An acoustic and perceptual study of the Spanish sound change s > h

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Examination of acoustic properties of [s] and [h] and of listeners' perception of laryngeal adjustments for [s] in a preceding vowel suggests a phonetic explanation for the sound change s > h in Spanish that is based on universal principles. While many of the ordinarily robust perceptual cues for [s] are degraded in the original conditioning context of the sound change, vowel margins preceding [s] show a breathy voice quality whose auditory properties mimic the effect of postvocalic [h]. I hypothesized that, in the absence of a strong [s], this murmured vowel offset might be perceived as intentional aspiration. Two perceptual tests were designed to assess listeners' interpretation of this effect by preparing stimuli consisting of a vowel extracted from an [s] environment which was then framed in a context devoid of any sibilant noise. Results indicate that listeners identify a significant number of such stimuli as containing lexical /s/ and as originating from informal discourse, in much the same way that Spanish speakers today process aspiration that is naturally produced. Such findings support the proposed mechanism underlying the historical change.

1. Introduction

Spanish is currently undergoing a sound change in which the alveolar sibilant is reduced to a breathy sound, a phenomenon which Spanish linguists have labeled s-aspiration and have formalized as s > h. The change originally affected [s] in syllable-final position, but has since spread to prevocalic environments. The aspirate pronunciation is a regional characteristic of extensive areas of the Spanish speaking world and is a defining feature of informal discourse. Often syllable-final [h] is subsequently eliminated as a consequence of its low auditory saliency before another consonant.

From an historical perspective, the shift s > h > 0 represents a change in progress that is steadily spreading among speakers of Spanish. While recent studies have focussed on the accommodation of the language system to this change (see Guitart (1983) and Terrell (1982) for reviews), our knowledge of the physical mechanism underlying the innovation itself remains inadequate. Phonetic arguments addressing the initiation of s-aspiration have been limited to only the most general formulations in terms of articulatory weakening and gradual change[1] (e.g. Terrell (1979)). Similar changes in other languages such as Old

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French, Greek, etc. suggest that there may be overriding phonetic principles operating to constrain the shift in the given direction. With regard to the phenomenon in Spanish, Guitart (1982:69) claims that it responds to "certain physiological inevitabilities in human pronunciation" and Terrell (1981) concurs:

> [...] the development of this sound change is due more to universal constraints on sound change in general than on [sic] the specific situation of the speech communities which have participated in the change [...]. An explanation for such universal tendencies will no doubt be found from articulatory and acoustic phonetics (116-17).

Since the shift from [s] to [h] involves the fricative sounds it seems likely that perceptual considerations also play a motivating role. Changes stemming from the auditory similarity of the acoustic signals of fricatives are common in Spanish (e.g. f > h, s > ʃ, s > θ, ʃ > x, x > f) as well as in other language systems and are well documented experimentally in laboratory studies (relevant studies reviewed in Krieg (1980)).

The purpose of the present study is to explore a phonetic basis for the Spanish sound change s > h by examining the physiological, acoustic, and perceptual features involved in the production and identification of these sounds. First, it will be shown how naturally occurring modifications in the acoustic signal of VsC sequences degrade the signal of [s], potentially leading to misperceptions of [s] as an [h]-like sound. Then, two perceptual studies will be presented which test the viability of such an explanation.

2. Phonetic correlates of s-aspiration

It should be noted from the outset that the formula s > h is a notational convenience which does not reflect the precise physical nature of the sounds involved. The essential quality of aspiration is breathy phonation near vowel margins with some optional turbulence in the vocal tract, not necessarily in the glottalic region (Kim 1970). [s]-aspiration results in postvocalic breathiness, the acoustic properties of which may only approximate those of initial [h] (Lehiste 1964). Thus, in the exposition that follows no claim is made that the signal of [s] is confused with [h], only that certain aspirate properties come through in a weakened signal of [s].

The acoustic pattern of [s] is characterized by a number of cues encoded in the frequency, amplitude, and duration of the energy present in the quasi-static frication portion of the signal as well as in formant

transitions. While all of this information is available to listeners, the relative contribution of each cue to sound recognition is highly variable. Confusion studies of fricative sounds demonstrate that listeners weigh secondary cues more when data from the primary sources conflict or are attenuated (Harris 1958, Repp & Mann 1980, McCasland 1980, Manrique & Massone 1981, Gurlekian 1981).

Conditions coincident with s-aspiration combine to alter the quantity and quality of [s]. In addition, [s] itself conditions significant alterations in adjacent vowel segments. These are briefly outlined below.

2.1. Quantitative reductions in [s]

There is a strong correlation between s-aspiration and forces which alter the duration of [s]. Polysyllabic words, unstressed position, fast rate of speech, and clustering are all factors which systematically shorten the [s] (Terrell 1979). These are precisely the conditions which occasion the highest incidence of s-aspiration in Spanish. Klatt (1974:60) observes that "some of these factors are physiologically conditioned and thus likely to operate as universal tendencies in language".

Quantitative studies show dramatically higher percentages of word-final s-aspiration as word length increases (Terrell 1987). Crystal & House (1988) confirm that the duration of [s] decreases as the number of syllables increases. Klatt (1974) finds [s] to be variably shortened by 5-20% in polysyllabic words according to its occurrence in pre-stressed, pre-unstressed, and word-final position.

Alba (1982) has shown that the occurrence of [s] in unstressed environments is consistent with higher rates of aspiration, whereas the presence of stress acts to retard such reductions. According to Klatt there is a clear tendency for the [s] in stressed syllables to be longer than its unstressed counterpart. He shows this difference to be around 15% and further states:

> It seems likely that unstressed syllables are not only spoken more rapidly, but also with a reduced muscle tonus or relaxed criteria for the attainment of target configurations (1974:62).

Thus, the presence or absence of stress may contribute to qualitative as well as quantitative adjustments in [s].

As with most natural phonological developments, s > h has been closely linked to casual, spontaneous speech. It is probably no coincidence that the change from [s] to [h] originated in Southern Spain and the Caribbean colonies where the rhythm of speech is much more animated than in the more measured speaking habits prevalent in

Castile (Navarro Tomás 1966). Shockey (1987) suggests that rapid speech may result in a speech strategy which leads to phonological reductions unless extra effort is consciously exerted. Klatt (1976) claims that shortening of [s] may occur in a faster speaking style, but notes that this effect is small and bounded by a durational minimum. However, utterance-final [s] is rarely reduced since prepausal lengthening affects [s] as articulatory movement slows down near the end of the speech act.

[s]-aspiration in Spanish began in syllable-final position, where the [s] occurs before another consonant. Both Haggard (1973) and Klatt (1974) have shown substantial abbreviation of [s] in preconsonantal position. According to Klatt, the case of [s] followed by a stop presents "the most striking example of a cluster-induced durational change" (1974:58), producing a reduction in [s] by 30-40% (1976). This shortening of [s] brought on by the abutting consonant contrasts sharply with a much longer sound in syllable-initial, pre-vocalic position. Klatt explains the reduction of [s] in consonant clusters in the following way:

> The production of a fricative such as [s] or a vowel requires a controlled articulatory gesture toward a target configuration. In a stop, the articulatory gesture is more ballistic in nature, the rapid closing motion ceasing abruptly when closure has occurred. In an intervocalic [s], the tongue tip must make two controlled movements in opposite directions, and synchronization of laryngeal activity is also required. When [s] is followed by a stop, the second movement is ballistic and does not involve laryngeal coordination. These factors permit an earlier onset of closure motion and a more rapid cessation of frication if [s] is followed by a stop (1974:62).

Quantitative studies show that [s] reduces much less when clustered with [t] than in other combinations (Terrell 1979; Longmire 1976). Méndez Dosuna (1985) claims that the change s > h progressed from (-sp-) to (-sk-) to (-st-), which coincides with an incremental shortening of [s]. Borden & Gay (1979) found significant durational differences between shorter, heterorganic and longer, homorganic (-sC-) clusters. They attributed the difference to the degree of autonomy that the articulating organs have in producing the two consonants in the clusters.

The abbreviation of [s] in syllable-final position adversely affects transitional cues between [s] and the next consonant, particularly when this is a stop, in two important ways. First, the transition into the following sound is much shorter due to the abruptness of the pending stop closure and any coarticulatory overlap as noted above (cf. Borden & Gay 1979). Second, the brief, transient element of a noisy [s] into a smooth, periodic vowel is eliminated altogether. In effect, the [s] is unreleased much like the initial stop in obstruent clusters.

While none of the systematic shortening forces affecting [s] is very large, their cumulative effect is notable. For example, in conversational speech, the duration of [s] may be as little as 50 ms or less (Klatt 1976). This may be significant since, according to Klatt (1974:59), "there may be a lower bound on the duration of an acceptable [s]". A maximally shortened [s] creates greater perceptual pressure on those qualitative cues which serve to characterize it.

2.2. Qualitative reductions in [s]

The change s > h also reflects significant alterations in salient acoustic information encoded in the signal of [s]. Characteristic features of [s] include intense, aperiodic noise sustained at the mid to high frequency range (energy peaks appear near 5 and 8 kHz). Perceptual research has shown that a substantially weakened amplitude causes an [s] to sound less sibilant (Gurlekian 1981), especially when the duration of [s] is short (McCasland 1980). Lowered frequency levels of frication will likewise affect the perception of [s] (Harris 1958).

The loudness of the [s] noise is attenuated by a number of factors that correlate with s-aspiration. For example, the occurrence of s > h originally in unstressed environments corresponds with a general reduction in the intensity of [s] in such cases. The relative amplitude of [s] in atonic syllables is much less than in stressed position because of the decreased rate of airflow. According to Shadle (1990), one of the key spectral properties of [s] is a maximum rate of change of amplitude with flowrate. In addition, the lowering of intensity for [s] in response to airflow rate is greatest at the higher frequency ranges where the characteristic (peak) noise occurs.

That s-aspiration has flourished throughout the Spanish speaking world except where Castilian-like speech habits are maintained may be due to the very different way in which [s] is produced in these areas. Quilis (1981) notes that the Castilian [s] is apicoalveolar and inherently more intense than the dental [s] heard in other dialects. He explains that the latter is less strident owing to inefficiencies in the noise generation mechanism as the distance between constriction and sound source (teeth) is minimized (Quilis 1981:235-36).

The intensity and frequency of [s] are modified by coarticulatory effects common in VsC sequences. For example, coarticulation by a labial gesture enlarges the resonating chamber forward of the constriction and lowers frequencies. In addition, rounded lips create a secondary constriction coinciding with a velocity maximum in the standing wave pattern of all resonances which further lowers frequencies (Ohala 1985). Lip rounding effectively acts as a low-pass filter by lowering the higher frequencies of [s] and attenuating the intensity of the noise downstream of its source.

In velar environments, anticipatory raising of the tongue back produces a secondary constriction which impedes airflow to the noise source and lowers the intensity. Preservatory velarization effects also lower frequencies since Spanish back vowels are secondarily rounded. In nasal environments similar bleeding of the pressure buildup needed for effective sibilant noise generation occurs through velic leakage (Ohala - personal communication 1990).

2.3. Modifications by [s]

While the above conditions reduce or attenuate the static and release portions of [s], transitions into [s] from the preceding vowel remain fully intact. The relatively long transitional element between vowels and [s] is influenced by the nature of the anticipated sibilant noise. As evidenced by the sample waveform in Figure 1, Vs margins exhibit an extensive stretch of periodic vibration of lowered amplitude with signs of increasing airflow throughout. While the vocal cords continue to vibrate there is reason to believe that the glottis begins to open at least partially in anticipation of [s] well into the preceding vocalic formation.

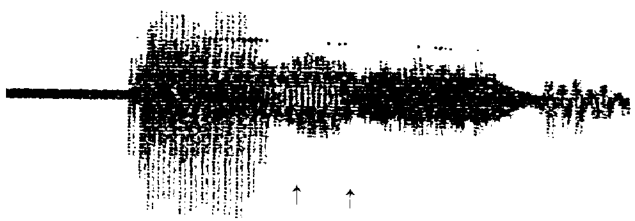

Figure 1. Waveform illustrating breathy voice phonation over vowel transitions into [s] in the token [paʰsa] 'raisin'. The interval indicated by arrows represents the effect of anticipatory glottalic widening prior to onset of oral constriction for [s]

There are two aerodynamic reasons why vowels before [s] might show anticipatory widening of the glottis. The first is due to what Ohala (1989) terms "elasto-inertial constraints" on the articulators. Since the

state of the glottis can change only gradually, devoicing for [s] may require considerable lead time into the previous vowel. Studies of airflow during speech confirm this assertion:

> [...] when a vowel is followed by a voiceless fricative consonant, the airflow traces suggest that the abduction of the vocal cords is initiated well before the end of the vowel, so that a substantial glottal opening is achieved before the supraglottal constriction appropriate to the consonant is produced (Klatt et al. 1968:53).

Secondly, the wider glottis needed to produce the characteristic high airflow of [s] may spread partially to the previous vowel as an anticipated effect. Ohala states:

> [...] there is strong evidence that consonants having greater than normal airflow have a more open glottis and thus that, through assimilation, vowels adjacent to these consonants will be produced with a slightly open glottis, although still sufficiently close to allow vibration (1980:88).

This physiological depiction of Vs margins coincides closely with Ladefoged's (1982) description of murmured sound. He defines murmur or breathy voice as a state of the glottis in which the vocal cords vibrate at one end while air rushes through the other, and this vibration continues in spite of gradual separation of the vocal bands.

Conceptually, one might view the transitional effect between Vowel [+ voice] and Sibilant [- voice] as a reversal of the more traditional VOT which occurs in the movement from Consonant [- voice] to Vowel [+ voice]. This voice 'offset' time produces a breathy effect on the vowel, similar enough to the stop burst to bear the same name and symbol: aspiration ([h]).

The murmured vocalic portion preceding [s] offers listeners a perceptual cue very similar to that for [h]. Normally this cue is consigned a redundant role as a physiological inevitability of the anticipated fricative and is completely masked by the long, intense, high frequency noise which follows. Alternatively, in the presence of perceptible [s], it may be the case that listeners do process the aspirate cue but correctly ascribe the aspiration to coarticulation by [s] (Fowler 1984; Fowler & Smith 1986; Whalen 1984). In either case, as the primary cues for [s] are attenuated as described above, the hidden aspirate facsimile in the margins may surface as an intended feature of pronunciation. The experiments described below test this hypothetical explanation motivating the innovation s > h in Spanish.

3. Experiments

3.1. Stimuli

Natural speech samples were obtained from an adult male informant from a conservative Mexican dialect in which s-aspiration rarely occurs.[2] The corpus consisted of minimal triplets contrasting the canonical forms (C)VC : (C)Vs : (C)VsC (e.g. *roca* 'rock' : *rosa* 'rose' : *rosca* 'coil') including a variety of vowel and stop consonant types.

Test tokens were created using the HONDAS waveform editor on the RT-11 micro computer system at the Phonology Laboratory of the University of California at Berkeley. Stimuli were prepared by removing the vocalic portion of a (C)VC sequence and filling this empty slot with the 'same' vowel gated out of a (C)Vs context as illustrated in (1):

(1) $r[o]_s ca = r(\emptyset)ca + [o]_s$ (< r[o]sa)

The separation of vowels from initial stop consonants was accomplished by locating the burst transient and excising the vowel where periodic sound waves began. Initial trills were spliced at the end of the last abbreviated vocalic segment created by the vibrating tongue tip prior to the onset of the true vowel which followed. For words beginning with [m] and [l] I detached the vowel where discontinuities in the wave amplitude and formant frequencies indicated a break between the weaker consonantal noise and the stronger vowel harmonics.

Location of the onset of sibilant noise was apparent through visual inspection of the waveform display and audio playback, which guaranteed clean separation of the test vowel. The objective consistent with the experimental hypothesis was to create stimuli such that subject reaction would be solely in response to the weakened, breathy voice murmur isolated over the vocalic transition and not to any vestige of intentional frication.

Since Spanish vowels show regular phonetic differences in open (lower F1) and closed (higher F1) syllables, care was taken to control for this variable in stimulus preparation. Rather than obtaining test words by merely attenuating the sibilant from a (C)VsC sequence, the method described was used to minimize qualitative incongruities between the vowel stimulus and its test environment. This assures that in the test procedure subject response to the test stimuli is not significantly influenced by conditioned differences in formant structure.

Hammond (1978) has demonstrated that vowel length may provide

an important perceptual cue in marking vowels where syllable-final [s] has been reduced to [h] or eliminated altogether. He claims that such vowels are 36.3% longer than vowels in open syllables where no such reduction has taken place, and that listeners are highly successful in using this cue to distinguish minimal pairs of words. During segmentation few durational differences between original and imported vowels were observed.

In cases where differences were found adjustments were made to minimize them by adding or subtracting a period or two from the middle of the vocalic waveform so as to not alter the breathy effect at the margins.

Tab. 1 presents the corpus of test stimuli used in the perceptual experiments to be described below.

Table 1. Test stimuli used in experiments 1 and 2. Tokens were derived by inserting into a (C)__C environment vowels excised from a (C)__s context ([V]s)

Token	*Gloss*	*Token*	*Gloss*
$p[a]_s ta$	'paw'	$p[i]_s ta$	'string'
$c[a]_s pa$	'layer'	$m[i]_s ma$	'(s)he spoils'
$[a]_s ma$	'(s)he loves'	$r[o]_s ca$	'rock'
$r[a]_s pa$	'(s)he shaves'	$c[o]_s to$	'pasture'
$p[e]_s co$	'I sin'	$m[o]_s co$	'mucous'
$r[e]_s ta$	'(s)he scolds'	$b[u]_s que$	'large ship'
$p[i]_s co$	'beak'	$L[u]_s cas$	'Luke'
$L[i]_s to$	'Lito' (= Alberto)		

3.2. Perceptual test 1

The test tape consisted of the 15 test tokens (Table 1) plus 30 control items from the corresponding (C)VC and (C)VsC original sequences. The material was randomized on tape and separated by a constant interval of 3 seconds between stimuli with an additional pause of 5 seconds after every fifth stimulus. Subjects listened to the tape over earphones and responded by circling the item on an answer sheet in a two alternative, forced-choice identification task. Twenty five students from the Universidad del Bío-Bío in central Chile with no formal linguistic training, all monolingual speakers of Spanish where s > h is common, served as volunteer subjects. This yielded a sample of 375 = 25 subjects X 15 tokens per condition. Total test time, including instructions and a brief biographical survey at the end, was approximately 10 minutes per subject.

In the crucial test case subjects were asked to identify the derived stimuli as one of the corresponding control items. This task is represented in (2):

(2) $r[o]_s ca$ = roca or rosca (?)

The null hypothesis established by the experimental design posits no meaningful difference between the test vowel $[V]_s$ and the corresponding vowel in the control sequence (C)VC. Therefore, test stimuli perceived as (C)VsC were interpreted as errors in identification. Any deviation from the expected identification pattern should not differ significantly from the error rate of the other two control conditions.

Tab. 2 summarizes the error rate of independent variables for this first test.

Table 2. Error incidence in the classification of independent variables in a two alternative, forced-choice identification task. Test tokens classified as (C)VsC sequences were interpreted as misperceptions

Variable	*Form*	*Misperceptions*
Control #1	(C)VC	1.1%
Test	$(C)[V]_sC$	32.5%
Control #2	(C)VsC	0.3%

The number of control items incorrectly perceived is predictably low and probably due to subject inattention or some other spurious effect. In contrast, the 32.5% error rate of test words is much higher than the two control conditions. Results of an ANOVA show this differential treatment of test stimuli to be highly significant [$F(2,48) = 75.59$, $p < .01$], which favors rejecting the experimental null hypothesis.

The results of this first test support the proposal that acoustic effects of high airflow fricatives spread to the previous vowel and that listeners attend to these when the more dominant cue of frication is eliminated. The identification $[V]_s$ = /Vs/ is essentially the same association that speakers of s-aspirating dialects make when they interpret the intentional aspiration they hear to what they have internalized as lexical /s/. However, the test design is equivocal as to whether subjects

actually perceive an aspirated sound or whether they respond instead to some kind of low-grade [s] that persists in the signal. Although the latter possibility seems unlikely it nevertheless represents a potential interpretation which requires further testing.

More crucial in the interpretation of test results is a basic design flaw[3] which adds a further confounding effect. It is possible that subject responses to test stimuli may not be as much a consequence of the additional transitional cues imported into an incongruent environment as it is an artifact of the manipulation itself. An acoustic signal is always degraded by even the most careful editing (Martin & Bunnell 1982), and this may increase subject uncertainty on the doctored test tokens and result in more guessing than occurs with controls. However, the identification task only allows subjects to err by responding contrary to the experimental null hypothesis (e.g. in favor of a (C)VsC response), which biases the results. The design of the second perceptual test addresses this problem by allowing subjects to respond freely to edited test stimuli by writing down the word they perceive. In this case, there would be no incentive to conjecture that the item contained an [s] unless there were actually something in the signal that favored such a percept.

3.3. *Perceptual test 2*

At present s-aspiration signals that speakers are using a casual register. The approach used in this test takes advantage of this shared knowledge by presenting native subjects with test stimuli from the first experiment and asking them to judge whether the token came from formal or informal speech. The hypothesis is that, if test vowels really mimic the acoustic effects of aspiration, then subjects will classify the tokens as informal. On the other hand, any kind of [s], good or bad, should elicit a formal response.

An additional set of training words was added to the test corpus used in the previous experiment in order to establish a clear pattern of speech styles. These included words exhibiting a number of common phonological reductions in Spanish that roughly correspond to informal discourse. Natural speech tokens were elicited from the same native informant as before who was instructed to exaggerate a formal or informal style of speech (Tab. 3).

The test tape consisted of 15 test stimuli, 15 (C)VsC controls, and the 20 training items from Table 2, randomized and temporally spaced as in the first experiment. Subjects responded by classifying tokens as exemplars of formal or informal speech and by spelling out the lexical form on an answer sheet. They were instructed to base their judgments solely on pronunciation and were told that the

Table 3. Training items used in experiment 2 exemplifying common phonological reductions in Spanish. Formal tokens are carefully articulated forms while informal tokens incorporate the phonetic reductions marked [ ].

Formal	*Gloss*	*Informal*
soldado	'soldier'	solda[ ]o
cuñado	'brother-in-law'	cuña[ ]o
pelado	'peeled'	pela[ ]o
huevo	'egg'	[g]uevo
bueno	'good'	[g]ueno
teatro	'theater'	t[j]atro
peor	'worse'	p[j]or
para atrás	'behind'	p[a:]trás
para allá	'over there'	p[a:]llá
para mí	'for me'	p[a:]mí

formal and informal categories corresponded with careful and colloquial usage respectively. Fifteen Hispanic students from a variety of dialect areas at the University of California at Berkeley participated as subjects. The resulting sample size for test stimuli was 225 = 15 subjects X 15 tokens. The test was administered over earphones and required 10 minutes per subject. Responses to the test stimuli and controls in this second perceptual test are presented in Tab. 4 below.

Table 4. Identification of test stimuli (C)[V]sC according to lexical category and speech style. Subjects rated formality of tokens and transcribed them orthographically.

Lexical Identification	*Formal Judgment*	*Informal Judgment*	*%*
(C)VsC	2	108	48.9%
(C)VC	90	25	51.1%

As in the first experiment the number of test stimuli identified as (C)VsC sequences is significant (48.9% here, higher than the 32.5% previously). Nearly all of the test tokens so identified (108/110 = 98.2%) were judged to be exemplars of informal speech. These results support

the proposed hypothesis that test vowels imitate the quality of aspiration rather than a continuance of the sibilant percept.

4. Conclusions

This study has attempted to account for the initiation of the Spanish sound change s > h on general phonetic principles. It has been proposed that the change reflects misperception of a weakened acoustic signal triggered by naturally occurring articulatory adjustments.

This proposal was derived from a close analysis of the phonetic correlates of the original conditioning factors and was tested by laboratory experimentation.

The proposed account of s-aspiration offers a few theoretical refinements to accepted theory. In contrast to a proposal that speakers transform the sibilant into a glottal fricative, I suggest that the [h] is always present in the environment of [s] but is only detected when essential attributes of the [s] are degraded beyond some minimal value. In essence, [s] serves more as a conditioner than a conditionee of change. Thus, the new formulation in (4) (following Ohala 1991) has more explanatory value than the traditional rule abbreviated in (3):

(3) s —> h / ____ C

(4) a. /Vs/ —> [Vhs]

b. [Vhs'] —> /Vh/

Rule (4a) represents the physical reality of speech, while (4b) corresponds to listeners' misattribution of lexical importance to the automatic vocalic murmur in the absence of a good [s]. Implicit in (4b) are the aerodynamic rules specifying the forces which reduce the sibilant to some minimal value [s']. Experimental support for the proposed account of s-aspiration provides an empirical basis for this formulation and makes it a viable alternative to existing models.

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Notes

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1 However, Joaquin Romero offers a more current and comprehensive articulatory account of this change in the present volume.

2 Extensive conversations with the informant allowed the investigator to verify that his speech was characterized by well articulated sibilants without incidence of aspiration.

3 I am grateful to Carol Fowler for bringing this to my attention.

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