Transparent /aɪ/-Raising as a Contact Phenomenon

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1 Introduction

Canadian Raising is a phonological process which raises the nucleus of both the /aɪ/ and /aʊ/ diphthongs above 60Hz (Labov et al. 2005: ANAE, p. 205) before voiceless segments. The /aɪ/ diphthong is raised in much of Canada as well as in many American dialects, including the Inland North, resulting in alternations among a large number of minimal pairs distinguished by their voicing, some of which are listed in (1). This /aɪ/-raising is a classic example of phonological opacity because it is canonically conditioned not only by surface voiceless segments but also *underlyingly* voiceless segments, as with the flapped /t/ in *writer* as in (2). However, not all /aɪ/-raising speakers exhibit this opaque pattern: so-called *transparent* or *phonetic* /aɪ/-raising speakers only raise before surface voiceless segments as in (3). The existence of this latter group has renewed debate about the ultimate origins of the raising patterns and the relationship between transparent and canonical raising. This paper contributes to that discussion with a new model of child language acquisition in variable settings, finding that the presence of transparent /aɪ/-raising as well as its rare attestation and sparse distribution can be accounted for as a contact phenomenon in which some child learners innovate a novel transparent raising pattern when their communities contain the appropriate mix of canonical raising and non-raising speakers.

(1) Sample /aɪ/-raising minimal pairs
/lʌɪf/ 'life' ∼ /laɪv/ 'live'
/spʌɪs/ 'spice' ∼ /spaɪz/ 'spies'
/trʌɪp/ 'tripe' ∼ /traɪb/ 'tribe'
/brʌɪt/ 'bright' ∼ /braɪd/ 'bride'

(2) Canonical raising before underlyingly voiceless segments
/raɪd/ 'ride' ∼ /raɪɾɚ/ 'rider'
/rʌɪt/ 'write' ∼ /rʌɪɾɚ/ 'writer'

(3) Lack of transparent raising before underlyingly voiceless segments
/raɪd/ 'ride' ∼ /raɪɾɚ/ 'rider'
/rʌɪt/ 'write' ∼ /raɪɾɚ/ 'writer'

The population-level development and spread of /aɪ/-raising has received particular attention because it seems to have occurred rapidly despite its apparent opacity, and communities containing any variants other than the non-raising and the canonical raising patterns of (1,2) have been very difficult to find with few exceptions. Joos (1942) described one such group of speakers in Ontario with the transparent raising pattern alongside speakers who exhibited the canonical pattern. Until recently, no instances of transparent raising had been identified since the 1942 study; however, using a targeted acoustic production study of local speakers, Berkson et al. (2017) have now found transparent raising in Fort Wayne, Indiana, alongside some non-raising and canonical raising speakers. Berkson et al. (2017) intend to continue studying the local population over time, and posit that the transparent grammar, which has only been observed within the past decade or so, could be completely overtaken by the full raising grammar in as little as a generation. However, in a detailed longitudinal study of the Philadelphia Neighborhood Corpus (Labov and Rosenfelder 2011), Fruehwald (2016, 2017) identified increasing prevalence of the raised /aɪ/ in the city's population over time but did not find evidence for any intermediate transparent or phonetic raising pattern (conditioned by surface rather than underlying properties), concluding that if any such intermediate stages existed there, they must have been extremely brief.

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Discussions of the elusive transparent grammar often frame it as a step in the initial actuation of /aɪ/-raising; the vowel raising could plausibly be phonetically motivated by co-articulation with a following voiceless consonant, with the extent of raising incremented over time and eventually becoming allophonic (Fruehwald 2016, Berkson et al. 2017). Specific phonetic mechanisms that have been suggested include offglide peripheralization (Moreton and Thomas 2007, Berkson et al. 2017) and pre-voiceless shortening (Joos 1942). The further change from surface-based raising to canonical /aɪ/-raising that is also conditioned by flapped underlying /t/ is then described as phonologization. These co-articulation effects may very well be the ultimate origin of /aɪ/-raising, but they need not account for its present-day expansion – we propose that dialect contact is a much more likely source than spontaneously repeated phonetic incrementation and phonologization. In particular, the sudden recent appearance of both canonical and transparent raising in formerly non-raising Fort Wayne, which is not far south of the traditional /aɪ/-raising Inland North as described in the ANAE (Figure 1), is best described as a contact scenario. This contact would only mix canonical (fully allophonic) raising and non-raising speech, so the attested transparent raising would not be a result of gradient articulatorily-motivated phonetic incrementation, but rather an instance of actuation resulting from the inconsistent input which young learners received.

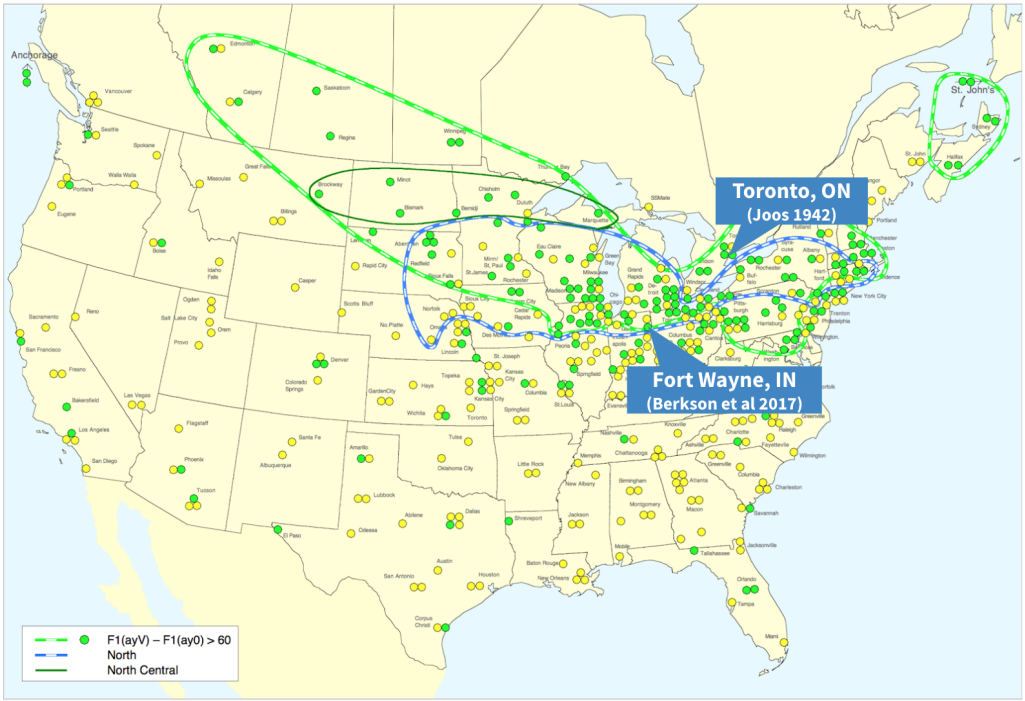

Figure 1: Transparent /aɪ/-raising locations investigated by Joos (1942) and Berkson et al. (2017) superimposed on ANAE Map 14.10. The primarily canonical raising region extending from Western Canada through the Great Lakes into New England is bounded by the bright green line. The North and North-Central dialect regions are bounded by the blue and dark green lines respectively.

1.1 Contributions

Following our proposal, transparent /aɪ/-raising is a contact phenomenon which emerges sporadically among native language learners in populations at the geographic frontiers of /aɪ/-raising, implying that children are capable of hypothesizing transparent raising given input that is some combination of raising and non-raising without exposure to transparent raising itself. We investigate this acquisition process with an extension of the Tolerance Principle (Yang 2016), a model for the acquisition of productive patterns, to describe language learning in variable environments.

We clarify a number of points in our treatment of /aɪ/-raising: first, that the transparent raising pattern is not merely a 'partial' grammar with respect to raising or an incipient step on the way to canonical raising, but a distinct grammar in which raising is allophonic and conditioned by surface voicelessness. Second, raising patterns need not always arise independently in new areas, since they are easily spread by contact and migration like many other regional dialect features of North American English (e.g., short-*a* tensing in New Orleans; Berger 1980, Labov 2007; or Northern Cities features in St. Louis; Labov 2007, Friedman 2014). The recent emergence of /aɪ/-raising in some North American communities should be viewed as a process of dialect contact, distinct from initial community-internal phonetic actuation of Canadian Raising. Third, the sparse individual attestation and lack of transparent raising communities can be accounted for by the limited range of linguistic environments in which the corresponding grammar is learnable. Finally, the *de novo* innovation of a distinct transparent raising grammar provides a study of children as actuators of change and an empirically testable comment on the classic actuation problem (Weinreich et al. 1968). We begin by summarizing the distribution of transparent raising and the related debate before introducing our model in Section 2, applying it in Sections 3 and 4, and discussing its predictions and implications in Section 5.

2 Learning from Mixed Input

Phonemes and allophones are acquired early in development. Children have a sense of the inventory of surface segments in their native languages by six months to a year (Werker and Tees 1984, Kuhl et al. 1992), and they are capable of learning allophonic relationships between segments as well towards the end of that time period (Pierrehumbert 2003, Pegg and Werker 1997). Although in a non-raising grammar words like *writer-rider* in which /aɪ/ precedes an alveolar flap are pronounced with the same vowel quality and similar flap realization, they are reliably pronounced with a vowel length difference reflecting the voicing of the following underlying stop. Therefore, flapped /t/-/d/ word pairs have distinct pronunciations in both raising and non-raising grammars, allowing children to recover underlying stop voicing for words pronounced with flaps. The vowel length information regarding underlying stop voicing must be cognitively available to learners fairly early, as it is already systematic in productions before 24 months; even before children are entirely competent with flap articulation itself, they reproduce the adult pattern of shortening before underlyingly voiceless flaps (Rimac and Smith 1984, Ko 2007). This observation may also call into question the actual opacity of /aɪ/-raising.

We model child language acquisition as described by the Tolerance Principle (TP; Yang 2016), which has enjoyed recent success as a model of productivity learning, addressing a wide range of problems in syntax, morphology, and phonology. It distinguishes itself as a mechanistic online model by which learners decide whether or not some hypothesized pattern is productive in the grammar given known exceptions to that pattern. The TP provides a binary outcome: either there are few enough exceptions to the pattern that it can be learned as productive and is entered into the grammar as such, or it is non-productive, meaning that items that appear to obey the pattern are memorized individually. This outcome is dependent on whether or not the number of exceptions that a learner knows is below a *tolerance threshold* calculated according to the total number of relevant items that the learner knows. The threshold is derived given an Elsewhere Condition on the representation of productive patterns (Kiparsky 1973, Aronoff 1976), frequency-rank based lexical access (Murray and Forster 2004), and a generally Zipfian input distribution (Yang 2016: pp. 48-51). It is stated formally below:

Tolerance Principle: Generalization R applying over N *types* with e exceptions is *tolerable* if

$$e < \theta; \;\; \theta := \frac{N}{\ln N} \tag{1}$$

If a learner so far knows N items that should follow a pattern, say a raising rule and N items containing /aɪt/, that pattern is learnable if the learner knows fewer than θ exceptions to it, words in which /aɪ/ does not raise despite being in the appropriate pre-voiceless environment. If this number

of exceptions e is larger than θ, the learner can still learn the pronunciations of raised items, but cannot internalize a productive pattern describing them. Either some other pattern better accounts for the input, or the raised items just have to be memorized one-by-one.

In addition to the basic task of acquiring a native phonology, learners in contact settings must deal with mixed input where no pattern clearly stands out as the target for acquisition. Notably, young learners at the age of early phonological acquisition tend to handle this by regularizing inconsistent input rather than matching probabilities of variants, normally settling on the form that has been most prevalent in their input (Singleton and Newport 2004, Schuler 2017). This regularization is especially relevant for learning categorical generalizations, since many input phenomena occur in the input with some range of variation. Sneller et al. (2019) apply the Tolerance Principle to native language acquisition from mixed phonological input: if a lexical item is heard more often in one variant than the other, that is the variant that is learned, and the variant relevant to the child's evaluation of possible grammars. Naturally, if a child happens to hear much more of one variant than the other, then that child's lexicon will tend to contain more vocabulary which matches that variant. The TP can then be used to determine which input mixes should drive children to acquire which grammar, by evaluating the learnability of each grammar given each learner's own lexicon. In Section 2.1, we extend this intuition to develop a probabilistic version of the Tolerance Principle describing language communities with variable mixed input.

2.1 Applying the Tolerance Principle to /aɪ/-Raising

The particular problem at hand provides an additional challenge since it amounts to an instance of actuation: transparent raising may be a learner's best option given the input even if none of that input was generated by transparent raising. Additionally, canonical raising applies in every instance that transparent raising would plus more, so it subsumes transparent raising in the conditions where it can be learned. As a result, transparent raising is only learnable when there is enough evidence in its favor but not enough evidence for canonical raising – there must be "enough" evidence for raising before surface voiceless segments but "not enough" evidence for raising before flapped /t/. This is technically possible in a mixed canonical/non-raising input environment if the learner happens to acquire more surface-voiceless raising items from raising speakers and more flapped /t/ words from non-raising speakers.

Cast in terms of the Tolerance Principle, a learner may hypothesize two raising grammars, a narrower one which amounts to transparent raising (g_{trans}) or a broader one that amounts to canonical raising (g_{full}), or resort to non-productive raising instead (g_{none}) if neither of the others is tenable. Canonical raising is tenable if there are few enough exceptions among $N_{\text{full}} = N_{\text{trans}} + N_{\text{flap}}$ items with flapped and surface /t/, and Transparent raising is tenable for a learner who has learned few enough exceptions among N_{trans} surface /aɪt/ items but too many exceptions among the N_{flap} items for canonical raising. We follow Sneller et al. (2019) in modeling learners who acquire the most frequent variant of each item, since young learners regularize input variation. That is, if a child happens to hear raised 'writer' more often than non-raised 'writer,' that child will initially learn the former rather than the latter, and if the child hears non-raised 'spite' more often than raised 'spite,' the child will acquire the non-raised form, and so on.

The learnability pattern is visualized in Figure 2. There are two number lines, the top one for canonical raising which extends from 0 to N_{full} and the bottom for transparent raising which extends from 0 to N_{trans}. If the number of potentially raisable items that are not learned as raised is high, falling in the blue zone on the number lines, then neither raising generalization is learnable and the learner is forced to acquire non-productive raising. On the other hand, if few enough items are learned as non-raised such that that number falls in the gold zone, canonical raising is learnable. Transparent raising is only learnable if the number of exceptions exceeds the tolerance threshold for g_{full} but does not exceed the tolerance threshold for g_{trans}, such that it falls in the red zone. This can happen if too many surface-raisable words are learned as non-raised but not too many flapped raisable words are. The width of the red part of the number line is the number of raisable flapped words (/aɪɾ/ with /ɾ/ from underlying /t/) in the learner's lexicon.

The probability that a learner happens to hear a given item more often as raised or non-raised,

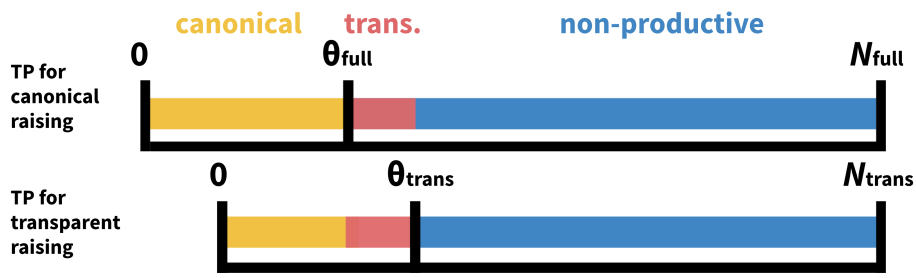

Figure 2: Range of exceptions in which canonical raising is learnable (gold), transparent raising is learnable (red), and neither is learnable (blue). Number lines are oriented such that the red zones line up. The red zone is the range in which exceptions fall above the tolerance threshold for canonical raising but below the threshold for transparent raising. The red zone is as wide as the number of potentially /aɪ/-raised flapped /t/ words in the vocabulary.

and therefore learn it as such given frequency-based regularization, is conceptualized as a coin flip weighted by the proportion of non-raising speakers p_{none} in the environment.[1] The number of exceptions e to a raising generalization then is the number of coin flips that come out 'non-raising' rather than 'raising' after N trials. The number of exceptions to canonical raising e_{full} is modeled for N_{full} coin flips, and the exceptions to transparent raising e_{trans} is modeled for N_{trans} flips, both weighted by p_{none}.[2] As with coin flips, whether a given word happens to be learned one way or the other is independent of how the other words were learned.

The Tolerance Principle just asks whether e falls above or below a tolerance threshold θ, not what the specific value of e is, so if e is the random variable, the probability of a generalization being tolerable is the probability of e falling below θ. This can be calculated for each grammar with the binomial cumulative density functions as in Equations 2-3.

$$p(g_{\text{trans}} \text{ tolerable}) = \sum_{e_{\text{trans}}=0}^{\lfloor \theta_{\text{trans}} \rfloor} \binom{N_{\text{trans}}}{e_{\text{trans}}} p_{\text{none}}^{e_{\text{trans}}} \, p_{\text{full}}^{N_{\text{trans}}-e_{\text{trans}}} \tag{2}$$

$$p(g_{\text{full}} \text{ tolerable}) = \sum_{e_{\text{full}}=0}^{\lfloor \theta_{\text{full}} \rfloor} \binom{N_{\text{full}}}{e_{\text{full}}} p_{\text{none}}^{e_{\text{full}}} \, p_{\text{full}}^{N_{\text{full}}-e_{\text{full}}} \tag{3}$$

The probability that g_{trans} is learnable, that the learner falls into the red zone in Figure 2, is probability that g_{trans} is tolerable *and* g_{full} is *not* tolerable because if g_{full} were tolerable, it would subsume g_{trans} (Equations 4-5).

$$p(\text{learn } g_{\text{full}}) = p(g_{\text{full}} \text{ tolerable }) \tag{4}$$

$$p(\text{learn } g_{\text{trans}}) = p(g_{\text{full}} \text{ not tolerable and } g_{\text{trans}} \text{ tolerable}) \tag{5}$$

Whether or not the number of exceptions falls precisely in that red zone for a particular learner depends on the number of surface [t] and flapped /t/ words that that learner has acquired as exceptions (e_{trans} and e_{flap} respectively). The red zone is bound by θ_{full} and θ_{trans}. Taken together, this specifies the ranges over which to calculate the binomial CDF (Expressions 6-7).

$$e_{\text{trans}} \in [\theta_{\text{full}} - N_{\text{flap}}, \lfloor \theta_{\text{trans}} \rfloor] \tag{6}$$

$$e_{\text{flap}} \in [\theta_{\text{full}} - e_{\text{trans}}, N_{\text{flap}}] \tag{7}$$

[1] At this point, the model assumes that all members of the population providing learner input are either non-raising or exhibit canonical raising, so the proportion of the population that has canonical raising $p_{\text{full}} = 1 - p_{\text{none}}$.

[2] The binomial distribution, which is used to model binary outcomes like coin flips, is weighted here by p_{none}, but equivalent results could have been calculated with weighting by p_{full}.

Note that in the first set of bounds, $e_{\text{trans}} \leq \lfloor \theta_{\text{trans}} \rfloor$ so that g_{trans} is tolerable, and in the second set of bounds, $\theta_{\text{full}} - e_{\text{trans}} \leq e_{\text{flap}}$ can be rewritten as $\theta_{\text{full}} \leq e_{\text{flap}} + e_{\text{trans}} = e_{\text{full}}$ so that g_{full} is not tolerable, which makes it clear that the value of e_{full} is dependent on the value of e_{trans}. Making the same independence assumption between lexical items as between coin flips, this allows the previous joint probability to be written as a conditional probability. Finally, applying the e bounds to the binomial CDF yields Equation 8. This equation gives the probability that learners fall in the red zone on the Figure 2 number lines, that is, the probability that transparent raising is learned.

$$p(\text{learn } g_{\text{trans}}) = \sum_{e_{\text{trans}}=\theta_{\text{full}}-N_{\text{flap}}}^{\lfloor \theta_{\text{trans}} \rfloor} \left(\binom{N_{\text{trans}}}{e_{\text{trans}}} p_{\text{none}}^{e_{\text{trans}}} \, p_{\text{full}}^{N_{\text{trans}}-e_{\text{trans}}} \sum_{e_{\text{flap}}=\theta_{\text{full}}-e_{\text{trans}}}^{N_{\text{flap}}} \binom{N_{\text{flap}}}{e_{\text{flap}}} p_{\text{none}}^{e_{\text{flap}}} \, p_{\text{full}}^{N_{\text{flap}}-e_{\text{flap}}} \right) \tag{8}$$

3 Actuation of Transparent Raising

The equations in the previous section reveal that the chance that a learner will innovate a new transparent raising grammar is dependent not only on the linguistic composition of the surrounding community but also the composition of the lexicon. Transparent raising is feasible because of the relative sizes of the sets of surface [t] and flapped /aɪt/ words N_{trans} and N_{flap} respectively. To approximate the size of these classes in individual learners' linguistic experiences, we estimate them from corpora of child-directed speech at varying frequency cutoff thresholds. We take counts from the Brown (Brown 1973) and Brent (Brent and Siskind 2001) corpora. The vocabulary sizes of both frequency-trimmed lexicons roughly correspond to those of a child around school age, while the full-corpus lexicons reflect learners far past the age of basic phonological acquisition (Anglin 1993, Nation and Waring 1997). Therefore, these estimated lexicons contain a sufficiently complete representation of the input data that learners would acquire their /aɪt/-raising system from, and the convergent predictions we obtain from modeling the various lexicons are reliable predictions of acquisition outcomes (and input to subsequent learners). Estimates of N_{full} and N_{trans} ($N_{\text{flap}} = N_{\text{full}} - N_{\text{trans}}$) are summarized in Table 1.

Corpus	**Freq. Cutoff**	**# Tokens**	N_{full} **(Types)**	N_{trans} **(Types)**
Brown	≥ 5	356,959	53	45
Brown+Brent	≥ 5	883,698	82	69
Brown	≥ 1	364,267	122	103
Brown+Brent	≥ 1	895,501	182	155

Table 1: Number of potentially /aɪ/-raisable items by sample lexicon

There are far fewer flapped /t/ items than surface [t] items in each sampled lexicon, which means that the red zone in which transparent raising is learnable is relatively small and that transparent raising is unlikely to be learned regardless of the mix of grammars that a learner's input is drawn from. This is consistent with the empirical evidence that transparent raising is rare – it should not appear frequently in the grammars of young people.

It is possible to calculate the distribution of learning outcomes for any input distribution p_{none} as in Figure 3 by fixing the N values. In this figure, the x-axis is p_{none}, the proportion of the input that is generated by a non-raising grammar g_{none}, with p_{none} increasing to the right. Since $p_{\text{none}} + p_{\text{full}} = 1$, the proportion of input generated by a canonical raising grammar p_{full} increases towards the left. The y-axis is the probability that a learner exposed to the input mix specified on x should acquire each raising grammar, that is, the probability that e falls into the gold, red, or blue zone for that learner's Tolerance Principle evaluations. With independence assumptions, the y values can also be taken to represent the proportion of learners who acquire each type of raising grammar given an input mix.

It is clear from the plot that most learners should acquire either canonical raising or a non-raising grammar regardless of the mix of inputs to which they are exposed. Nevertheless, there is

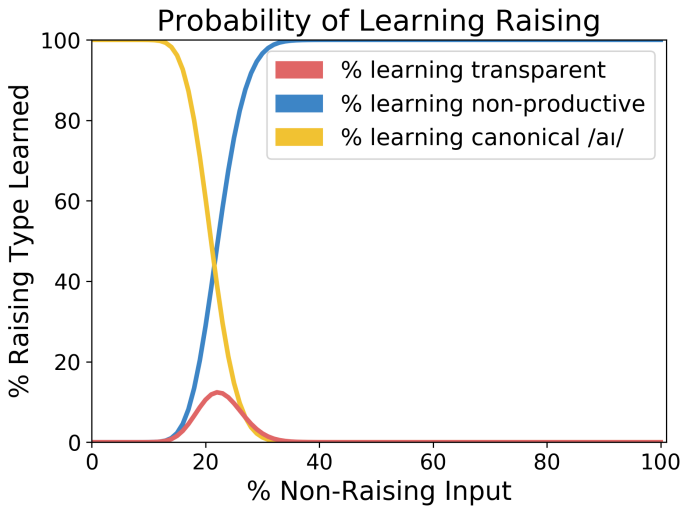

Figure 3: Learner outcomes by input mixture estimated from Brown with a ≥ 1 frequency cutoff. The x-axis represents the proportions of non-raising and canonical raising input, and y-axis represents the probability of a learner acquiring each variant raising grammar.

a narrow range, between about 15% and 30% non-raising input as estimated from the full Brown corpus in Figure 3, where some learners do indeed acquire novel transparent raising, showing that it really can be actuated *de novo* in dialect mixing situations and from non-raising and canonical raising inputs alone. The calculation on the other lexicon estimates from Table 1 yields convergent learning outcomes with the peak transparent raising rate consistently occurring between 20% and 30% non-raising input.

These results indicate that transparent raising can be innovated sporadically at dialect boundaries, which comports with the distribution of transparent raising *individuals* observed in the map in Figure 1. The next section considers how populations should evolve over time to answer the question of why no transparent raising *populations* have been observed.

4 Transparent Raising over Time

It is possible for transparent raising to emerge as a novel grammar at low rates in mixed populations of non-raising and canonical raising speakers. As those new transparent raisers mature, they will provide additional input to their younger peers, so future cohorts receive transparent raising input as well as non-raising and canonical raising. Modeling how populations of non-, canonical, and transparent raising speakers evolve over time reveals why transparent raising speakers have been so sparsely distributed.

Learning outcomes in three-way mixtures of non-, canonical, and transparent raising input are presented in ternary plots in Figure 4 (left) where every point represents some mixture of the three inputs. The corners of the triangle represent 100% non-raising, canonical raising, and transparent raising input, and the opposite edges represent 0% of each respectively. The right edge of the triangle where the rate of transparent raising in the input is 0 corresponds to the plot in Section 3. The black star on the right edge thus corresponds to the 22% non-raising, 78% canonical raising, 0% transparent raising input mixture at which transparent raising is first actuated at the highest rate. Color is used in the left plot to convey the proportion of learners acquiring transparent raising given the input, with darker red corresponding to a higher probability of acquiring transparent raising. The probability of acquiring transparent raising generally increases as the proportion of transparent raising input increases (as one moves toward the left corner of the triangle), but all in all, transparent raising is only viable over a narrow range of input mixtures visualized as a red band on the plot.

Transparent raising is not learnable from input mixtures located off this band of viability.

The narrowness of this band hampers transparent raising's long-term prospects, because as soon as it is innovated somewhere around 78% canonical raising / 22% non-raising (the black star), the population will shift rapidly towards canonical or non-raising as the input mixture for subsequent cohorts transitions away from the band, rapidly killing it off. This is visualized as a phase plot in Figure 4 (right) which shows how populations evolve over time given slight perturbations in their initial conditions. To create this plot, several model communities are initialized around the best-case scenario represented by the black star and then allowed to evolve for several iterations. At each iteration, 10% of the community, representing a cohort of learners, acquires a new grammar from the current input mixture. The three-way mixture of grammars in the population therefore shifts at every iteration, eventually tracing lines across the ternary plot. Rainbow coloring indicates iteration number, so the evolution of each community can be tracked by following the colors from red through to magenta. Depending on exactly where the community is initialized, within several iterations it falls towards either 100% canonical raising at the top corner or 100% non-productive raising at the right corner. No primarily transparent raising population ever has a chance to develop.

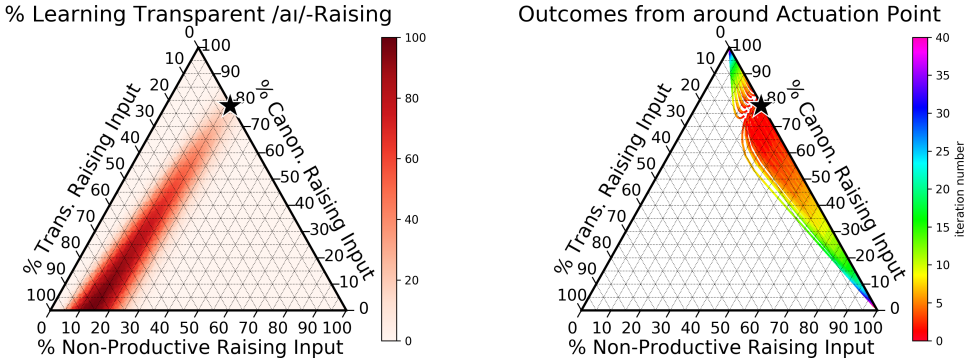

Figure 4: **Left:** Proportion of learners acquiring transparent raising (depth of red) for each three-way input mix. Transparent raising is only viable on a narrow band of input mixtures, indicating that specific input conditions are needed to support it. **Right:** Phase plot showing the rapid defeat of transparent raising. The community always shifts away from the conditions in which transparent raising is actuated (around the black star) towards canonical or non-raising (top or right corners) after several iterations. Rainbow coloring indicates iteration number and progresses from red through to magenta.

5 Discussion

The computational model provided here accounts for the actuation of transparent /aɪ/-raising as a response to mixed canonical and non-raising input, which amounts to the innovation of a new categorical grammar without prior attestation. The model contributes to a local understanding of the actuation problem by specifying a measurable description of one mechanism for it as a natural outcome of general processes of child language acquisition given certain mixed input. This approach recognizes the plausible distinction between how canonical /aɪ/-raising first arose and how it has since spread, and has a number of advantages over previous accounts: it explains why no stable transparent raising populations have been discovered, why transparent raising speakers are almost entirely absent in the historical record, and why the transparent raising speakers who have been identified have been found near dialect boundaries.

The model makes a number of testable quantitative predictions regarding the relationship between phonological input and change in progress, most importantly the ratio of non-raising and canonical raising input at which transparent raising may be innovated in a given community. A

comparison to Berkson et al.'s experimental results on young adults provides very rough validation and suggests a path for validation in the future. They find that at the time of study, 37% of their 27 young adult participants exhibited Pattern 0 or Pattern 1 (in our terms, non-productive raising), 33% exhibited Pattern 2 (transparent raising), and 30% exhibited Pattern 3 (canonical raising). Our model predicts that a speech community that has just innovated transparent raising, roughly twenty years previously in Fort Wayne, would exhibit the three grammars at 48%, 13%, and 39% respectively. This is reasonably in the ballpark given that the studies are not directly comparable.

The introduction of the Tolerance Principle to this problem has additional implications for lexical raising, that is, the circumstance where otherwise non-raising speakers raise /aɪ/ in a finite set of words rather than through a consistent pattern. Examples of lexical raising include situations where speakers pronounce 'high school' as [hʌɪskul] but do not raise otherwise, or the production of raised tokens in some words before underlyingly voiced segments as in [tʌɪgɚ] 'tiger.' The presence of such lexical raising is a prediction of the TP, which explicitly allows for individuals to learn a non-productive pattern as a memorized list; in mixed input environments, a learner who fails to learn enough raised examples to acquire productive raising may still have learned some words as raised regardless. It is also entirely consistent for several lexically raised words to exist in uniformly non-raising communities, as long as few enough lexically raised items exist to render the potential generalization unproductive.

The predicted absence of stable transparent raising populations suggests possible approaches for studying transparent raising. Aggregate corpus studies such as Fruehwald (2016) are useful for tracking the spread of raising at a population level but are unlikely to find transparent raising if it exists, since speaker-by-speaker analysis of the historical data is likely required. Lab based methods may prove critical for finding more transparent raisers at large, and searching communities at the boundaries of the Canadian Raising region would be a good place to start. Future work should also investigate the distribution of lexical raising in such boundary communities and its relationship to transparent and canonical raising.

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