

# ASYMMETRICAL EQUIVALENCE CLASSIFICATION – CLUSTER AFFRICTION VS. LENIS STOPS IN THE SPEECH OF POLISH LEARNERS OF ENGLISH

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## **Abstract:**

According to the Speech Learning Model (Flege 1995), successful L2 phonological acquisition is facilitated by the formation of new phonetic categories in the L2. However, category formation may be hindered by equivalence classification, wherein speakers perceptually merge L1 and L2 sounds. This study examines L1 Polish learners of English, including a phonetic parameter that has received minimal attention: affrication of /tr-dr/ clusters in English. Two groups of speakers, comprising B1 level and C2 level learners, produced word lists containing both initial /tr-dr/ clusters, as well as singleton voiced stops /b, d, g/. The results revealed an asymmetry: both groups failed to suppress pre-voicing in /b, d, g/, but were successful in producing affricated clusters. A new category has therefore been formed for the clusters, but not for the singleton stops. Phonological implications of this finding are discussed.

**Keywords:** Speech Learning Model, Polish phonetics, equivalence classification, Onset Prominence

## **1. Introduction – equivalence classification and its phonological insight**

One of the main focuses of L2 speech research has been the identification of factors that contribute to success, or lack thereof, in L2 phonological acquisition. These factors have included age of arrival (AoL), length of residence (LoR), L1 background, additional languages, just to name a few (Munro et al. 1996; Saito and Brajot 2013; Flege 1988; Bongaerts et al. 1997; Baker 2010). A common and expected finding is that speakers with earlier AoL, or longer LoR, have more success in acquiring difficult sounds in the L2, as measured by either acoustic studies, or listener ratings (Antoniou et al. 2010; O'Brien 2016; Kornder and Mennen 2021). In most of this research, the phonological status of the particular phonetic variable under study is typically taken as a given. As a result, not much

attention has been devoted to a different question: what can L2 speech data tell us about the phonologies of the interacting languages?

This phonological question may be addressed by considering an important principle of one influential model of L2 speech acquisition – the Speech Learning Model (SLM; Flege 1995). In the SLM, the primary source of cross-linguistic phonetic interaction (CLI) is the principle of *equivalence classification* (Flege 1987). It states that if the new L2 sound is different enough from an already existing L1 category, a new and separate L2 category for it will be formed, leading to minimal CLI between them. By contrast, if the L2 sound is deemed to be similar to an L1 category, the learner will perceptually link them and the phonetic details distinguishing them will be tuned out. This opens the door to CLI, whose effects are claimed to be bi-directional. It is predicted that if equivalence classification takes place, we might expect L1 interference in L2, leading to foreign accentedness, as well as L2 effects on L1, resulting in phonetic drift (Chang 2012). Since the SLM is based on perception, which is governed by language-specific phonologies (e.g. Boersma & Hamann 2009), by looking at CLI we can gain insight into the phonologies of the interacting languages. Stated briefly, the presence of CLI may be taken as evidence for phonological equivalence across languages.

Interestingly, some studies have found that CLI can be observed in one phonological dimension but not another. For instance, phonetic studies dealing with Voice Onset Time (Lisker and Abramson 1964) in language pairs with two-way contrasts, usually attest more CLI for the voiced series relative to the voiceless one (see Schwartz (2022a) for Polish and English, Herd et al. (2015) for American English and Spanish, Sučková (2018) for Czech and English, Simon (2009) for Dutch and British English, Kang et al. (2016) for Tagalog and English). The results cited above suggest therefore that equivalence classification effects can be asymmetrical. Asymmetrical equivalence classification in turn implies asymmetrical phonological correspondences across languages. In the aforementioned two-series laryngeal contrasts it appears that voiced stops are perceptually linked and no new category is formed. Therefore, we may assume similar phonological representations for pre-voiced and unvoiced /b, d, g/. In turn, as CLI is minimal in the voiceless series, we may assume that a new category is formed for /p, t, k/, suggesting different representations for plain and aspirated voiceless stops.

SLM-inspired explanations based on equivalence classification most commonly refer to L1-L2 equivalence between single sounds, or phones as they are referred to by Flege (1995). By contrast, to the best of our knowledge, the SLM's postulates have not been applied to the question of whether CLI may be observed between sequences of sounds, such as consonant clusters. With regard to word-initial clusters, English is known to exhibit a number of cluster-induced allophonic processes that are absent from other languages. One of these, the affrication of /tr/ and /dr/ onsets (e.g. in words such as *train* or *drive*), will be the focus of the present study, a production experiment on the speech of L1 Polish learners of English. We examine whether L1 Polish learners of English are

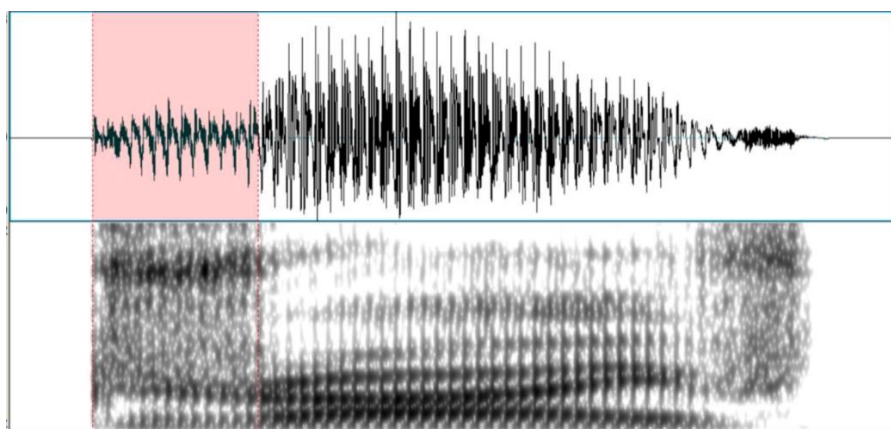
successful in producing native-like affrication of the L2 clusters. Further, we compare the rate of successful cluster productions with the rate of production of unvoiced initial lenis stops in English, which as mentioned above has been shown to be particularly prone to CLI that is attributable to equivalence classification.

This paper proceeds as follows. Section 2 provides background on the production of initial /tr/ and /dr/ clusters in English and Polish, along with the production of initial lenis (voiced) stops in the two languages. Section 3 describes the acoustic experiment and presents its results. Section 4 considers the phonological implications of the results, with a particular focus on the prosodic representation of clusters in the two languages.

## 2. Background

### 2.1. /tr/ and /dr/ onsets in English and Polish

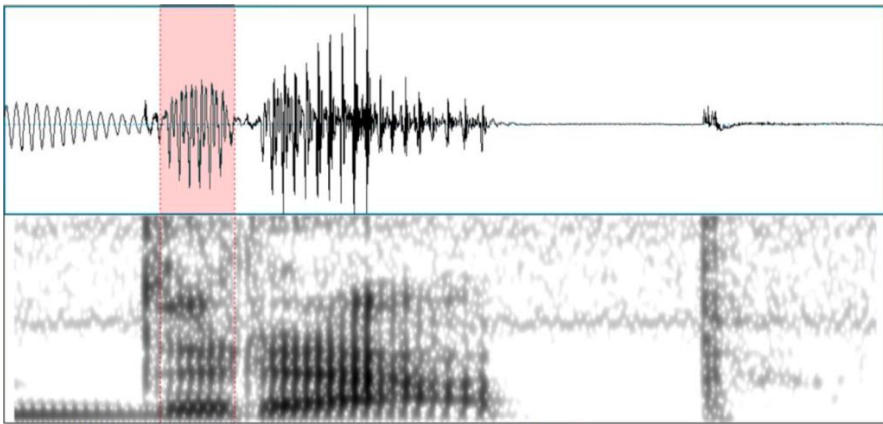
Word initial /tr/ and /dr/ clusters in English, which in principle combine an alveolar stop with an alveolar or post-alveolar approximant, are known to be characterized by affrication. Textbooks of English pronunciation draw attention to the fact that /r/ following an alveolar stop is usually realized as a fricative, with the stop slightly retracted (e.g. Cruttenden 2014: 192; Wells 2011). Additionally, the fricativized /r/ is devoiced after the voiceless onset. In textbook descriptions of English the clusters are usually transcribed as [tʃ], [dʒ]; Cruttenden additionally uses the IPA diacritic for raising - [tʃ̠] and [dʒ̠]. He also explicitly advises foreign learners not to confuse these fricativized realisations with the affricates /tʃ/ and /dʒ/ (Cruttenden 2014: 192), while Carley and Mees (2020: 23), in their textbook on American English pronunciation, describe those sequences as “phonetic affricates”. Figure 1 provides an acoustic display *drive* spoken by a native speaker of English. The affrication is clearly visible as fuzziness on the waveform, and noise in the upper portion of the spectrogram immediately after the release of the stop.



**Figure 1.** Waveform/spectrogram display of *drive* produced by a native speaker of English.

Affrication of /tr-/dr/ clusters is one of a number of allophonic processes that are said to apply to word-initial rising sonority onsets in English, the others being approximant devoicing (e.g. *clean* [kʎi:n], *twin* [twɪn]) and j-coalescence (e.g. *tune* /tju:n/ > [tʃu:n]). A common thread uniting all of these processes is that they are induced by relatively synchronous productions of the clusters. In other words, the processes typically are the product of simultaneous or near-simultaneous articulatory gestures. Notably, the phonetic synchronicity of English onset clusters, visible in the acoustic display in Figure 1, has been documented in a number of articulatory studies using electromagnetic articulometry (Browman and Goldstein 1989; Marin and Pouplier 2010; Tilsen et al. 2012).

In contrast to English, available descriptions of Polish suggest that onset clusters in the language are characterized by asynchronous articulation – i.e. there is greater temporal separation between the consonants in the cluster. Notably, textbook descriptions (Dłuska 1986; Dukiewicz and Sawicka 1995) observe that the types of processes described above for English are absent. On the contrary, Dłuska (1986: 121) notes that Polish onset clusters, particularly those containing /r/, are frequently interrupted by so-called ‘intrusive’ vowels. Figure 2 provides an acoustic display of Polish *drap* ‘scratch’. The intrusive vocoid is selected in the display.<sup>1</sup> Intrusive vowels, which interrupt consonant clusters are generally not perceived by the speakers who produce them (Hall 2006) are a clear sign of asynchronous cluster articulation. Additional experimental studies documenting asynchronous Polish onset clusters include Świąciński (2012) and Hermes et al. (2017).

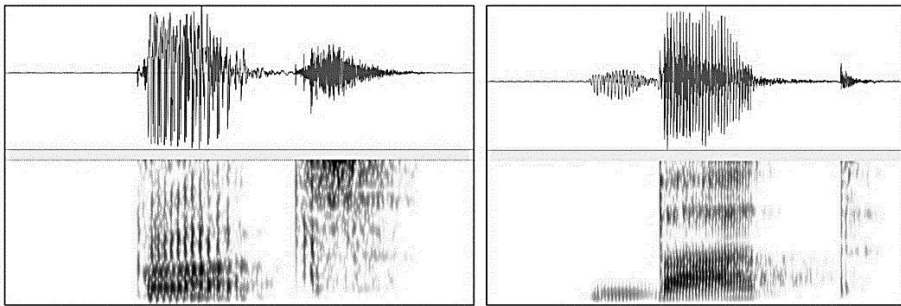


**Figure 2.** A spectrogram of the word *drap* ‘scratch’ produced by a native speaker of Polish.

<sup>1</sup> A reviewer raises an interesting question about how much of this vocoid may ‘belong’ to the /d/ and how much to the /r/, noting that similar vocoids may also be observed in singleton initial /r/. The main point here is that the vocoid is a sign of separation between the two consonants, so the question is not directly relevant to our argument. However, if forced to assign the vocoid to one consonant or the other, we would be inclined to assign it to the /r/, for the reason that the reviewer mentions.

## 2.2. Initial voiced stops in English and Polish

While a majority of research into L2 English stop production focuses on voiceless stops (e.g. Zampini 1998, Waniek-Klimczak 2011), which in English are aspirated and characterized by long VOT, the production of English voiced stops also differs dramatically from learners of many L1 backgrounds, including Polish. Figure 3 illustrates voiced stops in English (left) and Polish (right) on the example of /b/. We can observe positive VOT of 10ms in the English word *but* [bʊt] (top right), while the Polish word *bat* ‘a whip’ [bat] (bottom right) displays negative VOT values (i.e. voicing-lead) of -113ms, followed by a burst and some accompanying noise, which indicates the release of the closure.



**Figure 3.** Word-initial /b/ in English *but* (left) and Polish *bat* ‘whip’ (right).

## 2.3. Asymmetrical CLI in the speech of Polish learners of English – initial stops

The goal of the study described in the following section is to determine whether initial voiced stop production and initial /tr/-/dr/ cluster production are characterized by asymmetrical CLI in the speech of Polish learners of English. An analogous asymmetry has been observed in initial singleton stop production (Schwartz 2022a; Wojtkowiak 2022) – a greater degree of cross-language phonetic interaction is usually found in the voiced series of stops than the voiceless series. These findings held both in studies of L2 acquisition, as well as in studies of L1 phonetic drift (cf. Chang 2012). For example, in the Schwartz (2022a) study, although both B1-level students and C2-level L1 Polish speakers produced English voiceless plosives with long VOT, suggesting successful acquisition of aspiration, pre-voicing was present in both groups’ production of /b d g/. Meanwhile, Wojtkowiak (2022) concentrated on L1 phonetic drift – changes in L1 production induced by exposure to a second language – and again observed this asymmetry. In a longitudinal study of first-, second-, and third-year university students of English, in both a word-reading and sentence-reading task, the voiceless category remained relatively unaffected by phonetic training in L2 English. In contrast, the voiced series showed notable effects of drift, with negative VOT in Polish undergoing progressive shortening, or being lost

altogether. Notably, similar findings have also been observed for a number of other L1-L2 pairings (see Schwartz 2022a for discussion).

On the basis of the above-described studies of initial stops, we may conclude that equivalence classification governs production of the voiced series, but not the voiceless series. If we consider the implications of equivalence classification for the phonologies of the interacting languages, this suggests that voiced initial stops in Polish and English are phonologically equivalent, but voiceless stops are not. That is, L1 Polish speakers perceptually link Polish and English /b d g/, but form a new category for /p t k/. By the same token in the present study, if Polish learners of English successfully produce affrication of /tr/-/dr/ onsets, we can assume a new category has been formed for the clusters. This in turn would imply that the clusters constitute phonologically different structures in English and Polish. If on the other hand cluster production is subject to CLI, it can be claimed that equivalence classification has taken place, and that the phonological representations of these structures are identical. We will return to these issues in Section 4.

### 3 The present study

In what follows, we describe a production experiment on initial lenis stops and initial /tr/-/dr/ clusters in the speech of L1 Polish learners of English. The research questions underlying our study are stated below.

- RQ1 – As with previous studies (Schwartz 2022a; Wojtkowiak 2022), do L1 Polish learners of English show a significant degree of CLI in lenis stop production, manifested as a large number of items produced with L1-style pre-voicing?
- RQ2 – Do Polish learners of English show a significant degree of CLI in cluster production, manifested as a large number of items produced without affrication?
- RQ3 – Will the level of proficiency in English, supplemented with training in English pronunciation, interact with the results for RQ1 and RQ2?

#### 3.1. Participants

Our participants can be subdivided into two groups. The first group (Teachers) consisted of 14 Professors and PhD students (6 male and 8 female, aged 27-45, median age: 32) working at the Faculty of English of Adam Mickiewicz University in Poznań. All of them had undergone phonetic training in L2 English prior to their employment and their overall proficiency may be described as native-like (C2 according to *CEFR*; Council of Europe 2001), with none of the

typical features associated with Polish-accented English (e.g. final devoicing, vowel substitutions, substitutions for the dental fricatives; see Gonet and Pietroń (2004)). The nature of the phonetic training in which this group had taken part entails two years of courses in practical phonetics (i.e. drilling exercises designed so as to acquire all British or American segments that lasts one academic year, followed by another year when the students learn suprasegmental features of English and practice intonation, connected speech processes, etc.), as well as a theoretical course in English Phonetics and Phonology that lasts one year. The participants received bookstore vouchers for taking part in the experiment (=20PLN each).

The second group (Students) comprised 20 B1-level students enrolled in the first year of the English philology program. In order to be accepted into the program, they all had to pass their high school advanced English exam and at the time of the recordings (i.e. the first two weeks of the academic year) they were only just starting phonetic training in English. They were all native speakers of Polish, claiming not to be fluent in any other foreign language aside from English. They had never had any classes with native speakers, nor had they spent any significant amount of time in an English-speaking country (aside from short holiday visits in the case of 6 participants). They were all 19-20 years old (median age: 19; 16 female and 4 male) and received lab credit for taking part in the experiment.

### **3.2. Materials and procedure**

The materials consisted of a word list in English, which contained /b, d, g/-initial as well as /tr/- and /dr/- initial items (see Appendix 1) as well as some filler words serving as distractors. All of the initial stops and clusters were followed by a non-high vowel, and the target words were either mono- or disyllabic. We obtained 38 such items per speaker, which resulted in 1292 items analyzed in total.

All participants were recorded in a sound-attenuated booth at our university. The items were elicited using PowerPoint slides, in a pseudo-randomized order (the same for each participant). The recordings were conducted in English, to lower the risk of language-mixing effects (Grosjean 1998), by the second author of the article.

### **3.3. Acoustic annotation and statistical analysis**

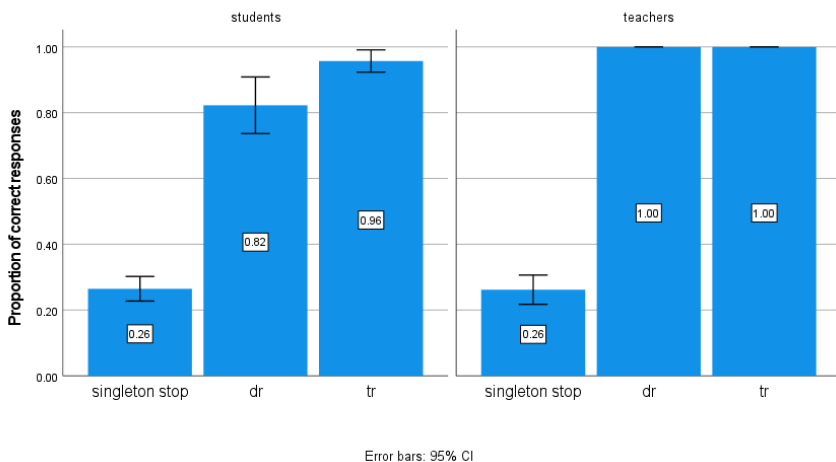
The recordings were manually annotated in Praat (Boersma and Weenink 2021) by two phonetically trained annotators, on the basis of acoustic displays (waveform and spectrogram), supplemented by auditory judgements. There were no cases of uncertainty in the annotation – the presence or absence of pre-voicing and affrication was easily identifiable on the acoustic displays. Items were coded in a binary way: we marked “correct” realizations of voiced stops and /tr/ clusters

(yes/no). The “correct” realization of voiced stops was operationalized as lacking pre-voicing, with short, positive VOT, as shown in the left panel of Figure 3. The “correct” realization of /tr/ and /dr/ clusters was operationalized as affricated, as seen in Figure 1, without any intrusive vowels present in their production, as in Figure 2. There was a small number of affricated /dr/ items that also exhibited pre-voicing (13% of the total of /dr/-initial words across both groups) – these were marked as “correct” for reasons that will be explained in Section 4.

The “correct” realizations of the stops and the clusters were plugged in as the dependent variable in a mixed-effects logistic regression analysis, performed in SPSS (version 27.0, IBM Corporation 2020), with Type (singleton-initial vs. tr-initial initial vs. dr-initial), Group (Students vs. Teachers), and a Type\*Group interaction as fixed predictors, and Speaker and Item were as random factors.

### 3.4. Results

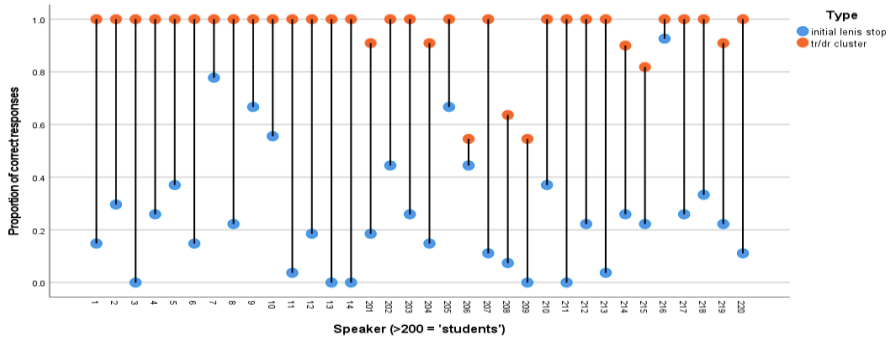
Across both groups, 95% of the initial /tr/-/dr/ items were produced “correctly”, with affrication, while only 26% of the initial lenis stops were produced “correctly”, without pre-voicing. This general pattern held across both groups, and was significant ( $p < .001$ ). Comparing groups, the Teachers produced affrication in 100% of the cluster-initial items (across both /tr/ and /dr/), while the Students produced affrication in 91% of the initial items. This difference turned out to be significant ( $p = .017$ ). Turning to the effects of voicing in clusters (/tr/ vs /dr/), the students produced a higher percentage of correct affricated items for initial /tr/ (82%) vs. /dr/ (96%), but the effect did quite reach significance ( $p = .061$ ). For the initial stops, both groups produced correct realizations without pre-voicing in 26% of the items. The results are shown graphically in Figure 4.



**Figure 4.** The percentage of “correct” realizations of initial lenis stops and /tr/, /dr/ clusters, sorted for group. Error bars indicate 95% confidence intervals



Figure 5 summarizes the results of individual speakers using drop-lines, which show the difference in the proportion of correct responses between item Types, as a function of Speaker. On the x-axis, the Teachers are numbered 1-14, and shown on the left-most section of the axis, and the Students are numbered 200 and above and occupy the right-hand section. Orange dots indicate the proportion of correct productions for cluster-initial items, while blue dots indicate the proportion of correct productions of initial lenis stops. Note that every single speaker produced a higher proportion of correct items for the cluster-initial items than for the lenis stops. Except for three individuals (206, 208, 209), all of the Students produced affrication in at least 80% of the cluster-initial items. Additionally, only one of the twenty Students (216) successfully suppressed pre-voicing in more than 50% of the stop-initial items.



**Figure 5.** Drop-line graph illustrating the difference in the proportion of “correct” responses between item Types for individual Speakers.

### 3.5. Discussion

Recall from Section 1 that in the SLM, CLI is expected in cases of equivalence classification between languages. The sounds deemed as ‘similar’ induce the most robust CLI effects. By contrast, ‘new’ sounds are perceived as sufficiently different from the parallel L1 categories, facilitating successful acquisition while inducing minimal CLI effects. Our results suggest that /tr/-/dr/ affrication is ‘new’ – affrication was for the most part acquired successfully by students, even though phonetic training was just starting. Additionally, the Teachers showed a 100% rate of affrication production. By contrast, lenis stops without pre-voicing are ‘similar’, seeing as there was little progress in pre-voicing suppression found for either group.

The finding for pre-voicing is in line with findings from a number of earlier studies with L1 Polish learners, as well as learners from other L1 backgrounds (e.g. Schwartz and Dzierła 2017, Wojtkowiak 2022, Zajac 2015; Simon 2009). It thus appears that pre-voicing is something to which L1 Polish learners are not

very perceptually sensitive. This is also the conclusion of recent perception studies in L1 Polish using stimuli in which pre-voicing was removed (Schwartz and Arndt 2018; Schwartz et al. 2019): regardless of the presence or absence of negative VOT, Polish listeners robustly perceive the voice contrast on the basis of cues such as pitch ( $f_0$ ) and F1 onset. As a result, we assume that when Polish learners come across singleton unvoiced lenis stops in L2 English, they perceptually equate them with their own pre-voiced stops, leading to a significant degree of CLI. While it is true that L1 speakers of English sometimes produce pre-voicing,<sup>2</sup> such that the L2 realizations seen here are not necessarily ‘incorrect’, transfer of L1 pre-voicing is a problem if applied to medial clusters, as in Polish-accented realizations of *update* [abdejt] and *Facebook* [fejzbuk]. Wantuch (*in preparation*) has observed that L1 Polish speakers who pre-voice word-initially are more likely to produce such errors in medial clusters.

The results for cluster affrication, to the best of our knowledge, represent the first production data on this particular phonetic parameter in L2 English in the speech of L1 Polish learners, or for that matter learners from any other L1 backgrounds. The production results described here are compatible with perception results obtained by (Schwartz 2022b), who performed a forced-choice identification task aimed at evaluating Polish listeners’ sensitivity to cluster affrication in English. That experiment showed Polish listeners to be quite adept at perceiving the affrication, which induced no confusion with affricate-initial items. In other words, Poles could easily distinguish between the affricated /tr/ in *train* and the post-alveolar affricate /tʃ/ in *chain*. In sum, both the production results described here, as well as Schwartz’ (2022b) perception results, suggest an interpretation whereby L1 Polish learners of English form a new category for affricated clusters. They do not confuse them with /tr/ and /dr/ clusters in their L1.

As mentioned above, the SLM principle of equivalence classification has clear and robust implications for our understanding of the phonological systems of interacting languages in L2 speech acquisition. When CLI is observed, we may assume cross-language phonological similarity. When it is not, we may assume phonological differences across languages that facilitate category formation and successful acquisition. Our results suggest similar phonological representations for lenis stops, alongside distinct representations for /tr/-/dr/ clusters, in Polish and English. In what follows, we shall consider these results from the perspective of theories of phonological representation.

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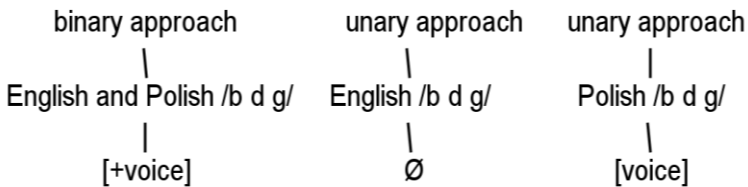
<sup>2</sup> Pre-voicing in L1 English has been found to be most prevalent in the South of the United States (Jacewicz et al. 2009), and in the African American community (Herd 2020)

#### 4. Phonological implications of our results

In this section we consider phonological issues underlying the equivalence-based interpretation of our results, i.e. that lenis stops are phonologically similar in Polish and English, but English /tr/-/dr/ clusters represent ‘new’ structures for which learners form distinct categories from their Polish counterparts.

With regard to the representation of voicing contrasts, there are two established traditions in the phonological literature. In one tradition, made popular by Chomsky and Halle (1968), there is a single *binary* feature [voice], so /bdg/ are specified as [+voice] and /ptk/ are specified as [-voice]. These representations are assumed regardless of VOT patterns. In this way, the Polish and English laryngeal systems would have identical phonological representations, and VOT is determined by language-specific rules of ‘phonetic implementation’ (see e.g. Keating 1984). By contrast, in a *unary* approach, such as that argued for by Harris (1994), Honeybone (2012) and Beckman et al. (2013), the phonological representation of the voice contrast is dependent on the implementation of the VOT patterns. In languages like English, lenis (voiced) stops are said to be phonologically unspecified, while aspirated stops are marked with a feature [spread glottis]. In voicing languages such as Polish, voiced stops are claimed to be specified with a feature [voice], while voiceless stops are claimed to be unspecified. Crucially, the unary approach is said to equate short-lag positive VOT with a lack of phonological specification, a postulate that has been dubbed *Laryngeal Realism* (Honeybone 2012). Notably, there is still a great deal of debate between scholars adopting these two approaches (e.g. Beckman et al. 2013; Bennett and Rose 2017; see also Cyran (2014) who adopts a unary approach but rejects Laryngeal Realism). A summary of voiced stop representation in these two approaches is given in (1).

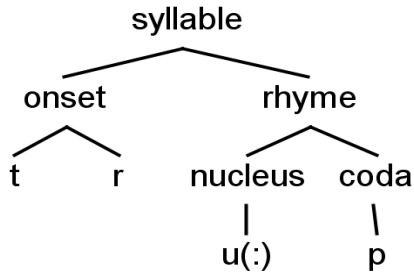
(1) Summary of traditional approaches to the representation of voiced stops in Polish and English.



Turning to initial /tr/ and /dr/ clusters, we must consider textbook representations of syllable structure, by which pre-vocalic consonants at the beginning of a word or syllable are said to be contained in the syllable *Onset*. In cases like /tr/ and /dr/, where the cluster increases in sonority (e.g. Parker 2002), the single onset status of the cluster is widely accepted, regardless of whether the /r/ is an approximant as in English or a trill/tap as in Polish. In other words, /tr/ and /dr/ are classic cases of a ‘branching’ onset that combines the two

consonants into a single prosodic constituent. In (2), we see a traditional approach to the representation of a /tr/ cluster within a syllable. Notice that the tree in Figure 7 posits equivalent structures for the English word *troop* and the Polish word *trup* ‘corpse’. In both cases, according to this tradition, the cluster constitutes a single onset.

(2) Traditional representation of syllable structure for English *troop* and Polish *trup* ‘corpse’



Now let us consider the implications of these traditions for equivalence classification within the SLM. In (1) we saw how voiced stops in English and Polish would be represented in both a unary and binary approach. In the binary approach, English and Polish show phonological equivalence, while in the unary approach they do not. The binary approach is thus compatible with the results described here, which suggests equivalence classification between voiced stops the two languages, inducing a large degree of CLI. The problem with adopting the binary approach for equivalence classification in stops is that it predicts symmetrical equivalence and CLI between voiced and voiceless stops, whereas previous research (e.g. Schwartz 2022a; Wojtkowiak 2022) has found an asymmetry by which there was less robust CLI for the voiceless series.

If we think about the implications of the traditional cluster representations for equivalence classification, we should arrive the prediction that Polish learners of English should equate the onset structures in the two languages, opening the door to CLI in cluster production. This CLI, of course, was not found in our study – our Polish participants clearly have mastered the affrication of /tr/ and /dr/ onsets in L2 English. Considering the results of our study against the backdrop of traditional phonological representations and their predictions for equivalence classification, we can see that the approaches described above cannot provide a satisfactory phonological explanation for why we should expect more CLI for voiced stops than for clusters.

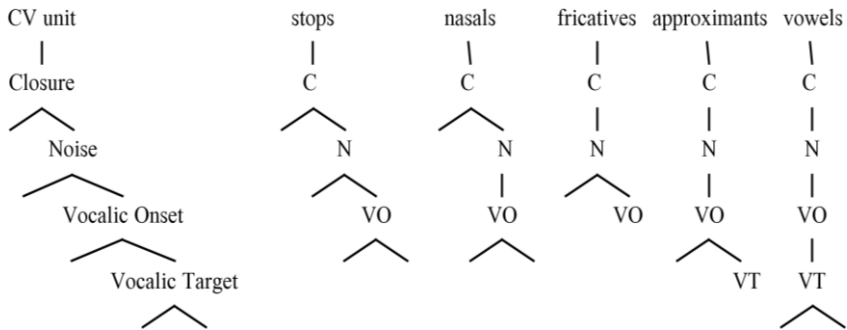
To explain our results, we need a refined phonological outlook, one in which voiced stops but not voiceless stops are phonologically equivalent in Polish and English, and one in which /tr/ and /dr/ onsets have different structural representations in the two languages. Such an outlook is provided by the Onset

Prominence representational framework (OP; Schwartz 2016 et seq.). In what follows, we shall provide a brief interpretation of our results from the perspective of the OP model.

#### 4.1. Onset Prominence and phonological equivalence.

Before presenting the OP interpretation of our results, we must provide a brief introduction to the representations adopted in the model. For a more thorough presentation of OP, see Schwartz (2016). Onset Prominence representations are constructed from a four-level right-branching hierarchy, derived from the phonetic events inherent in the articulation of a stop-vowel CV sequence. This is shown in (3). In the tree on the left we see the CV unit, while the remaining trees show manner categories.

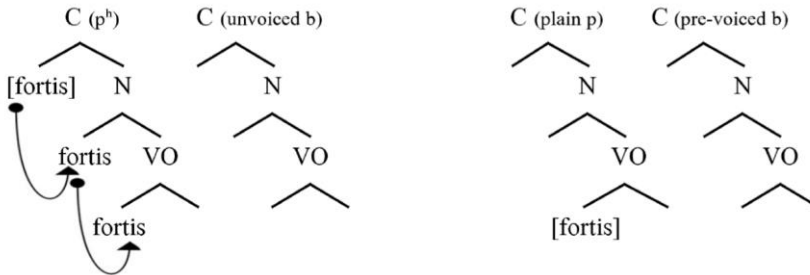
(3) The OP hierarchy (left); and OP manner categories (remaining trees)



A stop-vowel CV is of course the most common syllable shape across languages. The top layer of the OP hierarchy is Closure (C) associated with stops (and nasals), below which we find the Noise (N; stop/affricate releases, frication), Vocalic Onset (VO; CV transitions; approximants), and Vocalic Target (VT) layers. From this four-layer hierarchy (the left-most tree in (3)), individual segmental structures (the remaining trees) are constructed on the basis of which phonetic events are present in a given articulation. In this way, we can derive manner of articulation, including a version of the sonority hierarchy, using structural nodes rather than features. It is worth noting that this structural approach to manner of articulation provides a more transparent view of the relationship between consonant manner and the acoustic signal than approaches based on a linear string of segments.

Now we turn to brief illustration of OP's perspective on two-way voicing contrasts in stops (for a more thorough introduction, see Schwartz (2017) or Schwartz (2022a)). This is shown in (4), which depicts an English-type system on the left and a Polish-type system on the right.

- (4) Two-series laryngeal systems in OP; English is shown in the pair of trees on the left, Polish on the right



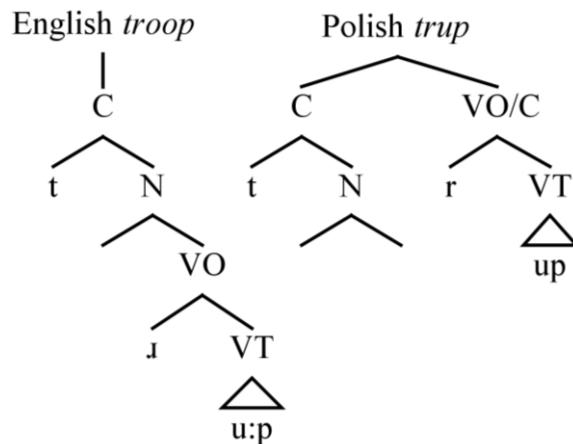
Two-way contrasts in stops are encoded by means of a feature [fortis], which may be assigned either at the Closure level or at the VO level. If the feature is assigned to Closure, the result is long VOT and aspiration, as is found in English, since the [fortis] feature is said to ‘trickle’ down to lower nodes (Schwartz 2016), and is therefore also realized on the Noise node. In systems such as Polish, when [fortis] is assigned to the VO node, the Noise node is left unaffected and aspiration does not occur – the result is short-lag VOT in voiceless stops. Crucially, the voiced series of stops is unspecified in both types of system, regardless of whether pre-voicing is observed. It is this postulate which is predictive of equivalence classification and CLI in L2 acquisition. Essentially the implication of the representations in (4) is that pre-voicing does not indicate the presence of a phonological feature, so voiced stops are phonologically equivalent in both voicing and aspirating systems. For proposals making a similar claim, see Iosad (2012) for Breton, Cyran (2014) for Southwest Polish, van der Hulst (2014) for Dutch, and Balogne-Berces and Huszthy (2018) for Italian. For additional discussion about why pre-voicing should not reflect a phonological feature [voice], see Schwartz (2017).

The strategy adopted in (4) serves as a compromise in the debate between Laryngeal Realism and the binary approach to voice contrasts. The main appeal of Laryngeal Realism is its ability to encode the VOT typology between voicing and aspiration systems in a phonetically transparent way. However, the Laryngeal Realism approach makes a prediction that voiceless stops in voicing languages are phonologically inactive and cannot participate in processes such as assimilation. Meanwhile, scholars advocating a binary approach (Rubach 1996; Wetzels and Mascaró 2001; Bennett and Rose 2017) have shown rather convincing evidence that voicelessness may indeed be phonologically active in voicing systems. The OP approach in (4) encodes the VOT typology transparently, as a function of level of [fortis] assignment, yet at the same time posits that voiceless stops are marked with an active phonological feature. We can see then that OP offers a way out of the theoretical impasse reflected in the debate between unary and binary approaches to two-series voicing contrasts. At the same time, it is necessary to

note that according to the OP proposal, whether a lenis stop is unvoiced for pre-voiced is not phonologically specified. In other words, the phonological equivalence between unvoiced and pre-voiced lenis stops gives rise to CLI, which is a function of the phonetic differences between the languages. By contrast, for the /p t k/ series, the cross-language difference is both phonetic and phonological, so CLI is less robust.

Now we turn to the representation of /tr/-/dr/ onset clusters in OP. Since the basic prosodic unit is a CV sequence with only a single onset consonant, consonant clusters in OP must be derived by phonotactic mechanisms that combine trees (see Schwartz 2016 for details). In the model, there are two such mechanisms by which rising sonority onset clusters can be formed. The difference between them is a function of whether or not the two consonants are combined (or *absorbed*, see Schwartz (2016: 59)) into a single tree, or whether they are contained in separate trees, forming an onset by means of *adjunction* (Schwartz 2016: 59). This is shown in (5), which depicts the English word *troop* on the left and Polish *trup* ‘corpse’ on the right.

(5) Two different representations for /tr/-/dr/ onsets in OP



In the English example, the stop and the following /r/ are combined in a single iteration of the OP hierarchy. This results in synchronous cluster production associated with allophonic processes such as affrication, which was the focus of our study. In the Polish example, the /t/ and /r/ are contained in separate OP trees, resulting in asynchronous productions. Crucially, the account in (5) posits two separate structures for the clusters in the two languages. For this reason, it is predicted that the English cluster should constitute a ‘new’ structure for Polish learners, a new category will be formed, and progress will be made in the acquisition of affrication.

This prediction is in line with the findings of our study – L1 Polish speakers of English are highly successful in the acquisition of affrication in /tr/ and /dr/ onsets – yet voicing remains a problem. This asymmetry was most robustly evident in the /dr/-initial items that were produced with both affrication and pre-voicing. These tokens showed that the structural difference giving rise to affrication may be acquired, even when feature-level phonological equivalence leads to CLI in pre-voicing. These items were marked as “correct” in the annotation procedure, since the affrication was a sign that the articulatory synchronicity of the affricated clusters had been successfully acquired. A question that remains is why there were not more such of these items. In other words, why were our speakers more likely to suppress pre-voicing in pre-rhotic /d/ than pre-vocalic /d/? A possible explanation is that co-articulation of the stop with the rhotic amplified aerodynamic constraints on the production of phonation, since we should expect increased duration of the consonant constriction, thus hindering airflow through the glottis.

#### 4.2. Why we need phonology

While the representations in (5) make successful predictions about the cross-languages differences in the affrication, which is an allophonic process, one may ask if phonological representations are in fact necessary to explain the Polish-English differences in cluster production. For example, could we not simply say that affrication is a function of the fact that English has an approximant rhotic, while the lack of affrication in Polish is attributable to the trilled/tapped realization of /r/? In such an interpretation, the participants in our study may be said to have formed a new category for the approximant rhotic, facilitating the acquisition of affrication. Additionally, one might ask about the phonological evidence for different structural configurations for the ‘same’ cluster in the two languages, since rhotics are often seen as phonologically equivalent across languages, despite differences in their phonetic realization. In what follows, we present arguments that there is more than just phonetics underlying the data presented in this paper, and that the phonological representations in (5) are successful in explaining our findings.

The first argument is purely phonological. Namely, the structures in (5) capture an important difference between Polish and English in the prosodic behavior of onset clusters. In English it is well known that onset consonants do not contribute to minimality for prosodic word status – minimal prosodic words in English must contain a long vowel (e.g. *grew*), diphthong (e.g. *eye*) or coda consonant if the vowel is short (e.g. *egg*). Onsets are unnecessary. This is reflected in (5) in the fact that both consonants in the cluster are contained in the same tree as the vowel (and coda), so the onset is not free to contribute to prosodic minimality. By contrast, in Polish minimality for the purposes of inflectional morphology



requires either a coda consonant, or an onset cluster (Comrie 1976; Garrett 1999; see discussion in Schwartz 2016: 58). Thus, in the Polish cluster in (5), the /t/ forms its own tree that contributes to the overall structure of the word.

While the phonetic observation, mentioned above, that affrication is only possible with approximant rhotics is valid, it is not the case that approximant rhotics always induce affrication. Polish is in fact a notable example. Careful phonetic study of Polish /r/ (e.g. Jaworski and Gillian 2011) has revealed that approximant realizations of the rhotic in Polish are in fact quite common, yet they do not induce affrication in /tr-/dr/ clusters. Thus, there must be another explanation for why the process is found in English, but not in Polish. The structures in (5) provide such an explanation.<sup>3</sup>

Additionally, in studies of other L1-L2 pairings, equivalence classification between different rhotic realizations is attested. For example, Major (1986) describes errors in the acquisition of the Spanish /r/ by L1 English learners – English speakers often substitute their L1 approximant [ɹ] for the target [r]. These errors may be assumed to be due to equivalence classification between the English and Spanish rhotics. Thus, it is clear that differences in rhotic realization do not rule out equivalence classification – there must be an additional factor underlying the Polish-English differences. The differences in (5) provide such an explanation.

Finally, on the basis of these arguments, we may be confident that structural differences indeed underlie the phonological representation of /tr-/dr/ onset clusters in Polish and English. Presumably it is these structural differences that explain why Polish learners are so successful in their acquisition of affrication in L2 English. Thanks to the different structures, a new category may be formed, and equivalence classification does not hinder acquisition. As has been shown above, the suppression of pre-voicing in L2 lenis stops is a very different story.

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<sup>3</sup> A reviewer mentions differences in place of articulation between English /t d/ (alveolar) and /ɹ/ (post-alveolar) as a possible explanation for why English behaves differently from Polish. In English, it is claimed you get place assimilation of the stop to the post-alveolar rhotic, so a single articulatory gesture induces affrication. As it happens however, Polish also has place differences between /t d/ (dental) and /r/ (alveolar), which by the same logic would be expected to merge the consonants into a single articulatory gesture, but do not.

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### Appendix 1: Dataset for the production study (without fillers, sorted alphabetically)

- |           |             |
|-----------|-------------|
| 1. back   | 20. drill   |
| 2. bar    | 21. drops   |
| 3. beg    | 22. duck    |
| 4. bell   | 23. Dutch   |
| 5. ben    | 24. get     |
| 6. bet    | 25. gets    |
| 7. buck   | 26. guess   |
| 8. bug    | 27. guest   |
| 9. bus    | 28. gull    |
| 10. but   | 29. gum     |
| 11. dead  | 30. gun     |
| 12. debt  | 31. gut     |
| 13. deck  | 32. tractor |
| 14. Depp  | 33. trap    |
| 15. die   | 34. trend   |
| 16. does  | 35. trick   |
| 17. done  | 36. trim    |
| 18. drab  | 37. trip    |
| 19. dress | 38. troupe  |

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