voiced obstruent coda: stage 1

|nit|	NoObs Coda	NoVcd ObsCoda	*/-asp/ [periodic]	Max	Dep	*/+voi/ [periodic]	*/+voi/ [nonperiodic]
√/nit/ [[ni:d]]	*! →		*→				
/nit/ [[ni:t]]	*!						
☞/ni/ [[ni:]]				* ←			
☞/ni.tə/ [[ni:tə]]					* ←		

However, even when NoObsCoda is demoted to below Max and Dep, Mandarin speakers' production will still be incorrect. As tableau (7) shows, the second candidate /nit/[[ni:t]] is always better than the correct candidate /nit/[[ni:d]]. Both violate NoObsCoda, but /nit/[[ni:d]] also violates the cue constraint */-asp/[periodic] which prevents unaspirated segment from being phonetically realized as periodic (i.e. with voicing closure). This cue constraint is ranked high in the interlanguage because Mandarin obstruents are phonetically voiceless in most cases. Therefore, no matter how the ranking changes, the correct output /nit/[[ni:d]] will never win out and Mandarin speakers will always devoice voiced obstruents in coda.

Yet, this does not mean that Mandarin speakers will never acquire voiced obstruent codas. As we can see here, the very reason why voiced obstruents cannot surface phonetically is that the feature voicing is not specified in the underlying form. As long as Mandarin speakers can establish the correct underling form, there will be opportunity for them to acquire voiced obstruent codas by adjusting constraint ranking. I hereby assume that in face of constant production mistakes of devoicing obstruents in coda position and the failure to remedy the mistakes by reranking constraints, the learning mechanism will change the underlying form from ｜nit｜ to ｜nid｜ with the feature [+voice] 1

When the underlying form is changed, perceptual learning will resume. As tableau (8) demonstrates, at this point, the perceived form is /nit/｜nit｜ rather than /nid/｜nid｜ because the structural constraint banning voiced obstruent coda is still ranked high. Therefore, perception errors will demote NoVcdObsCoda. The ranking of cue constraints will change too. Since voicing feature is specified in the phonological representations now, the cue constraints */-voi/ [periodic], */+voi/[periodic], */-voi/[lengthened vowel] and */+voi/[lengthened vowel] become relevant. Specifically, when */-voi/[periodic] outrank NoVcdObsCoda, Mandarin speakers will perceive them correctly[2].

(8) Mandarin speakers' perceptual learning of English voiced obstruent coda: stage 2

[[ni::d]]	NoVcd ObsCoda	NoObs Coda	*/-voi/ [periodic]	*/+voi/ [periodic]	*/-voi/ [lengthened vowel]	*/+voi/ [lengthened vowel]
√/nid/|nid|	*!→	*		*→		*→
☜/nit/|nit|		*	*←		*←	

As far as production is concerned, Mandarin speakers still make production errors when the correct underlying form is established. Tableau (9) demonstrates the grammar at this stage. Deletion and epenthesis will not happen because of the higher ranking of Max and Dep. Although devoicing violates Ident, it is still the preferred strategy to deal with voiced obstruent codas because Ident is ranked lower than NoVcdObsCoda. Therefore, /nit/[[ni:t]] is better than /nid/[[ni:d]]. The errors will consequently motivate an increase in the ranking value of Ident

[1] How the underlying form changes is crucial in the learning algorithm. Another possibility is that it is relevant to the acquisition of obstruents in general. That is, when Mandarin speakers learn that voicing is a distinctive feature for obstruents, they will have voicing feature specified in the underlying form. Discussion of this goes beyond the scope of this paper

[2] This predicts that Mandarin speakers rely more on voicing rather than vowel duration to detect voicing contrast in coda, which is different from the strategy used by native speakers. Since periodicity is also related with aspiration noise or burst, this prediction is supported by Flege & Wang's (1989) finding that Mandarin speakers rely more on burst rather than duration when perceiving word-final obstruent.

and a decrease in the value of NoVcdObsCoda. The change also involves two cue constraints */-asp/[periodic] and */+voi/[periodic] which prevents underlyingly unaspirated and voiced segment to be phonetically implemented as voiced. As mentioned before, because in Mandarin obstruents are mostly phonetically realized as voiceless and voicing is not contrastive, */-asp/[periodic] is ranked high and */+voi/[periodic] is ranked low in the grammar. Since they are violated by the correct output, they will also be demoted.

(9) Mandarin speakers' production learning of English voiced obstruent coda: stage 2

|nid|	NoVcd Obs Coda	Max	Dep	NoObs Coda	*/-asp/ [periodic]	Ident	*/+voi/ [periodic]	*/+voi/ [nonperiodic]
√/nid/[[ni:d]]	*!→			*	*→		*→	
☞/nit/[[ni:t]]				*!		*←		
/ni/[[ni:]]		*						
/ni.tə/[[ni:tə]]			*					

When Ident is promoted to a position above NoVcdObsCoda as in (10), the optimal surface form will keep the voicing feature of the word, i.e. [+voice]. However, phonetically, it is still devoiced because devoiced auditory form incurs less serious constraint violation than voiced auditory form. As tableau (10) shows, the correct output /nid/[[ni:d]] violates */-asp/[periodic] while the optimal one /nid/[[ni:t]] violates */+voi/[nonperiodic] which militates again mapping from voiced surface form to voiceless auditory form. Since */-asp/[periodic] ranks higher than */+voi/[nonperiodic], /nid/[[ni:t]] wins over /nid/[[ni:d]], resulting in devoicing of voiced obstruent codas. If given more negative evidence, the learners will continue demoting */-asp/[periodic] and promoting */+voi/[nonperiodic] until their positions are reversed.

(10) Mandarin speakers' production learning of English voiced obstruent coda: stage 3

|nid|	Max	Dep	Ident	NoVcd Obs Coda	NoObs Coda	*/-asp/ [periodic]	*/+voi/ [nonperiodic]	*/+voi/ [periodic]
√/nid/[[ni:d]]				*	*	*→		*→
☞/nid/[[ni:t]]				*	*		*←	
/nit/[[ni:t]]			*!		*			

Comparison of acquisitions of the three types of codas

On the basis of the above analysis, we can briefly summarize the acquisition tasks of the three types of codas as follows: 1) for voiceless obstruent codas, NoObsCoda must be demoted below Max and Dep; 2) for /m/ codas, NoLabialCoda must be demoted below Max and Dep; 3) for voiceless codas, NoObsCoda and NoVcdObsCoda must be demoted below Max, Dep and Ident, and */-asp/[periodic] must be demoted below */+voi/[nonperiodic].

Then the question is why voiceless obstruent codas are the easiest and voiced obstruent codas are the most difficult to acquire. Since acquisition is motivated by errors, the rate of acquisition is related with the number of errors which is in turn dependent on the amount of input. Therefore, to answer this question, we need to first of all know the frequency of the three types of codas. To make my analysis comparable to previous research, I adopt the frequencies of monomorphemic coda types calculated by Kessler and Treiman (1997) as cited in Broselow and Xu (2004): voiceless obstruent codas 41%, voiced obstruent codas 22%, and labial codas (including /m/) 21%. Given these frequencies, NoObsCoda is the constraint that is demoted the most quickly because it is violated by words with either voiced or voiceless obstruent codas, that is, 64% of monomorphemic words (41% + 22%). Since the production of voiceless obstruent codas only requires the demotion of NoObsCoda to below Max and Dep, they are thus the first to be acquired, a prediction consistent with Broselow & Xu (2004). Under the analysis of Broselow and Xu (2004), however, voiced obstruent codas and /m/ codas are of the same difficulty because NoVcdObsCoda and NoLabialCoda are violated by similar amount of words (22% vs. 21%). This is why they appeal to perceived frequency. That is, voiced obstruent codas are more difficulty to perceive than /m/ codas, resulting in a lower frequency.

With current analysis, the relative difficulty of voiced obstruent codas and /m/ codas can be explained naturally without resort to perceived frequency, a concept hard to operationalize. First of all, acquiring /m/ and voiced obstruent codas requires NoLabialCoda and NoVcdObsCoda to be below Max and Dep. While NoLabialCoda can be demoted in both perceptual and production learning (tableau 3 and 5), the value of NoVcdObsCoda cannot be changed due to the wrong underlying form (tableau 6 and 7). As a result, when the correct underlying form of voiced obstruent codas is established, NoLabialCoda is already ranked lower than NoVcdObsCoda and hence closer to Max and Dep.

Second, apart from Max and Dep, NoVcdObsCoda needs to be demoted below Ident for voiced obstruent codas to be produced. Because the production learning of all three types of codas (tableau 4, 5 and 7) involves Max and Dep moving up the ranking scale but only the production learning of voiced obstruent codas involves Ident (tableau 9), Max and Dep will be promoted faster than Ident. In other words, the distance between NoLabialCoda and Max and Dep is shorter than that between NoVcdObsCoda and Ident. Therefore, it is reasonable to expect that NoLabialCoda will be demoted to below Max and Dep earlier than NoVcdObsCoda will be demoted to below Ident.

Third, cue constraints need to be changed for the correct production of voiced obstruent codas but not for /m/ codas and such change can only occur in production learning (tableau 9 and 10). As assumed in our learning mechanism, only when there is negative evidence can production errors induce learning. Unnoticed errors will not help L2 learners develop their grammar. However, negative evidence is rare in a foreign language context. Moreover, in informal speech voiced obstruent codas are usually devoiced or even deleted by native English speakers (Flege & Wang, 1989). Thus, the learner may not consider devoicing as an error. These factors make the adjustment of the two cue constraints */-asp/[periodic] and */+voi/[nonperiodic] at a slow rate.

Given these reasons, it is reasonable to expect that /m/ coda is easier to master than voiced obstruent codas.

CONCLUSION

In this paper, I offer a new analysis of Mandarin speakers' acquisition of English codas within the framework of bidirectional OT (Boersma, 2009, 2011). Specifically, I provide an account of why voiced obstruent codas are more difficult than voiceless obstruent codas and /m/ codas. The difficulty lies in several factors. One reason is the establishment of wrong underlying representation of voiced obstruent codas as a result of native language phonological and orthographic interference. Mandarin learners need to change it to the correct form in order to produce voiced obstruent codas. Moreover, besides structural and faithfulness constraints, acquisition of voiced obstruent codas also involves the reranking of some cue constraints, which can only be made possible through negative evidence.

The present analysis has several implications for L2 phonology research. Since in bidirectional OT cue constraints are at the phonology-phonetics interface, the fact that they contribute to the difficulty in acquiring voiced obstruent codas lends support to the current view that knowledge at interfaces is difficult for L2 learners (Sorace, 2006). Furthermore, by considering both perceptual and production learning in bidirectional OT, the analysis makes it possible to formalize the role of perception and production in L2 phonological development. It shows that perception can greatly help grammar restructuring in interlanguage yet production is still needed to fully acquire the target language.

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