Fickle fricatives: Fricative and stop perception in Gurindji Kriol, Roper Kriol, and Standard Australian English

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ABSTRACT:

This paper uses a 2AFC identification task experiment to test listener perception of voiceless fricative-stop contrasts with minimal pairs modified along a 10-step continuum. Here, the authors focus on the uniqueness and near-uniformity of the phonological systems found in Australia. The languages involved in this study include Roper Kriol (an English-lexifier creole language), Gurindji Kriol (a mixed language derived from Gurindji and Kriol), with Standard Australian English (Indo-European) used as a baseline. Results reveal that just over 50% of the Roper Kriol and Gurindji Kriol listeners identified differences in the stop-fricative pairs with a high degree of consistency while nearly a quarter consistently identified the fricative-like stimuli as such, but showed random responses to the stop-like stimuli. The remaining participants showed a preference toward the fricatives across the entire continuum. The authors conclude that the fricative-stop contrast is not critical to the functionality of the phonologies in Roper Kriol or Gurindji Kriol, which could explain the high degree of variability. In addition, there is some evidence that the degree of exposure to English may have an effect on the degree of contrastability.
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(Received 25 February 2019; revised 17 July 2019; accepted 26 July 2019; published online 30 April 2020)

[Editor: Benjamin V. Tucker]   Pages: 2766–2778

I. INTRODUCTION

Australia is home to a number of English-based creoles and mixed languages, which offer a unique platform for examining how linguistic elements from distinct languages interact within a single system. One of the most understudied areas of contact language research involves the interactions and subsequent (re)-arrangements of their source phonologies. For mixed languages, their formation occurs in situations of advanced bilingualism and often involves the wholesale exchange of entire word classes or divisions between grammatical elements [see Meakins (2013) and Meakins and Stewart (2019) for an overview of mixed languages]. The sheer number of lexical borrowings coupled with the mastery of both languages often cause sounds that would otherwise assimilate or remain distinct under more "conventional" forms of language contact, such as borrowing or code-switching, to rearrange in non-intuitive ways (see Jones and Meakins, 2013; Jones et al., 2011; Rosen et al., 2016; Stewart, 2014, 2015, 2018a,b).

The goal of this study is to identify whether speakers of an English-based creole and a mixed language, containing varying amounts of English-derived lexicon, are able to acoustically distinguish voiceless fricatives ([f] and [s]) from their voiceless stop counterparts ([p^h] and [t^h]) in English-derived lexicon. This is of interest given that these contact languages have developed under the influence of traditional Australian languages, well-known for their lack of fricative-stop contrasts (Maddieson, 2011). We also test one case of [f] vs [p^h] as Stewart et al. (2018) showed that most Gurindji Kriol and Kriol listeners distinguish unaspirated and aspirated bilabial stops ([p^h] and [p]) aurally, while this was not the case for other places of articulation.

The languages involved in this study are spoken in northern Australia: Roper Kriol (henceforth Kriol), an English-based creole language spoken in the community of Ngukurr, and Gurindji Kriol, a mixed language spoken in the community of Kalkaringi. The latter combines linguistic elements of both Gurindji and Kriol [this lexical and grammatical fusion is shown in (1) with Gurindji origin elements in bold font and Kriol origin elements in normal font], and Standard Australian English (SAE) spoken in Brisbane, used as a control group as this dialect of English has a known fricative-stop contrasts (Cox and Palethrope, 2007).

(1) (O'Shannessy and Meakins, 2016)

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Dat man	**im** = **in**	**spiya-im**	(**im**)	dat guana	gat	jik	(K)
the man	3SG = PST	spear-TR	3GS	the goanna	PROP	stick	

↓

Man(-**tu**)	**i**	**bin**	**jarrwaj**	(**im**)	**dat**	**guana**	**karnti**-**yawung**	(GK)
man-ERG	3SG	PST	spear	3SG	the	goanna	stick-PROP	

↑   ↑

Ngumpit-**tu**	ngu = ø = ø		jarrwaj	pa-ni	**kirrawa**	**karnti**-**yawung**	(G)
man-ERG	CAT = 3SG = 3SG		spear	hit-PST	goanna	stick-PROP	

"The man speared the goanna with a stick."

Whether the language division in the morphosyntax of Gurindji Kriol [as seen in (1)] is reflected in the phonological system is one question addressed by this paper. This is of interest as the phonological system of Gurindji is standardly Australian (for example, the lack of a fricative contrast) and while the phonology of Kriol maintains some influences from SAE (via the original pidgin spoken on cattle stations across northern Australia), it is heavily influenced by its Australian source languages. The influence of English is especially noticeable in acrolectal Kriol varieties, which appear to have adopted phonemic contrasts from English (including phonemic fricatives) (Sandefur, 1979, 1984, 1986; Sandefur and Harris, 1986). On the contrary, basilectal varieties are closer to their Australian-language sources and lack phonemic fricatives. Recently, however, Bundgaard-Nielson and Baker (2016) have argued against the existence of a Kriol "continuum" and contend that much of the variation observed in earlier studies was due to speakers acquiring Kriol as an L2.

A. Fricatives and stops in English, Roper Kriol, Gurindji, and Gurindji Kriol

SAE, like most dialects of English, has clearly marked voicing contrasts in both the stop and fricative series in addition to fricative-stop contrasts (see, e.g., Cox and Palethrope, 2007). This can be seen in ample minimal pairs throughout the language (e.g., **b**et-**p**et, **d**ip-**t**ip, **g**ap-**t**ap, **f**at-**p**at, **s**ight-**t**ight, **v**ote-**b**oat, **z**ip-**d**ip). The "voiced" series of stops are produced with unaspirated (short-lag) voice onset times (VOT) while the "voiceless" series of stops are produced with aspirated (long-lag) VOT. Fricatives in both series are often longer than 130 ms in duration.

The number of substrate languages that have influenced Kriol, coupled with the high variation among basilect and acrolect varieties, has led researchers to call into question the exact nature of the phonological system that Kriol speakers operate. Most recently, Baker *et al.* (2014) used data from three bilingual Kriol-English speakers to suggest that the Kriol inventory is similar to that of Standard English in fricative-stop contrasts.

Traditional Gurindji phonology is considered typical of most Pama-Nyungan languages. It possesses a single series of oral stops, spread across five places of articulation, represented by the voiceless series, bilabial /p/, alveolar /t/, retroflex /ʈ/ palatal /c/, and velar /k/ (Meakins *et al.*, 2013). In addition, Gurindji does not contain a series of phonologically contrastive fricatives (Meakins *et al.*, 2013).

Turning to Gurindji Kriol, Jones and Meakins (2013) explored VOT production in Gurindji Kriol. They tested whether VOT durations systematically relate to those in SAE cognates. Their results suggest that there is little effect of the English contrast in Gurindji Kriol among words of SAE origin in word-initial position, although there is some degree of variability. Stewart *et al.* (2018) used an identification task experiment to examine the perception of minimal pairs in Kriol, Gurindji Kriol, and Gurindji, which differed in the degree of aspiration (long- vs short-lag) of word-initial stops. The Gurindji Kriol and Kriol listeners showed consistent response patterns to the aspirated series but more randomized responses to the unaspirated series, with the exception of the bilabial minimal pairs that showed a great deal of contrastability. The Kriol listeners showed marginally more consistent responses than the Gurindji Kriol listeners in the unaspirated-like token series. Stewart *et al.* (2018) conclude that Gurindji Kriol is currently in the process of adopting the contrasts through increased exposure to mainstream English through schooling. This is evidenced by the elderly Gurindji speaking listeners and very young children, who have little exposure and do not appear to be as advanced in the acquisition of stop voicing contrasts.

For fricatives in Gurindji Kriol, Buchan (2012) explored possible production contrasts between voiceless fricatives and stops ([f-pʰ] and [s-tʰ]) with an analysis of maternal speech in Gurindji Kriol. Her results suggest greater variability across place/manner of articulation in English origin words produced by L1 Gurindji Kriol speakers compared to English words produced by L1 speakers of SAE. Based on these findings, the importance of differentiating fricatives from stops may not yet be great enough to warrant explicit contrasts. However, for the three Kriol listeners tested in Baker *et al.* (2014, p. 336), fricatives already appear to form part of the phonemic inventory. Therefore, a high level of consistent responses to the stimuli might be expected.

Based on Buchan's (2012) analysis of fricative-stop production in Gurindji Kriol, we would hypothesize that Gurindji Kriol listeners may not have a strong perceptual

TABLE I. Minimal pair words used in the standard experiment task.

[f]-[pʰ/p]	[s]-[tʰ]
fut [fot] "foot" – *but* [pot] "boot"	*sedul* [ˈsadɫ] "saddle" – *tedul* [ˈtʰadɫ] "turtle"
filim [ˈfiːləm] "feel" – *pilim* [ˈpʰiːləm] "peel"	*seil* [saɪɫ] "sail" – *teil* [tʰaɪɫ] "tail"
fobala [ˈfoːbala] "four" – *pobala* [ˈpʰoːbala] "poor"	*sik* [sɪk] "sick" – *tik* [tʰɪk] "tick"
fok [foːk] "fork" – pok [pʰoːk] "pork"	*saun* [saʊn] "sound" – *taun* [tʰaʊn] "town"

contrast between fricatives and stops due to their variable use in production. For Kriol listeners, we predict similar results as Kriol phonology is greatly influenced by its substrate language(s) even though the majority of its lexicon is of English origin.

II. METHOD

This section outlines the methodology used to create and implement our identification task experiment. Section II A 1 details the stimuli used in the experiment and Sec. II A 2 describes the interface along with methodology used to present the data to the participants. In addition, Sec. II B outlines demographic information relating to the participants. The methodology used in this study follows that of Stewart *et al.* (2018).

A. 2AFC identification task

The 2AFC identification task used in this experiment was specifically designed to identify differences (or lack thereof) between fricative and stop consonant pairs based on the intuitions of native speakers of Gurindji Kriol, Kriol, and SAE. For the former two language groups, our experiments use English-source lexical items in Kriol that also form part of the Gurindji Kriol lexicon. The second experiment was run with adult speakers of SAE using similar stimuli as the previous experiment to judge the overall "goodness" of the experiments as SAE has well-known fricative-stop contrasts. Henceforth, we refer to these 2AFC identification task experiments as the "KGK experiment" (for Kriol and Gurindji Kriol speaking adults and children between the ages of approximately 10 and 58) and the "SAE experiment" (for speakers of SAE).

1. Stimuli

To gather stop perception data for our KGK experiment, we used eight word-initial minimal pairs of English-origin that contrast by a fricative and a stop in the same place of articulation (e.g., *sedul* [sadl] "saddle" and *tedul* [tʰadl] "turtle"). Each pair was found in both Kriol and Gurindji Kriol, where they maintain identical phonological shapes. Table I presents lexical data used in our 2AFC identification task. These words were chosen as they were all known to the listeners of both languages and nearly all were high frequency words, with the exception of *pok* "pork" and *seil* "sail," which fell in the mid frequency range.[1] The [f-pʰ] pairs contain four word-initial minimal pairs with one pair containing an unaspirated [p] (interpreted by both Gurindji

Kriol and Kriol speakers as /b/) to test whether aspiration makes a difference in fricative-stop perception as minimal pairs differing by word-initial /b-p/ were shown to be contrastive in Stewart *et al.* (2018). The [s]-[tʰ] series also contains four minimal pairs, all of which differ in word-initial position. However, since /d/ and /t/ were not shown to be distinguishable in Stewart *et al.* (2018), unaspirated (t) was not tested (though step 5 to approximately step 8 mimic unaspirated stops based on their VOT durations).

To gather stop perception data for our SAE experiment, we used four minimal pairs contrasting in word-initial position (see Table II). All pairs contain cognate words from the KGK experiment differing in the same place of articulation (e.g., *feel* [fiːɫ] and *peel* [pʰiːɫ]). Since the SAE experiment was only used to create a baseline, only four minimal pairs are used; two for [f-pʰ] and two for [s-tʰ].

Instead of using synthetic audio tokens for the stimuli, we modified natural speech to minimize quality issues that can make synthetic speech problematic (Vainio *et al.*, 2002). For both experiments, we manually modified several acoustic cues based on the percentage of the overall values of the original recorded tokens (see Fig. 1 and Table III). These included frication and aspiration duration, the first ten formant points in the following vowel, the overall pitch of the vowel, and duration of the following vowel. These acoustic cues were selected as we observed them to consistently differ in the original recordings of the fricative and stop pairs. This allowed us to limit the number of possible cues that could interfere with a chosen response, e.g., if the pitch, formant, and duration values of the fricative token at step 1 remained in the stop token at step 10, this stimulus could hypothetically present conflicting cues. We then combined any remaining portion of the original token containing the word containing the stop to create a more naturalistic sound sample.

For the KGK experiment, T.E., who is a native female speaker of Kriol from Ngukurr, produced the minimal pairs for each word in Table I. T.E. was recorded saying the pairs on an Edirol R09 portable digital recorder (Roland Corp. - Japan) using a Sony lapel mic (Sony Corp. - Japan). The sample rate was 44.1 kHz, and the files were rendered in 16-bit stereo WAV format. For the SAE experiment a native female speaker

TABLE II. Minimal pair words used in the SAE experiment task.

[f]-[pʰ]	[s]-[tʰ]
fork [foːk] – pork [pʰoːk]	sail [sæɪˈɫ] – tail [tʰæɪˈɫ]
feel [fiːˈɫ] – peel [pʰiːˈɫ]	sick [sɪk] – tick [tʰɪk]

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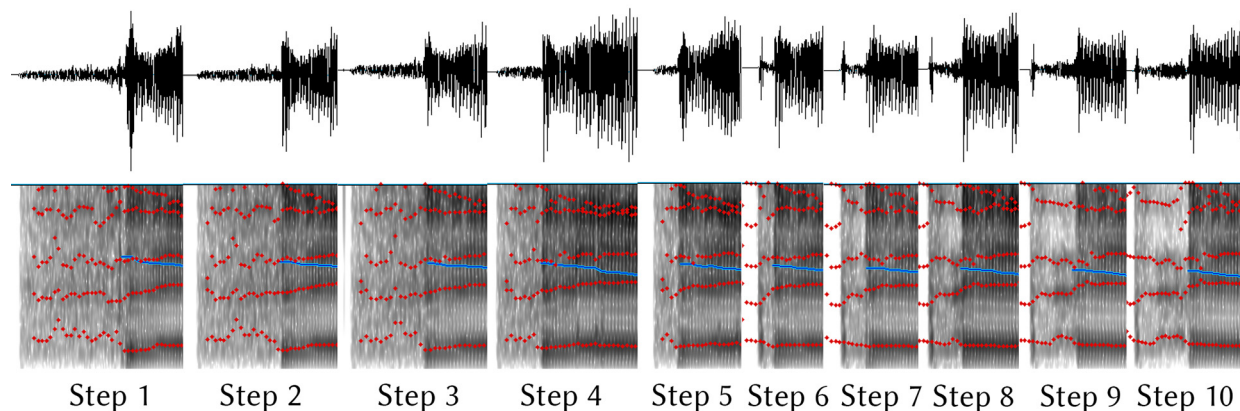
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FIG. 1. (Color online) Wave and spectrogram illustrations of each stop along the *seil-teil* "sail-tail" continuum.

of SAE from Adelaide was asked to produce the minimal pairs for each word in Table II. The same previously mentioned digital recorder and recording settings were used.

For both experiments, we gradually modified the tokens along a 10-step continuum at equal intervals based on the values identified in the original fricative and stop tokens (see Fig. 1 and Table III). Praat scripts to help automate portions of the process were written by J.S. For friction and VOT modification, we gradually shortened the noise of [f] and [s] of the first 5 stimuli by dividing the overall length of the frication by 5, then the next 5 stimuli involved lengthening the VOT of $[p^h]$ and $[t^h]$ by dividing the overall length of the VOT by 5 to cover a relatively large range of token samples. It is also worth noting that the burst portion of the stop remained in each stimulus.

To modify the pitch, a ridged diagonal falling tone across the vowel was created based on the fundamental frequency (Hz) taken at the beginning and end of the vowel in the original fricative token. These values were then incrementally shifted to match the values of the vowel in the original stop token. This process was achieved by opening the original tokens in Praat (Boersma and Weenink, 2016), and converting them to a *Manipulation* file with a time step of 0.01, a minimum pitch of 75 Hz, and a pitch maximum of 600 Hz. The file was then opened in the *View & Edit* window, and the *Stylize Pitch* function was set to 1.0, thereby reducing the number of pitch points (pitch points are represented with time along the *x* axis and frequency along the *y* axis). The first and last pitch points in the vowel were then

dragged up or down incrementally based on the calculated intervals and any remaining points in the middle were removed [*Pitch → Remove Pitch Point(s)*].

To modify the duration, each newly created token with modified pitch was opened individually in Praat and converted to a *Manipulation* file with the same values as previously mentioned. Next, each file was opened in the *View & Edit* window, and three duration points were added; the first point was added at the beginning of the vowel, the second at the end of the vowel, and the third at the middle of the vowel. The duration was then incrementally modified by dragging the midpoint up (slower) or down (faster) based on the calculated intervals.

To modify the values of the first 10 points of the *F*1, *F*2, and *F*3 formants, the tokens with modified durations and pitch were loaded into Praat, and a synthetic source-filter was created. The sound files were then resampled to 11 000 Hz (the standard for female speakers) with a precision value of 50 (as per Weenink, 2016, p. 219). Next, the resampled files were converted to *linear predictive coding* (LPC) *formants* (*burg*) with a prediction order of 10, a window-length of 25 ms, a time step of 5 ms, and a pre-emphasis frequency of 50 Hz. Then LPC and the resampled file were passed through an inverse filter. This process created a source-filter based on the resampled values and the formant information from the LPC file. This filter was later used to reconstruct the WAV file once the formant values were altered. The resampled token was then converted to a *Formant* (*burg*) file containing 5 formants (*F*1–*F*5) with a

TABLE III. [Fric]ation/ [asp]iration duration and mean post-vowel formant, pitch, and duration values across each continuum.

	Seil	Continuum steps								Teil
Correlates	1	2	3	4	5	6	7	8	9	10
Duration (ms)	178 fric	127fric	94 fric	61 fric	37 fric	19 asp	35 asp	55 asp	69 asp	88 asp
1st *F*1 point (Hz)	507	516	549	568	600	615	629	642	651	666
1st *F*2 point (Hz)	2052	2075	2082	2106	2148	2167	2173	2206	2232	2258
1st *F*3 point (Hz)	2964	2983	2965	2923	2974	2995	2961	2983	2897	2986
Pitch (Hz)	229	227	224	222	219	216	213	211	208	205
Vowel Dur. (ms)	479	487	499	511	523	536	548	560	572	584

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maximum possible formant value of 5500 Hz (the standard for female speakers). A window length of 25 ms and a pre-emphasis frequency of 50 Hz were also used. We then converted the formant file to a *FormantGrid* for editing. The frequency of all the vowel formant points from the first, second, and third formants were then gathered. This process was repeated for the first 10 $F1$, $F2$, and $F3$ formant points at equal steps along the continuum. After each point was modified, the *FormantGrid* and the inverse filter were both selected, and the *Filter* (*no scale*) function in Praat was applied. This produced a WAV file with the modified formant values. It should be noted that passing the FormantGrid through the filter slightly alters the pitch and formant adjustments. This results in continua that are not perfectly spaced at each interval. For example, Fig. 1 and Table III illustrate this effect of *seil-teil* "sail-tail" across the continuum. While this phenomenon does not affect a listener's ability to identify or ignore the overall contrasts, it may slightly alter where the categorical boundary between the fricatives and stops appears, if they are indeed distinguishable.

The differences in duration between the steps for each minimal pair in the KGK experiment are the same for the cognate minimal pairs in the SAE experiment to maintain similar experimental conditions. As the modified values become more distant from their prototypical forms, responses are predicted to become more random, if any degree of contrasts indeed exists. Alternatively, if a participant perceives the stimuli as the same, we would expect random responses throughout the continua or a listener may choose to assign anything that does not sound like a prototypical X to the Y category. However, if only one token appears phonemically in a participant's inventory, we expect they will consistently select the token at one end of the continuum while responses at the other end will be more random. If there is indeed a contrast found, using the 10-step continua allowed us to home in on the categorical boundaries of each minimal pair based on the 50% crossing point between the canonical forms.

2. Presentation

This section describes the user interface of the experiments. For the standard and SAE experiments, the 10 tokens of each minimal pair, described in Sec. II A 1, were placed in their own Power Point presentation along with corresponding images of each minimal pair (Fig. 2).

To achieve more accurate results, we designed both experiment presentations to have additional repeats of the most distant stimuli from the prototypical forms. Therefore, the participants who took part in the KGK experiment listened to the same minimal pair series along the continua 16 times for a total of 130 token samples when taking into account all eight minimal pairs. For the SAE experiment, this included 19 repeats for a total of 95 token samples when taking into account all four minimal pairs.

For both experiments, the Power Point presentation was set to play each token 50 ms after each new slide appeared on the screen. The presentation was also configured to use "Kiosk" mode restricting where the participant could click on the screen to just the images in order to move to the following slide. Each image was scripted using the Visual Basic for Applications (VBA) add-on in Power Point to record the participant's individual response for each slide. To avoid any type of pattern recognition in the data, the slides were reordered using a randomization macro. We then further adjusted the slides to make sure no two contained the same images in a row. For both experiments, example stimuli were presented before the experiment began and one slide containing a token from step 10 was placed at the beginning of the experiment. This provided the participants with practice and a prototypical form to get their bearings before being presented with non-prototypical forms at random.[2] For the KGK experiment, seven distractor tokens involving stop voicing minimal pairs were added to the experiment to reduce the constant repetition of the same eight minimal pairs. These included the words: *bak-pak* "bark-park," *boring-poring* "boring-pouring," *bai-pai* "sleep-pie," *dai-tai* "tie-dye," *traiyimat-draiyimat* "try-dry," *garram-katim* [ˈɡa.ɾəm/ ˈka.ɾəm] "have-cut," and *gol-kol* "gold-coal." For the SAE experiment, two distractor tokens were added to the experiment; these included *bark-park* and *boring-pouring*. The distract tokens were created and presented in a similar fashion. At the end of the experiment, Power Point was programmed to create a text file containing all of the participant's responses and demographic information collected on the first slide.

B. Participants

One hundred and eighteen participants took part in this experiment. This included 50 Gurindji Kriol listeners (43 F), 20 Kriol listeners (16 F), and 48 SAE listeners (35 F). Of the Gurindji Kriol listeners, 44 had a high level of exposure to SAE and 6 had low exposure. Thirty of these participants also had high exposure to Gurindji and 20 had low exposure. For the Kriol listeners, 19 had a high level of exposure to SAE and 1 had low exposure. Three of these participants had high exposure to a local traditional language such as Marra, and 17 had low exposure.

C. Procedures

For both experiments, the participants were told in Gurindji Kriol or Kriol, depending on their vernacular language, that they would hear a variety of words and their task was to choose the image that corresponded to the audio stimuli. The participants were also told that if they would like to hear the audio sample again, they could click on a speaker icon located at the bottom of the slide. However, we urged them to go with their first instinct. It was also mentioned that the words would be repeated many times and that some of them might be harder than others to understand but to try their best. Before beginning the experiments, we reviewed the minimal pairs with each participant with a printout of the picture pairs. This was to help avoid any
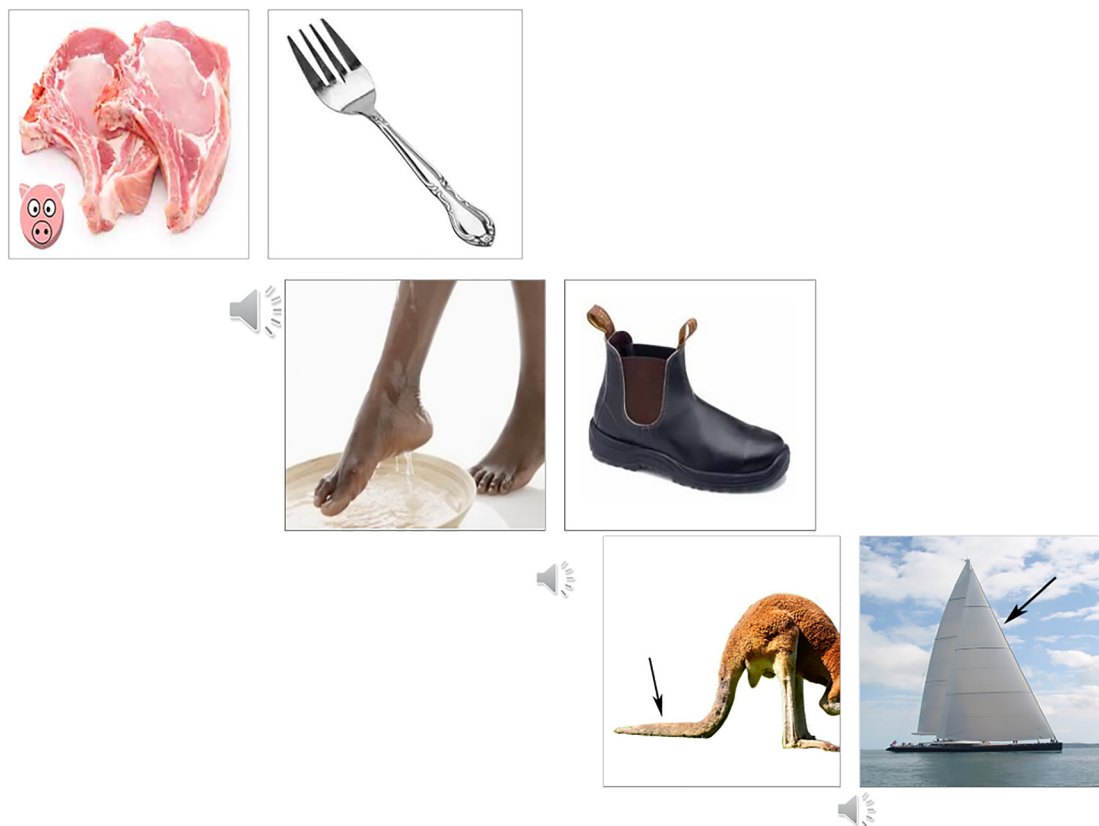
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FIG. 2. (Color online) Three slides from the Gurindji Kriol/Kriol 2AFC identification task. The top left slide shows the minimal pairs *fok* "fork" and *pok* "pork." The middle slide shows the minimal pairs *fut* "foot" and *but* "boot." The bottom right slide shows the minimal pairs *teil* "tail" and *seil* "sail."

confusion corresponding the images with the audio samples during the task. For the KGK experiment, the participants were told the entire task lasted about 15–20 min and there were no right or wrong answers. The participants performed the task on a PC laptop and noise canceling headphones for the experiments. Participants were monetarily compensated for their time.

III. RESULTS

This section is divided into two sections. Section III A details the SAE experiment, used as a baseline to judge the overall goodness of the experimental design. This was crucial since SAE contains well-known fricative-stop contrasts. If participants do not identify consistent differences in the minimal pairs, the experiment would require re-evaluation. Section III B details the Kriol and Gurindji Kriol experiment, which tests fricative-stop perception in Kriol and Gurindji Kriol.

To quantify the results, we built a generalized linear mixed effects model for the KGK experiment.[3] Logistic regressions help answer two basic questions: (1) is there a difference among the languages at the intercept?[4] And (2) do the slopes of the curves differ across the continuum by language? To answer the latter question, the models contain interactions between *continuum* and *language*. These models also look for differences across participant age range and

differences based on place of articulation (labial and alveolar).

The mixed effects model was created in R 3.2.1 with the *lmer* function of the *lme4* package (Bates *et al.*, 2015). Ninety-five percent confidence intervals (CI_{95}) were computed using *confint* function from the *lmerTest* package (Kuznetsova *et al.*, 2016). Each model included *speaker* and *word* as random effects. We considered the following predictors (fixed effects) for each model: *continuum* (steps 0–9), *sex* (female, male), *language group* (Gurindji Kriol, Kriol), *place of articulation* (labial, alveolar), *age*, *exposure to English* (low, medium, high),[5] *exposure to a traditional language* (low, medium, high),[6] and *word frequency of each word in the minimal pairs* (low, medium, high). Non-significant predictors were removed from the model one-by-one based on the closest z-value to zero, until only significant predictors remained.

Each section includes line plots containing the trajectories of the participant responses for each language group along the continuum. For additional analysis, line plots broken down by word are also included. This section also includes the results from the model summary of the generalized linear mixed effects model. When a result is significant, we are most interested in the coefficient estimate (*β*), a conservative estimate of the average difference in log-odds (a measurement of probability) response between the predictors in question. For example, a negative log-odd result for

continuum means the likelihood of a participant choosing a fricative token decreases *x* amount per step, while a positive log-result for *language* simply means a given variable, e.g., *alveolar*, was chosen significantly more than another by a specific language group. Because the continuum has fricatives on the left and stops on the right, the continuum variable should not be positive if there is indeed any degree of contrast between fricatives and stops.

A. SAE experiment

The results found in this section detail the participant responses to the SAE experiment. This section contains line plots for both the [f-p^h] and [s-t^h] minimal pair.

The raw data in Fig. 3 can be interpreted with three metrics: (1) where the categorical boundary falls for each place of articulation (i.e., the continuum step on the *x* axis where the trend line crosses the 50% line on the *y* axis), (2) the percentage of fricative responses for the canonical fricative stimulus (i.e., the percentage point at the first step of the continua), and (3) the percentage of fricative responses for the canonical stop stimulus (i.e., the percentage point at the last step of the continua). Overall, SAE listeners were able to identify acoustic differences in the stimuli produced in the labial and coronal regions with a high degree of consistency.

The average categorical boundary for the labial series (solid blue line in Fig. 3) appears just after step 4, and the percentage of fricative responses at the first step is 98% and 2% at the last step (step 9). For the coronal series (dotted red line in Fig. 3), the canonical boundary appears between steps 3 and 4, and the percentage of fricative responses at the first step is 100% (step 0) and 1% at the last step (step 9).

In both cases, listeners identified canonical stimuli with a high degree of precision. With respect to perception of the individual words, there is a slight deviation where the categorical boundaries appear for the [f-p^h] stimuli, with *feel-peel* appearing just before step 2 and *fork-pork* between steps 4 and 5. However, the categorical boundaries for the [s-t^h] stimuli both appear between steps 3 and 4. This suggests listeners identified more instances of [p^h] compared with [t^h]. These results reveal that the techniques used to create the continua stimuli render consistent and predictable
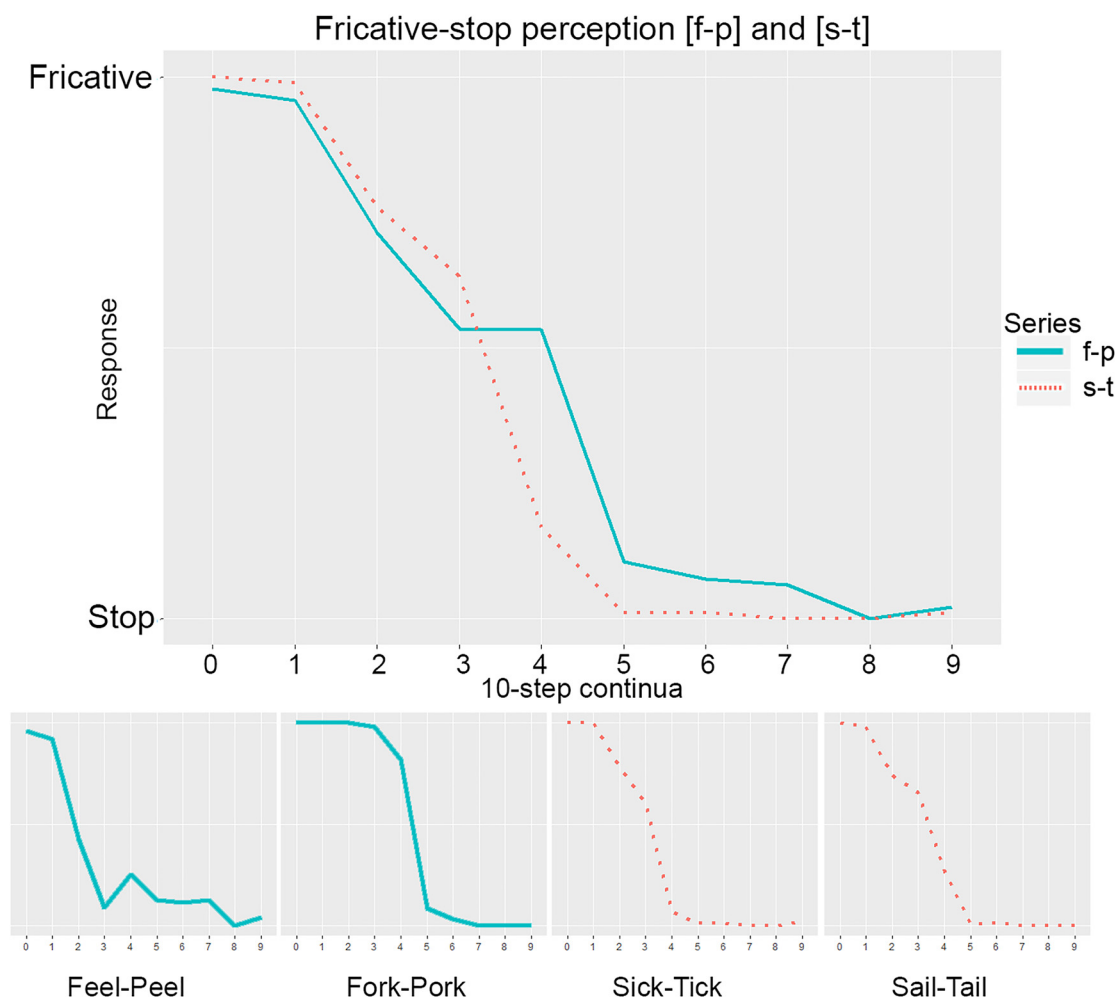

FIG. 3. (Color online) The top image represents the mean average of the responses to the [f-p^h] (solid blue line) and [s-t^h] (dotted red line) stimuli across the continua. The canonical fricative token is on the left (step 0) while the canonical stop token is on the right (step 9). The lower images represent the mean average of the responses to each one of the individual words across the continuum (from left to right, *feel-peel, fork-pork, sick-tick,* and *sail-tail*).

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results from participants with known fricative-stop contrasts. Due to the ceiling and floor results at steps 0 and 9, respectively, the experiment was judged a success, allowing us to confidently use the same methodology in in the KGK experiment (Sec. III B).

B. KGK experiment

The results found in this section detail the participant responses to the KGK experiment. This section contains line plots for both the [f]-[pʰ] (Fig. 4) and [s]-[tʰ] (Fig. 5) minimal pair responses in addition to the results of the linear mixed effects model. It should be noted that due to the novelty of the experiment and the computer component, near-ceiling and near-floor results were not predicted.

Similar to the results in Sec. III A, the raw data in Figs. 4 and 5 can be interpreted with three metrics: (1) where the categorical boundary falls for each place of articulation, (2) the percentage of fricative responses for the canonical fricative stimulus, and (3) the percentage of fricative responses for the canonical stop stimulus.

For the labial series ([f-pʰ]), the average categorical boundary for both Gurindji Kriol and Kriol listener responses (Fig. 4) appears between steps 6 and 7. For the Gurindji Kriol listeners (dotted green line in Fig. 4), the percentage of fricative responses is 74% at the first step (step 0) and 46% at the final step of the continuum (step 9). For Kriol listeners (solid purple line in Fig. 4), the percentage of fricative responses is 65% at the first step (step 0) and 45% at the final step of the continuum (step 9).

Regarding perception of individual words, Fig. 4 shows both Gurindji Kriol and Kriol listeners showed varied responses to the *filim-pilim* "feel-peel" stimuli across the entire continuum. In contrast, listeners responded differently to the *fok-pok* "fork-pork" stimuli suggesting that they were able to identify differences between both the canonical fricative and canonical stop stimuli with a moderate degree of consistency. For the other of the word pairs (*fut-but* "foot-boot" and *fobala-pobala* "four-poor"), listeners identified the first two tokens (canonical [f] and the second step) with a high degree of consistency while responses to canonical [pʰ] were more random. Interestingly, participants from both the Gurindji Kriol and Kriol groups had very similar

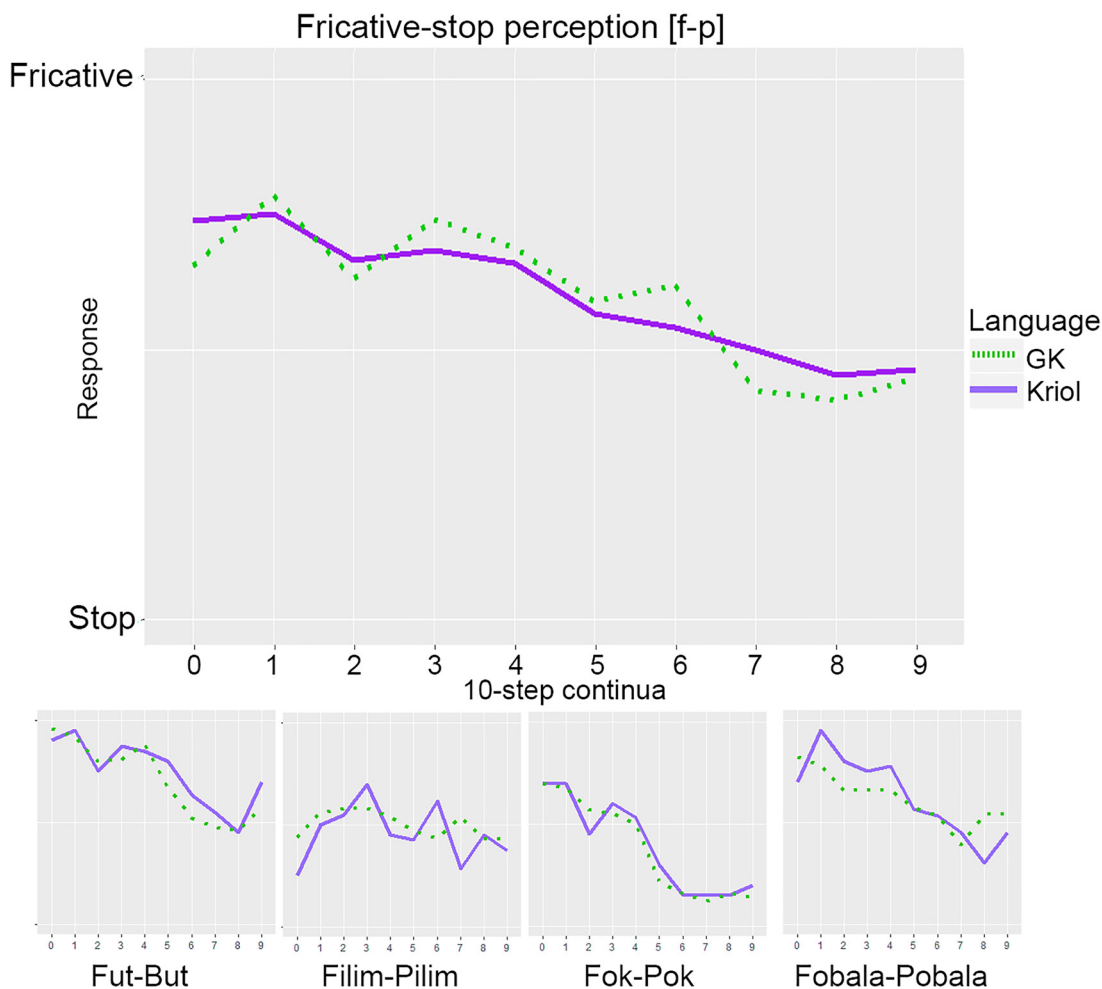FIG. 4. (Color online) The top image represents the mean average of the responses to the [f-pʰ] stimuli across the continua. The canonical fricative token is on the left (step 0) while the canonical stop token is on the right (step 9). The lower images represent the mean average of the responses to each one of the individual words across the continuum (from left to right, *fut-but* "foot-boot," *filim-pilim* "feel-peel," *fok-pok* "fork-pork," and *fobala-pobala* "four-poor").

responses to the individual words. Moreover, the unaspirated VOT of the stop in the *fut-but* foot-boot does not appear to increase or decrease the ability to identify minimal pairs contrasting by word-initial fricative and stops.

For the coronal series ([s-tʰ]), the average categorical boundary for the Gurindji Kriol listener responses (dotted green line in Fig. 5) appears just before step 4, and the percentage of fricative responses is 60% at the first step (step 0) and 21% at the final step (step 9). For Kriol listeners (solid purple line in Fig. 5), the canonical boundary appears between steps 4 and 5, and the percentage of canonical responses is 72% at the first step (step 0) and 25% at the final step (step 9).

Overall, Fig. 5 suggests that both Gurindji Kriol and Kriol listeners appear to identify differences between [s] from [tʰ] with a moderate degree of consistency. It is worth mentioning again that while the results are not near-ceiling/near-floor, the consistent negative trend line suggests that some degree of consistent response patterning is present.

It is important to note that when combining all of the minimal pairs into a single average, there was a relatively high degree of variation in the participant results for both groups. Some speakers were able to distinguish both series ([f-pʰ] and [s-tʰ]) with a high degree of consistency. Others showed more consistent responses to the fricative series but had random responses for the stop series. Several others preferred the fricative series across the continuum while a limited few actually showed a reverse trend; choosing the fricative token toward the end of the continua and vice versa. Figure 6 shows four individual listener responses that match these patterns and provide numbers of how many participants displayed each trend. These results will be further discussed in Sec. IV. Overall, fricatives appear to be the preferred series during the identification task, with the majority of speakers showing a clear contrast between the fricative and stop pairs.

Table IV contains the results from the generalized linear mixed effects model using *response* as the dependent variable. Based on the model output, the intercept contains the following four baseline categories: (1) the first step of the continuum, (2) the high/mid exposure to English group, (3) the Gurindji Kriol participant responses, and (4) the coronal series ([s-tʰ]).

The intercept, with a "base" value[7] of 1.1 log-odds, suggests that the probability of Gurindji Kriol participants, with
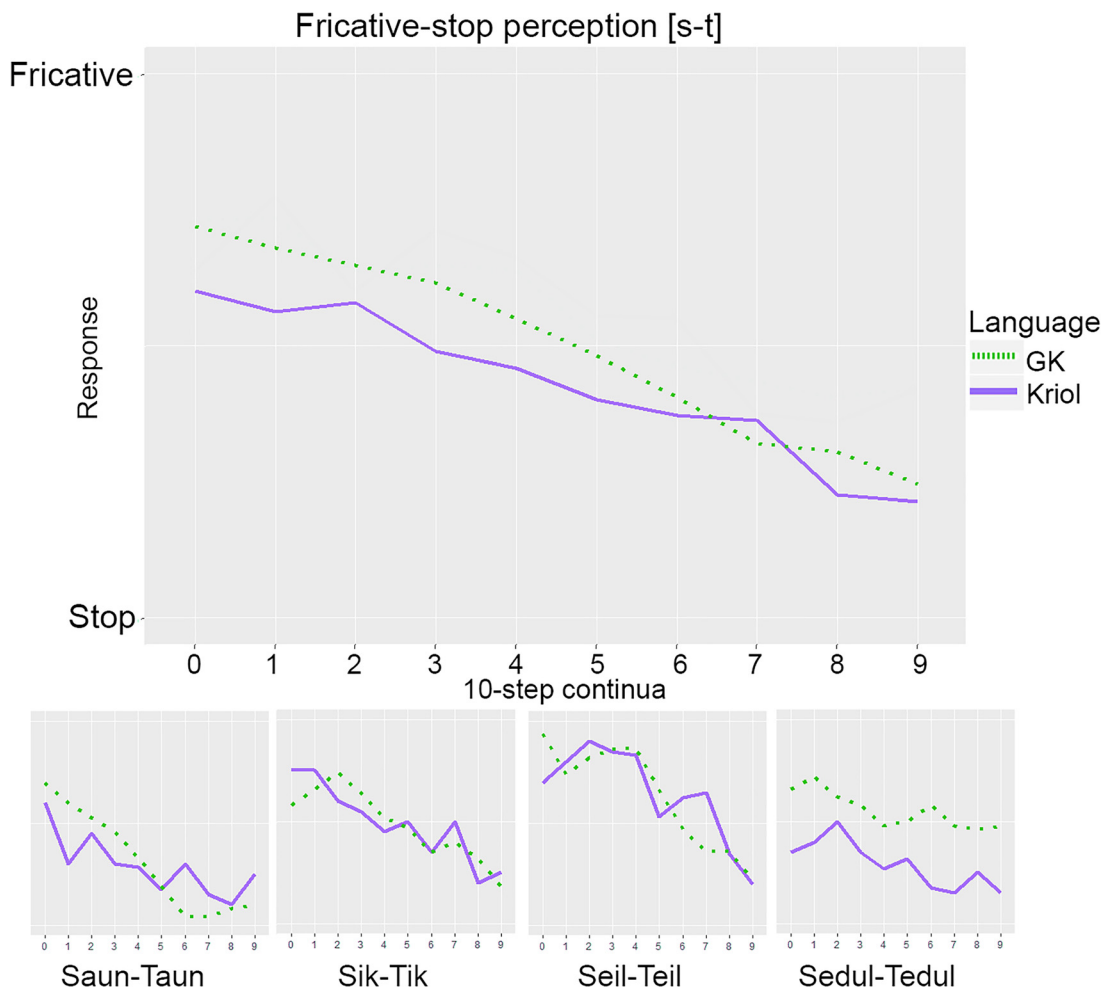

FIG. 5. (Color online) The top image represents the mean average of the responses to the [s-tʰ] stimuli across the continua. The canonical fricative token is on the left (step 0) while the canonical stop token is on the right (step 9). The lower images represent the mean average of the responses to each of the individual words across each continuum (from left to right, *saun-taun* "sound-town," *sik-tik* "sick-tick," *seil-teil* "sail-tail," *sedul-tedul* "saddle-turtle").

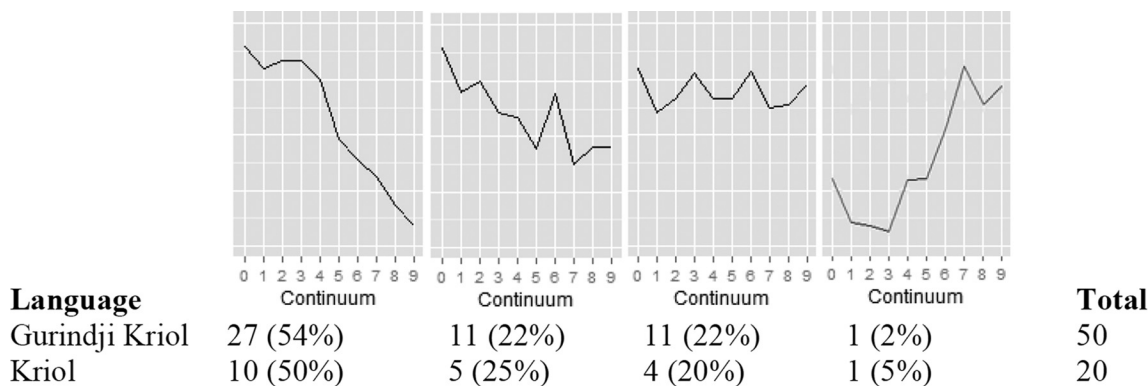| Language	Continuum	Continuum	Continuum	Continuum	Total
Gurindji Kriol	27 (54%)	11 (22%)	11 (22%)	1 (2%)	50
Kriol	10 (50%)	5 (25%)	4 (20%)	1 (5%)	20

FIG. 6. Individual participant perceptual trends across both places of articulation combined.

high/mid exposure to English, selecting the image containing the word-initial [s], upon hearing its canonical token at the beginning of the continua was 75%. This probability decreased by, on average, −0.24 log-odds per step along the continua. By the final step, the probability of selecting the image containing word-initial [s] upon hearing the stimuli containing the word-initial canonical stop token ([tʰ]) was 25%. The probability of Kriol participants selecting the image when hearing the canonical [s] fricative token significantly decreased to 69%. By the final step, the probability of selecting the image with word-initial [s] image upon hearing the stimuli containing the word-initial canonical stop [tʰ] token was 20%.

For the labial series, the probability of Gurindji Kriol participants with high/mid exposure to English, selecting the image containing the word-initial [f], upon hearing its canonical token at the beginning of the continua was 80%. By the final step, the probability of selecting the image containing word-initial [f] upon hearing the stimuli containing the word-initial canonical stop token ([pʰ/p]) was 31%. For the Kriol group, these results barely changed (80% and 33%, respectively) when taking into account the *Kriol*labial* interaction.

It should be noted that there was a high degree of variation in the *labial* responses as indicated by the standard error value of 0.039, which can most likely be attributed to the varied response patterns illustrated in the individual word-pair graphs in Fig. 4. Based on the *Kriol*labial* interaction, this also suggests that there might be more variations in how

TABLE IV. Generalized linear mixed effects model results for fricative-stop perception.

Variable	Estimate	Std. E	2.5%	97.5%	Z	Pr(>|z|)	
(Intercept)	1.1	0.28	0.52	1.63	3.81	0.00014	***
Continuum	−0.24	0.01	−0.26	−0.22	−22.36	$<2 \times 10^{-16}$	***
Low Exp Eng	−0.34	0.20	−0.73	0.05	−1.71	0.088	.
Kriol	−0.30	0.11	−0.52	−0.09	−2.80	0.0052	**
Labial	0.27	0.39	−0.49	1.03	0.69	0.49	
Cont*Low Exp Eng	0.12	0.03	0.06	0.18	3.79	0.00015	***
Kriol*Labial	0.36	0.10	0.15	0.56	3.43	0.00061	***

fricatives are perceived in Kriol than in Gurindji Kriol, indicating a subtle difference between the languages' phonologies.

Response patterns across the continua from both language groups were significantly affected by their exposure to SAE as indicated by the *Continuum—Low English Exposure* variable interaction. As graphed in Fig. 7, this result suggests listeners with a low level of exposure to English had more varied responses across the continua and showed reduced consistency in their responses to the canonical forms at the end of the continua.

Including the *Low Exposure to English* variable, the average categorical boundary for Gurindji Kriol listener responses appears between steps 4 and 5. For Kriol listeners, the canonical boundary appears just after step 3 for the alveolar series and between steps 5 and 6 for the labial series.

IV. DISCUSSION

Gurindji Kriol and Kriol provide a unique platform for exploring language contact. The development of Gurindji Kriol, in particular, involves a history of at least two stages of phonological reorganisation. The original pidgin language, which led to Kriol, appears to have taken the brunt of the phonological turmoil during the rearrangement of the English and Aboriginal source phonologies. Based on the resulting Kriol, it appears the pidgin heavily sided with the sound systems of Australian languages (fewer voicing and manner contrasts). This left the creators of Gurindji Kriol with relatively few phonological differences between their two source phonologies: Kriol and Gurindji. This is in marked contrast to other mixed languages such as Media Lengua and Michif that have very different source phonologies [see Bakker (1997) for Michif and Stewart (2015) for Media Lengua]. However, one place where Gurindji Kriol and Kriol have both deviated from traditional languages is in their fricative inventory (cf. Baker *et al.*, 2014).

The results of this study paint an interesting picture of two contact languages with varying degrees of fricative-stop contrasts, which cluster into various patterns. While over 50% of the listeners of Gurindji Kriol and Kriol were able to distinguish [f] from [pʰ] and [s] from [tʰ], nearly a quarter of the listeners only clearly identified the fricative-like stimuli

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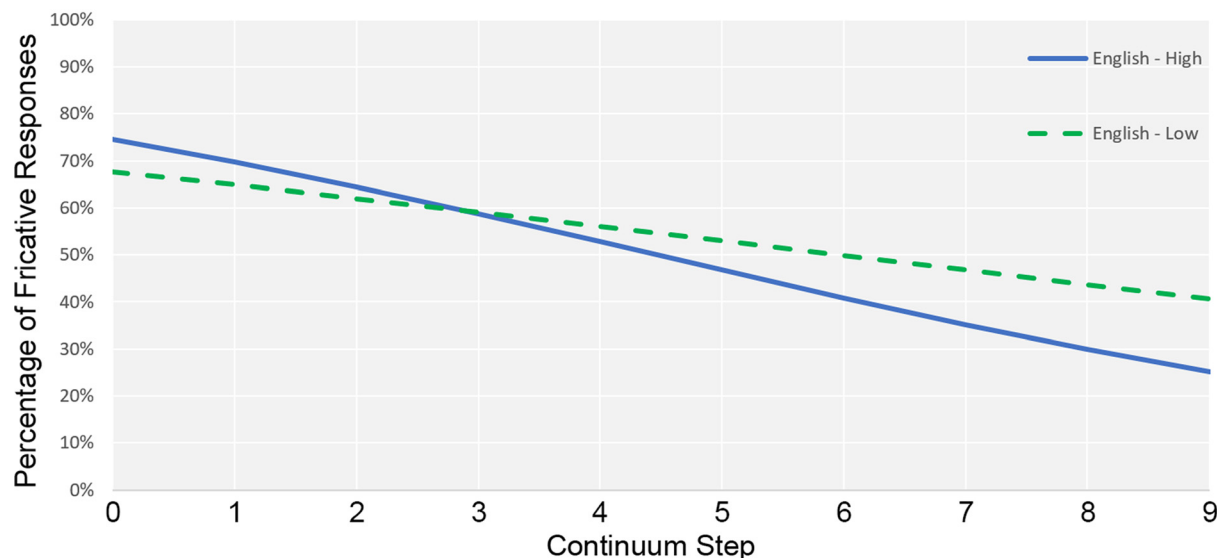
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FIG. 7. (Color online) Differences in response patterns based on exposure to SAE. Listeners with low exposure to SAE (dashed green line) show more varied response patterns compared to those with high exposure to SAE (solid blue line).

while showing random responses to the stop-like stimuli. Furthermore, nearly half of the participants identified the stimuli as fricatives across the entire continua.

This degree of variable identification does not reflect languages with a clear fricative-stop phonemic contrast as part of their phonological make-up (like SAE). Instead, most Gurindji Kriol and Kriol listeners appear to notice there is a difference in the sound sets, yet the distinction does not appear to be an important contrast. In the case of Gurindji Kriol, this suggests that its source phonologies were adequately optimised for dealing with the large fusion of the Gurindji and Kriol vocabulary during the development of the mixed language. The fact that listeners are able to identify differences in the fricative-stop pairs (although not to the degree we would expect in a language with a clear phonemic contrast, such as SAE) may suggest this phenomenon is a recent ongoing development or simply the sounds are sufficiently distinct that some listeners can identify them as different; even if the difference is not a productive part of their language. If the contrast is indeed in the midst of developing, it may be the fact that the functional load (the degree of importance given to a specific contrast in a language) has not increased to the point where a clear contrast is warranted in order to maintain an optimal phonology. As listeners begin to use English more and more, their ability to identify cognates will also improve, which may translate into a shift in pronunciation in the Gurindji Kriol and Kriol cognates. In fact, this can already be seen to some degree as those with higher exposure to English who participated in the KGK experiment, appeared to identify the canonical stimuli with a greater degree of consistency compared to those with less exposure to English.

Mixed languages and creole languages have been shown to essentially conform to the phonological make up of their ancestral source language(s), e.g., Media Lengua sounds like Quichua, Michif sounds like Cree, and in Haitian Creole the relexified French vocabulary conforms to Fon phonology in many aspects (Lefebvre, 1998). Similarly, Kriol, and by proxy Gurindji Kriol, sound more like their ancestral languages than SAE. This propensity for phonological material to conform to the language spoken before the introduced language appeared may affect the contact variety in a number of ways. If we look at their arrangements, elements that are transferred from the introduced language appear to organise in a similar fashion to the way a mid or late bilingual acquires their second language. Here, contrastive sounds may (1) collapse into a single non-contrastive sound (see the Gurindji Kriol stop system described in Stewart et al., 2018), (2) function with a substantial degree of overlap (see Media Lengua, Stewart, 2014, 2018b), and Michif (Rosen et al., 2016, for vowel systems), or (3) overshoot may occur (see the Media Lengua stop system described in Stewart 2015, 2018a), in addition to other arrangements. This type of acquisition, in which sounds may not be fully acquired to the same degree as they exist in the introduced language, may affect the degree of saliency in a contrast. This may leave speakers and listeners with a phonological system that may not be optimal for dealing with a new vocabulary.

It is also worth noting that such phenomena not only occurs in language contact scenarios but have also been observed in non-contact language phonologies where there is "variable degrees of contrast" (Goldsmith, 1995) or "intermediate phonological relationships" (Hall, 2013). In the Australian context, Butcher and McEntee (2018) have shown this to be the case for Adnyamathanha phonology. Evidence from such studies provide additional support to well-established notions that phonological systems are in a

constant state of flux as languages change and evolve over time. This in turn suggests that phonological stability could be better understood as a temporary synchronic state which may seem static over a lifetime or longer. Yet, during certain phases of phonological change, contrastability among certain phonemes may be gradient. This could require listeners to abandon a contrast all together, rely on other non-acoustic cues such as context, or allow for greater flexibility during the identification of a given sound. Assuming that such a gradient phase indeed exists during the evolution of a sound system, Gurindji Kriol fricative-stop contrasts may very well be in the midst of such a phase based on the results of this study.

Given that language contact is well-known to accelerate language change, speakers may be put into a situation where decisions (conscious or not) to ignore, adopt, or partially adopt sound contrasts may be needed. For the speakers of the original pidgin language, which contributed to both Kriol and Gurindji Kriol, it appears fricative-stop contrasts were not highly critical. This could have led to the variable degrees of contrasts currently found in the languages today. Indeed, the contrast is even less critical in Gurindji Kriol, which draws equal amounts of vocabulary from Gurindji and from Kriol (and therefore English), compared with Kriol (deriving most of its lexicon from English). However, according to Baker *et al.* (2014), later generations of Kriol speakers appear to have acquired both stop voicing contrasts and fricative-stop contrasts productively (although their conclusions are based on just three bilingual Kriol-English speakers). While there is no clear correlation between production and perception, it is curious that speakers may be producing such contrasts but with only limited perception. It may suggest that sounds have become desirable either for aesthetics (to sound more like English, the language carrying more social prestige) or for cognitive processes (lessening the strain on the phonological system). Results from Stewart *et al.* (2018) suggest that only about 35% of the Kriol participants tested (7 of 20 adult listeners) showed a clear ability to identify differences in stop voicing in all three places of articulation (labial, alveolar, and velar). The difference between production and perception may also simply suggest that there is a change in progress, or the contrast is just not important for comprehension.

For Gurindji Kriol listeners, Stewart *et al.* (2018) also show listeners are acquiring the stop voicing contrast although they appear to be trailing slightly behind the Kriol listeners. Those with increased exposure to English also showed a slightly greater ability to identify differences in stop voicing. For the fricative-stop contrasts described in this study, however, listeners from both groups appear to be further along in identifying differences. It would be of great interest to run a similar identification task experiment in 20 year time to see if the contrasts have become more salient or have remained variable across individual speakers.

[1]Frequency thresholds were based on an 80:20 h (59 933 clause) morphologically tagged corpus of speech from 73 Gurindji Kriol speakers. *Frequency* is considered as a statistical predictor in Sec. III to account for any variation between mid and high frequency words.

[2]An anonymous reviewer pointed out that placing prototypical tokens (step 10) at the beginning of the experiment could have inadvertently caused a bias. Therefore, we ran a McNemar's Chi-squared test with continuity correction on the responses from steps 10 and 9. We predicted that, under normal conditions, participants would not notice a difference in the stimuli as step 9 is nearly prototypical; therefore any variation in the response patterns might be attributed to a bias. However, results showed non-significant variation in how participants responded to steps 10 and 9 [McNemar's chi-squared = 0.061644, df = 1, *p*-value = 0.8039]. Therefore, we consider any bias to be negligible.

[3]Statistical analysis for the SAE experiment was not run due to the homogeneity of the response patterns (see III A).

[4]In this case by subtracting 1 from each step of the continuum so that the model treats step 1 as the intercept. All line plots are also presented in the same format (0–9).

[5]Exposure to English was based on the number of years of schooling where people have the greatest exposure to English (lower primary school = low; mid-high primary school = medium; high school/tertiary = high). This functions as a reliable correlate to judge overall English proficiency. Standard English is often taught under unguided conditions (i.e., explicit instruction in ESL is not part of the curriculum).

[6]Exposure to a traditional language was based on whether the person spoke the language or the number of years that a participant lived with a speaker of the language (speaker = high; grown up with speaker = medium; exposure only in the community to speakers but not at home = low).

[7]Most results are displayed to two decimal places, though calculated to the fifth decimal place.

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