OSU Working Papers in Linguistics 55, 117-171

Explaining Directional Asymmetry in Turkish [h] Deletion: A Crosslinguistic Study of Perceptibility[1]

Jeff Mielke
mielke@ling.ohio-state.edu

0. Introduction

[h] deletion is a common phenomenon. Some languages have orthographic *h* that is no longer pronounced in certain contexts, and some languages allow /h/ deletion in fast speech. An example of both is English *prohibit/prohibition*. Both words are spelled with *h* but while [h] is always pronounced in the former, it is optional in the latter.

(1)	prohíbət		*proíbət	'prohibit'
	pròhəbíʃən	~	pròəbíʃən	'prohibition'

The difference between the environments where [h] occurs in the two words is that the following vowel is stressed in *prohibit*, and unstressed in *prohibition*. English [h] is generally deleted when it precedes an unstressed vowel, especially in fast speech. This holds true for other pairs such as *inhibit/inhibition* and *vehicular/vehicle*. Thus, it is possible to unify the environments where English [h] is deleted according to whether or not stress is present on the following vowel.

---

[1] This paper builds on previous work by Lena Ovcharova (1999). It has benefited from comments from Elizabeth Hume, Keith Johnson, Donca Steriade, students in the Perception in Phonology seminars, members of the OSU phonetics and phonology discussion group, and audience members at the 2000 Montreal-Ottawa-Toronto Phonology Workshop, the 2000 OSU Colloquium Fest, and the 2000 Mid-Continental Workshop on Phonology. The French and Arabic experiments would not have been possible without the help of Nick Clements and Annie Rialland.

In contrast, Turkish [h] deletion presents an interesting challenge. Turkish [h] is often deleted in fast speech, but only in certain segmental contexts (Lewis 1967, Sezer 1986). While unifying the conditioning environments for English [h] deletion is fairly straightforward, unifying the diverse conditioning environments for Turkish [h] deletion is not. For instance, [h] can be deleted when it is preceded or followed by a fricative. It can also be deleted when it is followed by a sonorant consonant. However, [h] cannot be deleted when it is preceded by a sonorant consonant. The [h] deletion pattern is symmetrical for some contexts (fricatives) and asymmetrical for others (sonorant consonants). Not only is the pattern of [h] deletion asymmetrical, it is asymmetrical in the opposite direction for other contexts. [h] can be deleted when it is preceded by a voiceless stop, but not when it is followed by a voiceless stop. This is the opposite of the pattern of deletion with respect to sonorant consonants. These are just a few of the environments where [h] can be deleted in Turkish, but they are sufficient to show that what unifies the conditioning environments for Turkish [h] deletion is not as transparent as it is for English [h] deletion.

The immediate goal of this paper is to try to understand the seemingly unrelated environments where [h] deletes in Turkish. More generally, this paper is an exploration of the interaction between speech perception and phonology with respect to segment deletion. In the pages that follow, a perceptual account of Turkish [h] deletion is motivated. The findings from this case are then used to try to elucidate the relationship between perception and phonology.

The environments where [h] deletion occurs in Turkish are presented in more detail in section §1. The proposal that Turkish [h] deletion is influenced by perception is introduced in §2, along with the predictions that are made by such a proposal. Perception experiments were performed to test these hypotheses and predictions. The results of an experiment with Turkish-speaking subjects are presented in §3, and the results of a crosslinguistic experiment are presented in §4. §5 deals with issues relevant to aspirated stops, and in §6, the results of an additional experiment are presented to address these issues. The experiment results and their implications for the influence of phonology on perception are discussed in §7. Implications for the influence of perception on phonology are discussed in §8, and a model for predicting sensitivity is proposed, based on the factors found to influence sensitivity in this study. Concluding remarks are in §9.

1. [h] deletion in Turkish

[h] is optionally deleted in fast speech in Turkish, but only in certain segmental contexts. The inventory of Turkish consonants is given in (2), and the environments where [h] is optionally deleted are described in (3-7).

(2) *Turkish consonant phoneme inventory*

	bilabial	labio-dental	alveolar	palato-alveolar	palatal	velar	glottal
stops	p b		t d			k g	
fricatives		f (v)[2]	s z	ʃ ʒ			h
affricates					tʃ dʒ		
nasals	m		n				
liquids			l, r				
glides		v			y		

As mentioned above, [h] is optionally deleted *before* sonorant consonants, but not after them. When [h] is deleted from preconsonantal or final position, compensatory lengthening of the preceding vowel occurs, as in (3a) (Sezer 1986).

(3)	a.	fihrist	~	fi:rist	'index'
		tehlike	~	te:like	'danger'
		mehmet	~	me:met	proper name
		köhne	~	kö:ne	'old'
	b.	merhum		*merum	'the late'
		ilham		*ilam	'inspiration'
		imha		*ima	'destruction'
		tenha		*tena	'deserted'

[h] is optionally deleted *after* voiceless stops but not before them.

(4)	a.	ʃüphe	~	ʃüpe	'suspicion'
		ethem	~	etem	proper name
	b.	kahpe		*ka:pe	'harlot'
		sahte		*sa:te	'counterfeit'
		mahkum		*ma:kum	'inmate'

[h] is optionally deleted before *and* after voiceless fricatives.

(5)	a.	ishal	~	isal	'diarrhea'
		safha	~	safa	'step'
		meʃhur	~	meʃur	'celebrity'

[2] /v/ is realized sometimes as a labiodental fricative and sometimes as a labiodental approximant.

b.	mahsus	~	ma:sus	'special to'
	tahsil	~	ta:sil	'education'
	ahʃab	~	a:ʃab	'made of brick'

[h] is optionally deleted *after* voiceless affricates, but not before them.

(6)	a.	metʃhul	~	metʃul	'unknown'
	b.	ahtʃi		*a:tʃi	'cook'

[h] is optionally deleted intervocalically, as well as word-finally (perhaps categorically), but not word-initially.

(7)	a.	tohum	~	toum	'seed'
		mühendis	~	müendis	'engineer'
		sahan	~	saan	'copper food dish'
		muhafaza	~	muafaza	'protection'
	b.	timsah	~	timsa:	'crocodile'
	c.	hava		*ava	'air'

The environments where deletion occurs are summarized in (8). There is no evidence that [h] deletes before or after voiced obstruents, in part because it seldom occurs in these environments. In the next section, a perceptual account of Turkish [h] deletion is proposed. See Mielke (to appear a) for a discussion of formal phonological accounts of [h] deletion.

(8) *[h] deletion summary*

Context		Before Context	After Context
voiceless stop	[p, t, k]	no deletion	DELETION
voiceless affricate	[tʃ]	no deletion	DELETION
voiceless fricative	[f, s, ʃ]	DELETION	DELETION
voiced stop	[b, d, g]	no evidence	no evidence
voiced affricate	[dʒ]	no evidence	n/a[3]
voiced fricative	[z, ʒ]	no evidence	no evidence
sonorant consonant	[n, m, l, r]	DELETION	no deletion
intervocalic		DELETION	
word-initial		no deletion	
word-final		DELETION	

[3] [h] does not occur after the voiced affricate in Turkish

2. The role of perceptibility in deletion

It has been hypothesized that sounds which are less perceptible are more likely to be altered than more salient sounds (Hura et al. 1992, Kohler 1990, Steriade 2001). The rationale is that the loss of a sound which is already difficult to perceive is not as great as the loss of a more salient sound. The motivation for loss may very well be a non-perceptual factor such as articulatory ease, but the selection of a sound to be deleted may be perceptual (see Hume and Johnson 2001). Perceptibility may be responsible for selecting the environments where [h] deletes in Turkish.

It is reasonable to assume that the demand to minimize articulatory effort is ever-present, and that this demand can be met by segment deletion, but at the expense of the intelligibility of an utterance. Deleting a segment that is very salient will be noticeable to a listener, but deleting a segment that is not very perceptible involves a less significant loss of intelligibility. Ranking the environments in a perceptibility scale from the most salient to the least salient shows the relative cost of [h] deletion by environment.

2.1. Perceptibility scales

In her study of laryngeal neutralization, Steriade (1997) proposes a perceptibility scale for voiced and voiceless consonants, shown in (9), hypothesizing that neutralization of voice contrast will occur in environments where there are fewer cues to voicing. In the environments at the top of the figure, there are many cues to voicing, and these are the environments where voice contrast is most common cross-linguistically. In the environments at the bottom of the figure, there are fewer cues to voicing, and voice contrast in these environments is much more rare.

(9) *Perceptibility scale for laryngeal neutralization (Steriade 1997)*

	Environments	**Examples**
more cues ↑	[+son] __ [+son]	**a**b**a** vs. **a**p**a** & **a**b**ra** vs. **a**p**ra**
	# __ [+son], [-son] __ [+son]	**b**ra vs. **p**ra, **b**a vs. **p**a, as**b**ra vs. as**p**ra, & as**b**a vs. as**p**a
	[+son] __	a**b** vs. a**p**
	[+son] __ [-son]	a**b**sa vs. a**p**sa
	[-son] __ [-son]	as**b**ta vs. as**p**ta
	[-son] __ #	as**b** vs. as**p**
↓ fewer cues	# __ [-son]	**b**sa vs. **p**sa

The relevant cues to voicing are closure voicing, closure duration, vowel duration, F0 and F1 value of adjacent vowels, burst duration and amplitude, and VOT value. All of these cues are available for stops between sonorants, the highest category in (9). For the bottom three categories, only closure voicing and closure duration are available to the listener. The availability of non-internal cues (everything but closure voicing and closure duration) depends on context (Steriade 1997).

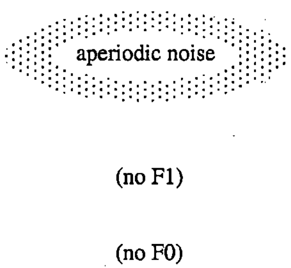
According to Steriade, a language with a voice contrast in a given environment will also have a contrast in other environments which have more cues to voicing. Likewise, a language with voice neutralization in a given environment will also have neutralization in environments with fewer cues to voicing. What unifies the environments with voice neutralization is that they are all perceptually weaker than the environments where contrast is maintained.

Perhaps what unifies the conditioning environments for Turkish [h] deletion is that these are the environments where [h] is the least perceptible, i.e., they are low on the perceptibility scale for [h] environments. The seemingly unrelated environments where [h] can be deleted may be related by being perceptually poor environments for [h].

(10) Hypothesis 1: [h] is less perceptible in environments where it deletes in Turkish than it is in environments where it does not delete.

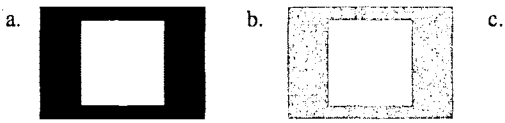
To determine which environments are weak perceptually and which are strong, it is necessary to first look at the cues to the presence of [h] and how neighboring segments can facilitate or detract from their identification. The voiceless glottal fricative has three main segment-internal cues to its presence (see Wright 1996): aperiodic noise in the F2 region, lack of an F1, and lack of an F0.

(11) *The segment-internal cues to [h]*



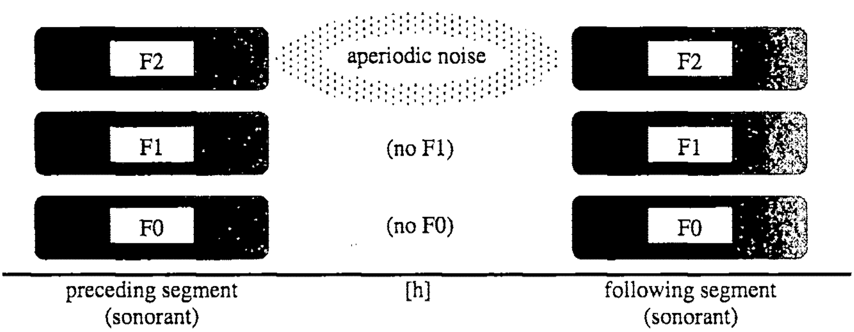
These cues, particularly the two characterized by silence, are very weak. Syntagmatic contrast is important for them to be recognized. A visual metaphor for perceptibility of silence is pictured in (12). There are three white squares, one on a black background (12a) one on a gray background (12b), and one on a white background (12c). Because it contrasts most with its with its surroundings, the square in (12a) is the most visible. The square in (12b) is not as striking because it contrasts less with the gray background, and the square in (12c) is the least salient because it does not contrast at all with its background

(12) *White squares on different backgrounds*



Similarly, [h]'s lack of an F0 is more salient when [h] precedes or follows a voiced segment, which has an F0. Silence does not contrast with silence, but it does contrast with sound. Similarly, [h]'s lack of an F1 is more salient when it is preceded or followed by a sonorant, which has an F1 resonance.

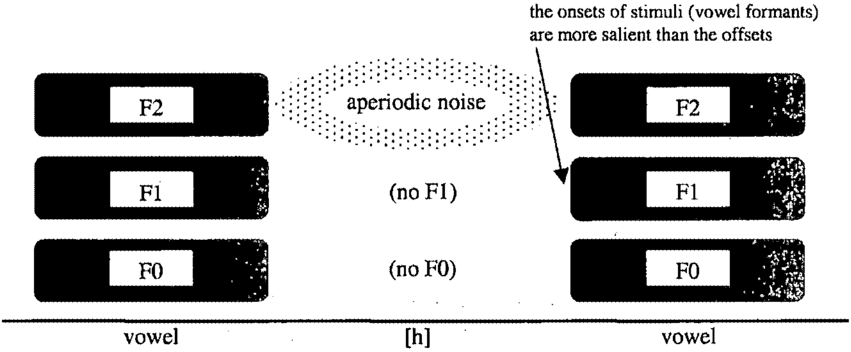
(13) *[h] is most salient between segments that contrast with it*



2.2. Hypotheses with evidence from deletion

The fact that deletion occurs after a sonorant and before a vowel, but not vice versa, can be explained by temporal asymmetries in the auditory system (Bladon 1986, Wright 1996). Auditory nerve fibers exhibit a greater response at the onset of a stimulus signal (such as a vowel) than at the offset. Therefore, all else being equal, consonants before vowels are more perceptible than consonants after vowels, and thus CV transitions provide better cues than VC transitions. This has been shown by Fujimura, Macchi, & Streeter (1978) and Ohala (1992). Fujimura et. al played VCV stimuli with conflicting consonant place cues in the VC and CV transitions to subjects forward and backward, and found that the transitional cues heard by the listeners at the onset of the vowel were more salient, regardless of whether they had been produced as VC or CV transitions.

(14) *CV transitions are more salient than VC transitions*



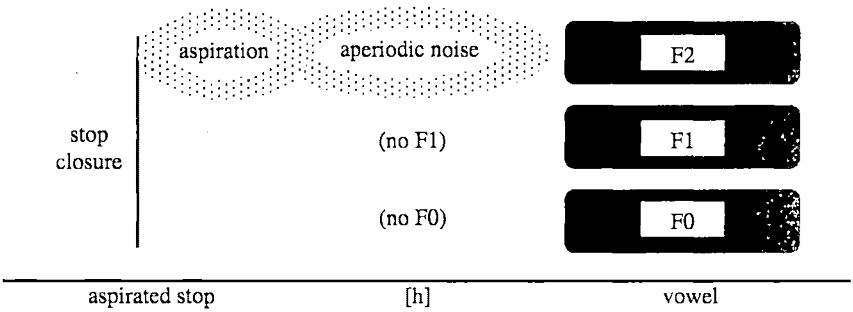
It follows that the contrast between [h] and a following vowel is more salient than the contrast between [h] and a preceding vowel. Therefore, [h] should be more perceptible before a vowel than after one. This could explain why [h] is deleted before a sonorant (and after a vowel) but not after a sonorant (and before a vowel).

(15) *Prediction: sonorant consonant asymmetry (R = sonorant consonant)*

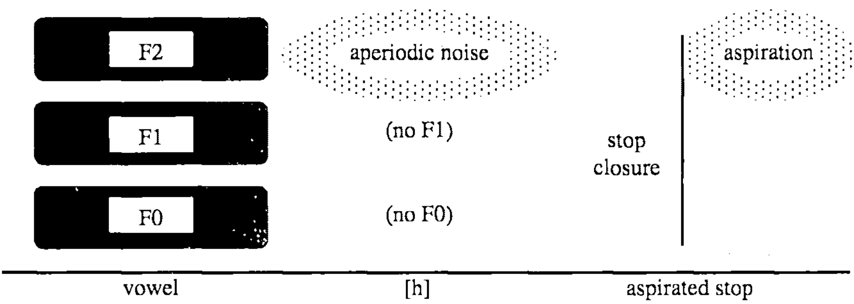
VR**h**V	[h] more perceptible
V**h**RV	[h] less perceptible

This may be a reason for [h] to be deleted before but not after sonorants, but it does not explain why the reverse is true for voiceless stops. It would be predicted that [h] would be more perceptible after a stop than before one because of the temporal asymmetry of the auditory system, but that does not appear to be the case. However, a crucial difference between sonorants and voiceless stops is that in Turkish voiceless stops are aspirated (Lewis 1967), and aspiration is an important cue to the presence of [h]. Hypothetically, if [h] is adjacent to aspiration from another segment as in (16), the aperiodic noise of [h] is less salient than if it is separated from the aspiration by the stop closure, as in (17). In (16) the aperiodic noise of [h] is not separable from the aspiration noise of the voiceless stop – it is essentially an extension of the stop aspiration. In (17) the [h] noise and the stop aspiration noise are separated by the silent stop closure interval.

(16) *[h] is hypothesized to be less salient after voiceless stops*



(17) *[h] is hypothesized to be more salient when the stop follows [h].*



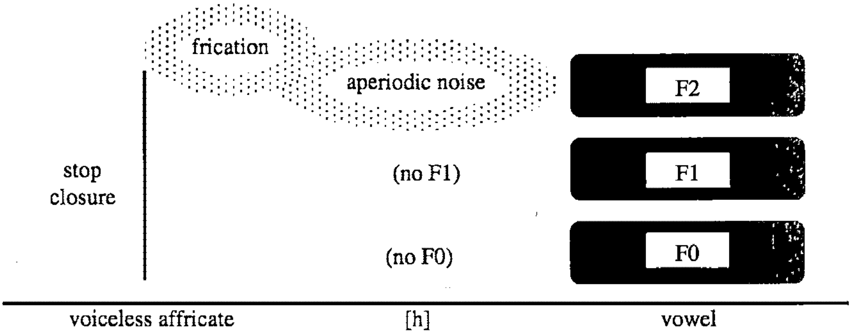
If true, this would help elucidate why [h] is deleted after voiceless stops but not before them. The cues to [h] are more robust before a stop closure than after the aspirated release.

(18) *Prediction: voiceless stop asymmetry (T^h = voiceless stop)*

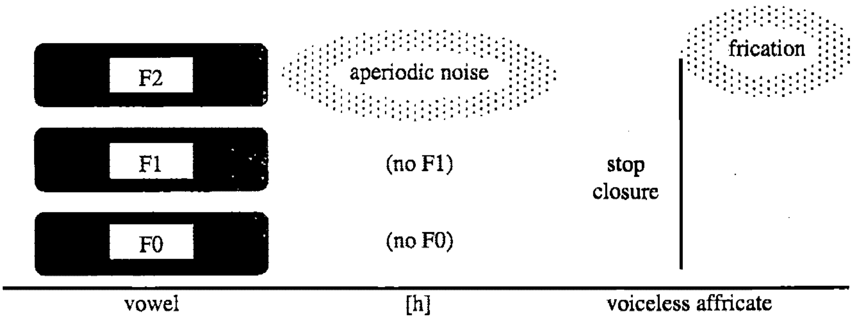
VT^h**h**V	[h] less perceptible
V**h**T^hV	[h] more perceptible

The fricated release of a voiceless affricate should similarly interfere with [h] perception, so that the cues to [h] are less robust after the fricated release, as in (19), than before the stop closure, as in (20).

(19) *[h] is hypothesized to be less salient after voiceless affricates*



(20) *[h] noise and frication are separated when the affricate follows [h].*



(21) *Prediction: voiceless affricate asymmetry (Tʃ = voiceless affricate)*

VTʃ**h**V	[h] less perceptible
V**h**TʃV	[h] more perceptible

The above figures demonstrate why the directional asymmetry in Turkish [h] deletion patterns is understandable. Unlike voiceless stops, affricates, and sonorant consonants, the deletion pattern for fricatives is symmetrical. Deletion occurs before and after fricatives, and this suggests a general property of fricatives that is detrimental to [h] perception regardless of which side the [h] is on. Specifically, the high-frequency frication noise associated with fricatives is confusable with the high-frequency aspiration noise that is a leading cue to the presence of [h]. Just as [h] is obscured by aspiration when it follows a voiceless stop, [h] is obscured by frication noise when it follows or precedes a voiceless fricative.

Fricatives, stops, and affricates all feature noise (frication or affrication) at the right periphery that can obscure the presence of a following [h]. Compared to [h] after a sonorant consonant, [h] should be less salient after fricatives, aspirated stops, and affricates.

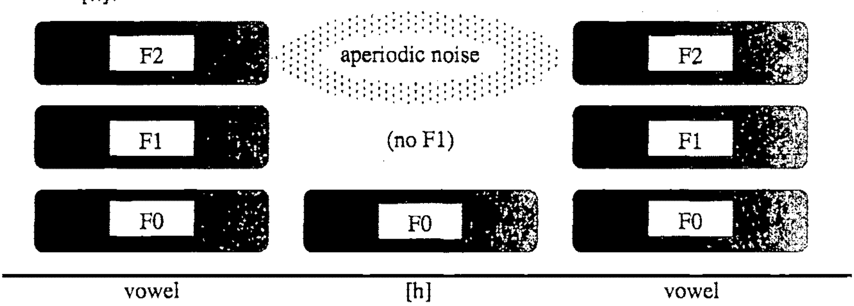
(22) *Prediction: noise affects salience (F = voiceless fricative)*

VR**h**V	[h] more perceptible
VF**h**V, VT^h**h**V, VTʃ**h**V	[h] less perceptible

[h] should also be more perceptible word-initially than word-finally, because the onset of the vowel following initial [h] is more salient than the offset of the vowel preceding final [h]. This is also consistent with the patterns of deletion.

Initial and intervocalic [h] are both followed by vowels, and so both benefit from CV transitions. However, [h] is voiced intervocalically in Turkish (Ovcharova 1999), and this should render it less distinct from a following vowel than when it is not voiced. Voicelessness is one of the cues to [h], and when it is lost, an important part of syntagmatic contrast is lost as well. Therefore, [h] would be expected to be less perceptible intervocalically than it is initially. This is consistent with data on deletion.

(23) *Because intervocalic [h] is voiced, it is hypothesized to be less salient than initial [h].*



This final example differs from the previous examples in that the difference in perceptibility between initial and intervocalic [h] is the result of an allophonic change in [h] that is conditioned by the environment, rather than a difference in perceptibility directly attributable to the environment alone. In addition to the intervocalic environment, [h] is voiced between a vowel and a glide in Turkish. For this reason, glides are not included in the predictions referring to sonorant consonants above and elsewhere in this paper, but would rather be expected to behave more similarly to vowels with respect to [h] perceptibility.

2.3. Hypotheses without evidence from deletion

To this point two kinds of reasons for claiming low perceptibility have been presented. One follows from the hypothesis that [h] is deleted in environments of low perceptual salience (Hypothesis 1). If [h] deletes in a certain environment and the hypothesis is true, then [h] must not be very perceptible in that environment. The second reason draws on what is known about acoustic cues. If an acoustic feature of an environment is likely to interfere with a cue that is important for perception of [h], then [h] must not be very perceptible in that environment. All of the above claims are based on both of these reasons for positing low [h] perceptibility.

The second reason for claiming low perceptibility makes a prediction, stated in (24). If the environments where [h] deletes are truly perceptually weak environments because of the perceptual cues being assumed, then it should be possible to predict other environments where [h] should be more or less salient based on these cues, even if there is no evidence from deletion.

(24) Hypothesis 2: [h] is less perceptible in environments where there are poorer cues to its presence.

One of the predictions this makes is that [h] should be less perceptible before voiceless fricatives than after them, for the same reason [h] is hypothesized to be less perceptible before sonorants than after them. This follows from the assumptions made about perceptual cues, but it does not follow from Turkish [h] deletion patterns, because apparently, [h] is sufficiently weak to be deleted before and after voiceless fricatives. Similarly, [h] should be less perceptible before a voiceless fricative than before a sonorant consonant, even though [h] is also deleted in both of these environments.

Because the prediction that [h] is more perceptible before a voiceless stop than after is based on the interference of aspiration, the same should not be true with respect to voiced stops, which are unaspirated. Rather, [h] would be expected to be more salient after a voiced stop (and before the onset a vowel) than before a voiced stop (and after the offset of a vowel), and certainly [h] would be expected to be more salient after a voiced stop than after a voiceless stop.

In addition to the confusability of [h] with its absence in the same environment, (e.g. Vt^hhV vs. Vt^hV), it is conceivable for [h] to be confusable with its absence in a different environment, i.e., a voiceless aspirated stop is confusable with a voiced stop followed by [h] (e.g. VdhV vs. Vt^hV). Aspiration is an important cue distinguishing voiced and voiceless stops in languages in which voiceless stops are aspirated. So a sequence of an unaspirated stop and [h] could be interpreted as an aspirated stop, and vice versa. This possibility is discussed in §5 and §6.

2.4. Summary

The predictions made up to this point about the relative salience of [h] are summarized in (25), along with the evidence and rationale for each one.

(25) *Summary of predictions:*

	Prediction	Deletion Evidence	Phonetic Rationale
a.	[h] / son __ V > [h] / V __ son	merhum, *merum fihrist ~ fi:rist	All else being equal, prevocalic consonants are more salient than postvocalic consonants.
b.	[h] / V __ vls stop > [h] / vls stop __ V	kahpe, *ka:pe ʃüphe ~ ʃüpe	Aspiration of voiceless stops and affricates interferes with [h] perception.
c.	[h] / V __ vls aff > [h] / vls aff __ V	ahtʃi, *a:tʃi metʃhul ~ metʃul	The fricated release of affricates interferes with [h] perception.
d.	[h] / son __ V > [h] / vls stop __ V	merhum, *merum ʃüphe ~ ʃüpe	Frication and aspiration both interfere with the perception of a following [h]. Sonorants have neither frication nor aspiration, and so do not interfere with [h] perception this way.
e.	[h] / son __ V > [h] / vls aff__ V	merhum, *merum metʃhul ~ metʃul	
f.	[h] / son __ V > [h] / vls fric __ V	merhum, *merum mahsus ~ ma:sus	
g.	[h] / # __ V > [h] / V __ V	hava, *ava tohum ~ toum	Prevocalic consonants are more perceptible than postvocalic consonants, and lenition of intervocalic [h] may render it less perceptible than word-initial [h].
h.	[h] / # __ V > [h] / V __ #	hava, *ava timsah ~ timsa:	
i.	[h] / vcd stop __V > [h] / vls stop __ V	n/a	[h] is predicted to be less perceptible after voiceless stops because of aspiration. Voiced stops, lacking aspiration, are not expected to show this effect.
j.	[h] / V __ son > [h] / V __ vls fric	n/a	Frication should interfere with [h] perception before voiceless fricatives.
k.	[h] / vls fric __ V > [h] / V __ vls fric	n/a	Prevocalic consonants are more perceptible than postvocalic consonants

> = "is more salient than"

In (26), the phonetic environments are listed according to how many of the cues in (11) they allow. Listing the environments this way gives a rough approximation of relative salience of [h]. Weighting the cues would allow a more accurate approximation (see §8). The three main cues to the presence of [h] are its lack of F0 resonance (except when it is voiced), lack of F1 resonance, and aperiodic noise in the F2 region. For each cue, there are two points in time at which they can contrast with neighboring sounds.

(26) *Phonetic environments listed by the number of cues to [h]:*

Environment	Cues					
	F0		F1		noise	
	offset	onset	offset	onset	onset	offset
sonorant __ V	X	X	X	X	X	X
V __ sonorant	X	X	X	X	X	X
vcd stop __ V	X	X		X	X	X
V __ vcd aff	X	X	X		X	X
V __ vcd stop	X	X	X		X	X
# __ V		X		X	X	X
V __ V			X	X	X	X
glide __ V			X	X	X	X
vcd aff __ V	X	X		X		X
vcd fric __ V	X	X		X		X
V __ glide			X	X	X	X
V __ vcd fric	X	X	X		X	
V __ vls aff	X		X		X	X
V __ vls stop	X		X		X	X
V __ #	X		X		X	X
V __ vls fric	X		X		X	
vls aff __ V		X		X		X
vls fric __ V		X		X		X
vls stop __ V		X		X		X

[h]'s voicelessness is apparent at the offset of a preceding voiced segment, and again at the onset of a following voiced segment. When [h] is voiceless and preceded and followed by voiced segments, both the F0 offset and the F0 onset are cues to the presence of [h] ("offset" and "onset" refer to the stopping and starting of F0, not [h]). For example, both the F0 offset and the F0 onset are available cues when [h] is preceded by a liquid and followed by a vowel. But when [h] appears between a voiceless segment and a vowel or between a word boundary and a vowel, only the F0 offset or F0 onset is an available cue. If the vowel precedes [h], only F0 offset is a cue. If the vowel follows [h], only F0 onset is a cue. If [h] appears intervocalically or between a vowel and a glide, [h] is voiced, and in that case neither F0 offset nor F0 onset is a cue to the presence of [h], because there is no interruption of voicing.

F1 offset is a cue to [h]'s presence when [h], which has no F1 resonance, follows a sonorant, which does have an F1 resonance. When [h] precedes a sonorant, F1 onset is a cue to the presence of [h]. When [h] is between sonorants, both F1 offset and F1 onset are cues to [h]'s presence. When [h] follows an obstruent, F1 offset is not a cue to [h] because there is no F1 resonance that stops when [h] starts. Similarly, when [h] precedes an obstruent, F1 onset is not a cue to [h].

While F0 and F1 resonances are properties of surrounding segments which may facilitate the perception of [h], aperiodic noise is a property of [h] that facilitates its own perception. This means that the onset and offset occur in the opposite order, compared to F0 and F1. The noise onset can occur at the beginning of [h] and the noise offset can occur at the end of [h]. Both noise onset and noise offset are cues to [h] when [h] is between vowels or between any other segments which lack high-frequency noise. When [h] is preceded by a fricative, only noise offset is a cue to [h]. Noise does not begin at the beginning of [h], because the preceding segment is already noisy. When [h] is followed by a fricative, only noise onset is a cue to the presence of [h]. Affricates and aspirated stops end with noise, so noise onset is not an available cue when [h] is preceded by an affricate or an aspirated stop. When [h] is followed by an aspirated stop, noise offset is still an available cue because noise stops at the end of [h] and does not start again until the release of the stop closure.

If the conditioning environments for Turkish [h] deletion truly are the environments where [h] is less salient, a perception experiment should show that the predictions about relative salience are correct.

3. Experiment 1: Turkish listeners

A perception experiment was designed in order to test the relative salience of [h] in various phonetic environments. In the experiment, subjects listened to nonsense words one at a time. Half of the stimuli contained [h] and half did not. Subjects were shown each word in Turkish orthography (minus any "h"s) on a computer screen and responded by clicking a mouse on where in the word they heard an [h] sound, if they heard one at all.

This experiment is similar to the experiment conducted by Ovcharova (1999). One crucial difference is that in Ovcharova's experiment, subjects indicated whether or not they heard an [h] in each word, but did not indicate where it was in the word. One advantage of this approach was that it was not necessary to show the subjects the word, and thus the subjects were not given any extra information (partial transcription) that they would not normally have. Because subjects were not provided with any of the segments in the stimuli, the possibility of confusing voiced stops and [h] with aspirated stops was still present. When the subject is provided with the other segments in the stimuli, this confusion is not possible. This concern is addressed below in §5 and §6.

A significant drawback to not giving a partial transcription (as in Ovcharova 1999), however, was that the approach made it impossible to study some of the types of errors made by subjects. Because there were two possible conditions ("[h]" or "no [h]") and only two possible responses, "yes" or "no", there were four possible scenarios. First, if the stimulus did not contain [h], and the subject answered "no", the subject was correct in not hearing [h]. Second, if the stimulus did contain [h] and the subject answered "no", it was clear that the subject failed to hear [h] in the environment where it occurred. Third, if the stimulus did not contain [h] and the subject answered "yes", the subject had incorrectly heard an [h], but it was impossible to tell where the false alarm occurred, e.g., whether the subject incorrectly heard an [h] before or after a consonant or at the beginning or end of the word, and this information is crucial for determining which environment is more confusing for the identification of [h]. Fourth, if the stimulus did contain [h] and the subject answered "yes", this was interpreted as a correct identification. However, it is not necessarily the case that the [h] the subject heard was in the right place. It is possible for a subject to fail to hear the actual [h] but believe there was an [h] somewhere else, and this should not be counted as a correct identification.

In the present study, by forcing subjects to indicate where they heard the [h], it is possible to determine in cases of the third type where the false alarms occurred and in cases of the fourth type whether the subjects were correctly identifying [h] or hearing it where it was not.

3.1. Methods

3.1.1. Subjects

Stimuli were produced by a male native speaker of Turkish. Six female and 15 male native speakers of Turkish, in Columbus, Ohio, aged 19-33, participated in the experiment as subjects. The results of one German-Turkish bilingual were not included in calculations, and the results of another subject were omitted because of experimenter error.

3.1.2. Procedures

160 target nonwords containing [h], 80 foil nonwords not containing [h], and 80 nontarget nonwords not containing [h] were recorded using a Shure SM10A head-mounted microphone through a Symetrix SX202 dual mic preamp into a Teac V-427C stereo cassette deck. The stimuli were then digitized at 22050 Hz using a Marantz PMD222 portable cassette recorder.

Half of the consonant foil stimuli contained a long vowel before the consonant and all of the word-final foil stimuli contained a long final vowel. This was to simulate compensatory lengthening that occurs in Turkish when [h] is deleted from preconsonantal or word-final position. In Turkish orthography this is indicated by a "ğ" following the vowel. This character was not included in the on-screen transcription because transcribing it would indicate that vowel length is not attributable to [h] deletion.[4]

[4] This should result in an increase in false alarms for postvocalic environments, as compared to a similar experiment with "ğ" in the transcription.

(27) *Stimuli in consonant environments*

Context		Target Stimuli Before	Target Stimuli After	Foil Stimuli
voiceless stop	[p, t, k]	8	8	8
voiceless affricate	[tʃ]	8	8	8
voiceless fricative	[f, s, ʃ]	8	8	8
voiced stop	[b, d, g]	8	8	8
voiced affricate	[dʒ]	8	8	8
voiced fricative	[v, z, ʒ]	8	8	8
nasal	[n, m]	8	8	8
liquid	[l, r]	8	8	8
glide	[j]	4	4	4
TOTAL		68	68	68

(28) *Stimuli in vowel environments*

Context	Target Stimuli	Foil Stimuli
intervocalic	8	4
word-initial	8	4
word-final	8	4
TOTAL	24	12

(29) *Total stimuli*

Total Target Stimuli (with [h])	Total Foil Stimuli (without [h])	Nontarget Stimuli (VCCVs without [h])
160	80	80

The stimuli were randomized and played to subjects over Sennheiser HD 420 headphones in a sound booth. As subjects heard each nonword they were presented with the segments in the word other than [h] on a computer screen and instructed to click on the point in the nonword where they heard [h] or to click on button representing no [h] if they heard no [h] in the word. An "h" appeared on screen at the point in the word where the subject clicked. See Appendix E for a sample screen view.

3.1.3. Data analysis

Sensitivity (d') (Green & Swets 1966, Winer 1971, MacMillan & Creelman 1991) was computed for each subject for each of the 21 environments. The d's for each environment were averaged. d' is a measure of sensitivity based on correct identification and false alarm rates. A d' of zero indicates that correct identification and false alarm rates were the same, that subjects had no sensitivity to the presence or absence of [h]. A positive d' indicates that subjects reported hearing [h] more often when it was present than when it was not. A very high d', such as 3, indicates a very high correct identification rate and a very low false alarm rate.

3.2. Results and discussion

The average sensitivity for each environment is given in (30). Sensitivity varied according to what type of segment was adjacent to the [h] (rows), and according to whether the [h] was before or after the segment (columns). The lowest measured sensitivity was in the word-final environment, and much higher sensitivity was measured in various preconsonantal and postconsonantal environments, as well as word-initially and intervocalically.

(30) *Sensitivity (d') by environment for Turkish subjects*

Context		Before Context (VhX)	After Context (XhV)
voiceless stop	[p, t, k]	2.583	2.233
voiceless affricate	[tʃ]	2.558	2.274
voiceless fricative	[f, s, ʃ]	2.423	2.144
voiced stop	[b, d, g]	2.861	2.707
voiced affricate	[dʒ]	2.769	2.838
voiced fricative	[v, z, ʒ]	2.841	2.426
nasal	[n, m]	2.838	2.964
liquid	[l, r]	2.841	3.028
glide	[j]	2.155	1.777
intervocalic		2.248	
word-initial		2.376	
word-final		0.734	

A repeated-measures analysis of variance (ANOVA) with [h] location (the 21 locations in (30)) as an independent variable showed a main effect for the location of [h] within the stimuli ($df = 1{,}18$; $F = 19.828$, $p < 0.001$).

The differences in salience are consistent with the hypothesis for most environments. In (31), the results of this experiment are given alongside the predictions about salience that were made in the previous section. Glides have not been included here with liquids and nasals because they pattern with vowels in terms of intervocalic voicing. Although nasals and liquids were not predicted to differ in their influence on [h] perceptibility, multiple p values are given for nasals and liquids, respectively, when the two p values are different.

(31) *Sensitivity (d') in terms of predictions*

	Prediction			Result			
a.	[h] / son __ V	>	[h] / V __ son	2.996	>	2.840	p = .285, .058
b.	[h] / V __ vls stop	>	[h] / vls stop __ V	2.583	>	2.233	p = .053
c.	[h] / V __ vls aff	>	[h] / vls aff __ V	2.558	?	2.274	p = .282
d.	[h] / son __ V	>	[h] / vls stop __ V	2.996	>	2.233	p < .001[5]
e.	[h] / son __ V	>	[h] / vls aff__ V	2.996	>	2.274	p < .001
f.	[h] / son __ V	>	[h] / vls fric __ V	2.996	>	2.144	p < .001
g.	[h] / # __ V	>	[h] / V __ V	2.376	?	2.248	p = .548
h.	[h] / # __ V	>	[h] / V __ #	2.376	>	0.734	p < .001
i.	[h] / vcd stop__V	>	[h] / vls stop __ V	2.707	>	2.233	p = .005
j.	[h] / V __ son	>	[h] / V __ vls fric	2.840	>	2.423	p = .001, .002
k.	[h] / vls fric __ V	>	[h] / V __ vls fric	2.144	?	2.423	p = .185

Prevocalic [h] is more perceptible than preconsonantal or prepausal [h]. In the case of [h]s which were adjacent to sonorant consonants (31a), sensitivity is marginally higher when [h] follows the consonant (i.e., is prevocalic) than when [h] precedes the consonant, thought not significantly for nasals, but nearly significant for liquids (p = .058). This is consistent with the prediction that [h] is more salient before a vowel, due to the heightened auditory response.

As shown in (31b), [h] is also more perceptible before voiceless stops than after them (p = .053). This is consistent with the hypothesis that the aspiration noise involved in these sounds interferes with the perception of a following [h] enough to overcome the prevocalic/postvocalic asymmetry found with [h] before and after sonorants. [h] is not significantly more perceptible before voiceless affricates than after them (p = .282), as shown in (31c).

[h] is significantly more perceptible after sonorant consonants than after voiceless stops (31d), affricates (31e), or fricatives (31f) (p < .001 in all three cases). This is consistent with the hypothesis that [h] contrasts with F0- and F1-bearing sonorants more than with voiceless obstruents which lack both.

[5] In (31d-f), p < .001 for both nasals and liquids.

Sensitivity to word-initial [h] is not significantly higher ($p = .548$) than for intervocalic [h]) (31g). This is not inconsistent with the prediction that because intervocalic [h] is voiced, syntagmatic contrast with vowels is reduced, as compared with unvoiced initial [h]. Sensitivity to word-final [h] is far lower ($p < .001$) than initial [h], consistent with the temporal asymmetry also borne out in the results for sonorant consonants (31h).

[h] is significantly more perceptible ($p = .005$) after voiced stops than before them (31i), consistent with the prediction that without aspiration, perceptibility of [h] before and after stops should match the perceptibility of [h] before and after other unaspirated consonants.

[h] is significantly more perceptible ($p = .007$) before sonorants than before voiceless fricatives (31j). This is consistent with the hypothesis that [h] contrasts with sonorants more than with voiceless fricatives.

The one area where the results are inconsistent with predictions is [h] before and after voiceless fricatives (31k). The context after a voiceless fricative was predicted to be a more salient environment due to the fact that [h] is prevocalic when it follows a fricative, but the opposite pattern emerges, though it is not statistically significant ($p = .185$).

3.3. Summary

With some exceptions, these results show a relationship between perception and phonology. However, the nature of this relationship is not clear in these results. Perception and phonology could be related because perception influences phonology, i.e., processes such as deletion occur according to universal patterns of perception. Alternatively, perception and phonology could be related because phonology influences perception, i.e., a process such as deletion influences the way speakers perceive sounds. Or perception and phonology could be related in both ways. The two possibilities are not mutually exclusive.

It is impossible to tell which of these is occurring without looking at more than one language. Each relationship makes predictions which can be tested in a cross-linguistic perception experiment or a cross-linguistic survey of deletion phenomena. A perception experiment on one language can show correlation between perception and phonology, but a cross-linguistic experiment is necessary to show causation.

If perception influences phonology, then languages with [h] deletion should delete [h] in environments which are perceptually weak universally, not just perceptually weak for languages with deletion. If speakers of languages which lack [h] deletion have more difficulty perceiving [h] in environments where it is frequently deleted in other languages than in environments where it is seldom deleted, this can be interpreted as evidence that the conditioning environments for deletion are the product of phonetic universals. If the relationship were strictly one in which phonology influences perception, speakers of languages without deletion would not show a difference.

Also, if perception influences phonology, languages that delete [h] where it is perceptually salient would be expected also to delete [h] in environments where it is less salient, and conversely, languages that preserve [h] where it is not very salient would be expected also to maintain [h] in environments where it is more salient. Testing these predictions requires a cross-linguistic typological survey which is beyond the scope of this paper (see Mielke, to appear b).

4. Experiment 2: Crosslinguistic [h] perception

If it is true that phonology influences perception, and listeners become more sensitive to contrasts based on their native phonology, then speakers should be more sensitive to the presence or absence of [h] in environments where it is phonologically significant (i.e., contrastive or at least present) in their own language, as compared to a language without a contrast. Whether or not speakers are good at perceiving [h] would depend on whether or not [h] is present in the language, on what environments it is allowed in, and on whether or not it is contrastive in those environments.

Additional languages were selected according to the distribution of [h] in each language, so that a variety of distributions would be represented among the listeners in this experiment. An ideal set of languages would include a language that allows [h] in many environments, a language that allows [h] only in certain environments, and a language that has no [h] sound at all.

Arabic, which allows [h] before and after nearly all consonants, was selected as a language with [h] in many environments. English, which has [h] in all of the prevocalic positions in the study, was selected as a language with [h] in fewer environments than in Turkish or Arabic. French was selected as a language with no [h] sound. If perception of [h] is influenced by the phonology, then speakers of these three languages should perform differently in the perception experiment, being less able to perceive [h] in environments that are unfamiliar.

The distribution of [h] in the four languages of this study is shown in (32). See Appendix A for lists of words in these languages with [h] in these environments.

(32) *Distribution of [h] in the four languages of this study*

Context			Turkish	Arabic	English	French
vls stop	__	vowel	YES	YES	YES	--
vls affricate	__	vowel	YES	--	YES	--
vls fricative	__	vowel	YES	YES	YES	--
vcd stop	__	vowel	YES	YES	YES	--
vcd affricate	__	vowel	--	--	YES	--
vcd fricative	__	vowel	YES	YES	YES	--
sonorant	__	vowel	YES	YES	YES	--
glide	__	vowel	YES	YES	--	--
#	__	vowel	YES	YES	YES	--
vowel	__	vowel	YES	YES	YES	--
vowel	__	vls stop	YES	YES	--	--
vowel	__	vls affricate	YES	--	--	--
vowel	__	vls fricative	YES	YES	--	--
vowel	__	vcd stop	YES	YES	--	--
vowel	__	vcd affricate	YES	--	--	--
vowel	__	vcd fricative	YES	YES	--	--
vowel	__	sonorant	YES	YES	--	--
vowel	__	glide	YES	YES	--	--
vowel	__	#	YES	YES	--	--

Sources: Harrell (1966), Kornrumpf (1979), Oflazer (1994), M. Alaoui (p.c.)

To determine whether the above results are universal or specific to Turkish and to tease apart the influence of perception from the influence of phonology, the perception experiment was repeated with subjects from the three additional languages.

4.1. Methods

4.1.1. Subjects

The English speaking subjects consisted of 17 female and ten male Ohio State University undergraduates, all native speakers of American English. The results of a Farsi-English bilingual subject were not included in calculations. The results of five other subjects were also not included because the subjects misunderstood the instructions and exhibited "spelling behavior", i.e., they indicated where words would be spelled with "h" in English rather than where they heard [h]. For example, these subjects placed "h" after "a" whenever they heard a long [a], even if there was no [h]. The French speaking subjects consisted of one male and twenty-four female native speakers of French in Paris, France, aged 18-28. The results of a German-French bilingual and a Polish-French bilingual were excluded, as well as the results of two others who misunderstood the instructions and exhibited English "spelling behavior". The Arabic speaking subjects consisted of two female and ten male native speakers of Arabic in Paris, France,[6] aged 20-36. Of the twelve, seven were from Morocco, three were from Algeria, one was from Mauritania, and one was from Jordan. The varieties of Arabic represented in the study maintain [h] in the contexts given in (32) (Zawadowski 1978).

4.1.2. Procedures

Procedures for English, French, and Arabic subjects were identical to procedures for Turkish subjects, except that French and Arabic subjects received instructions in French rather than English. Stimuli and other procedures were unchanged.

4.1.3. Data analysis

Sensitivity (d') was again computed for each subject for each of the 21 environments. The d's for each environment were averaged.

4.2. Results and discussion

The results from Turkish listeners were included with the results from the crosslinguistic experiment. A repeated-measures analysis of variance (ANOVA) with [h] location and language as independent variables showed main effects for language and for the location of [h] within the stimuli, and a significant interaction between language and location.

(33) *ANOVA results*

Source of Variance	DF	F	P
Between listeners			
Language	1,69	60.253	<0.001
Within listeners			
Location	1,69	41.855	<0.001
Location * Language	1,69	5.168	<0.001

The correlation of the results for the four languages was computed based on the entire set of d' values. An R square value close to one indicates a high degree of correlation between two languages, and an R square value close to zero indicates very little correlation between two languages.

[6] Arabic/French bilingualism is not viewed as a problem for the Arabic subjects, because French has no /h/ sound, and a speaker's language background with respect to /h/ should be the same as for a monolingual Arabic speaker (but very different from a monolingual French speaker).

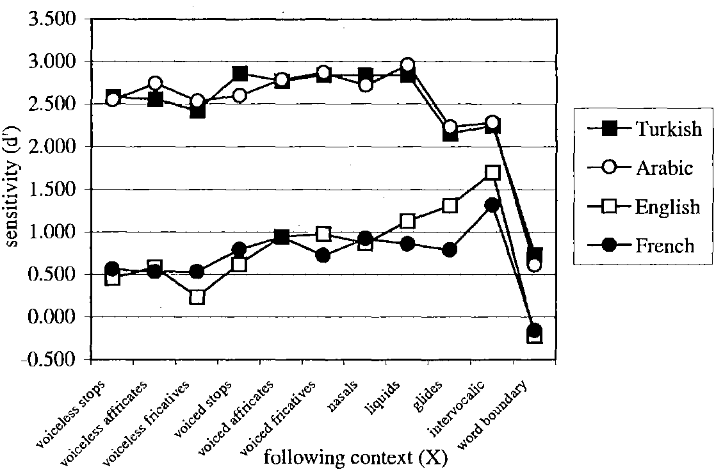
(34) *Correlation (R square)*

Languages	R square	DF	F	P
Turkish & Arabic	0.857	1,19	113.545	<0.001
Turkish & English	0.236	1,19	5.868	0.026
Turkish & French	0.301	1,19	8.180	0.010
Arabic & English	0.296	1,19	7.995	0.011
Arabic & French	0.405	1,19	12.936	0.002
English & French	0.733	1,19	52.288	<0.001

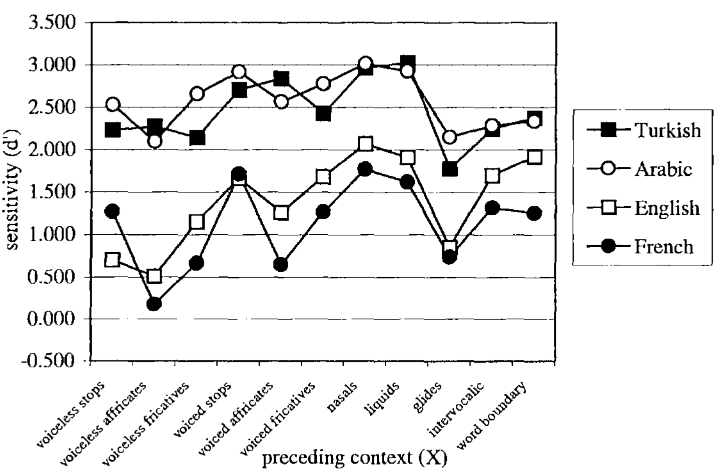
The results for Arabic are strongly correlated with the results for Turkish. Both groups of subjects showed very high sensitivity, as compared with English and French, which are also strongly correlated with each other. In fact there is no environment in which English or French subjects had higher sensitivity than either Turkish or Arabic subjects. This grouping of Arabic with Turkish in terms of sensitivity coincides with the grouping of Arabic and Turkish as languages that permit [h] in many environments, particularly preconsonantal environments. English and French have lower sensitivity, and similarly, both languages permit [h] in fewer environments than Turkish and Arabic.

Charts (35) and (36) show the results separately as "VhX" (before various contexts, postvocalic) environments in (35) and "XhV" (after various contexts, prevocalic) environments in (36). Displaying the results in this manner allows for comparison of all four languages on the same environments. The data used for these charts is located in Appendix C. Although nasals and liquids are grouped together elsewhere in this paper because they behave identically in conditioning Turkish [h] deletion and [h] perceptibility is expected to be very similar with nasals as with liquids, the results for nasals and liquids were calculated separately in order to test this prediction, and are presented separately in this section.

(35) *Sensitivity (d') to [h] before context (VhX)*



(36) *Sensitivity (d') to [h] after context (XhV)*

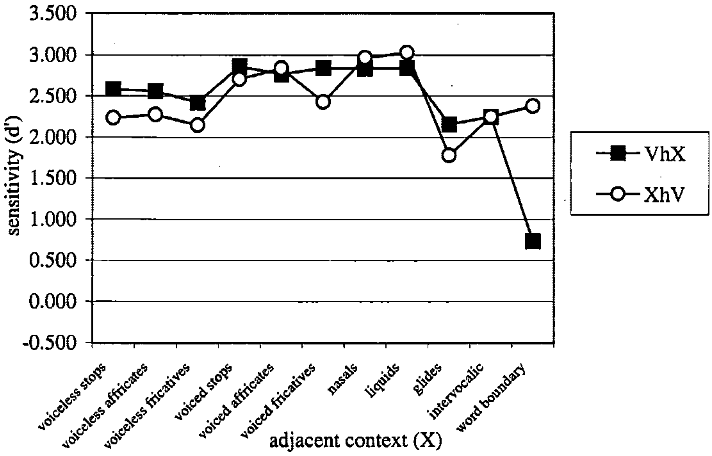


Sensitivity for Arabic subjects was relatively similar to sensitivity for Turkish subjects, while English and French subjects showed lower perceptibility than Turkish subjects in every environment. The difference between English and Turkish is significant (p < .05) in every environment. English subjects performed more similarly to Turkish subjects in prevocalic environments, especially in intervocalic and initial environments. Sensitivity of French subjects was significantly lower than Turkish in every environment (p < .05). French subjects did not improve as much as English subjects in prevocalic environments. The difference in sensitivity between Turkish and Arabic subjects is significant in only one environment, after a voiceless fricative, where Turkish subjects were more sensitive than Arabic subjects.

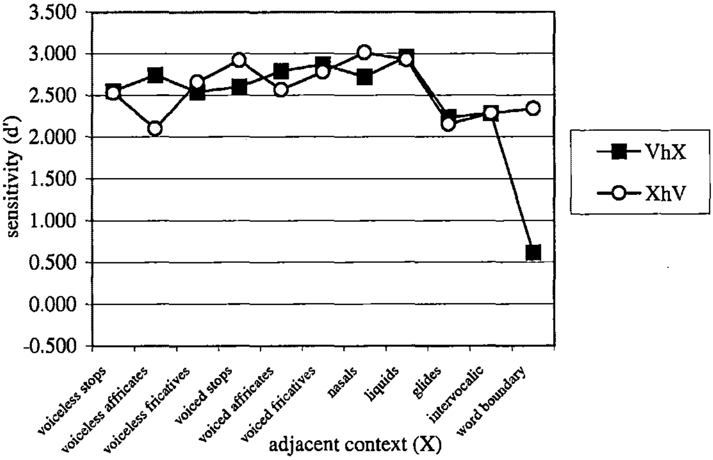
The difference in sensitivity between Arabic and English subjects is significant in all but one environment, word-initial (p = .096), where Arabic subjects were somewhat more sensitive than English subjects. p is less than .05 in all other environments. The difference in sensitivity between Arabic and French subjects is significant (p < .05) in all 21 environments. The difference in sensitivity between English and French subjects is significant in two environments. After a voiceless stop French subjects are significantly more sensitive (p = .032), and after a voiced affricate English subjects are significantly more sensitive (p = .039). Sensitivity is similar between English and French subjects in non-prevocalic environments, while in prevocalic environments, English subjects tended to be more sensitive than French subjects, with a near-significant difference after a voiceless fricative (p = .058).

The next four charts (37-41) show the results for all environments, with a different chart for each of the four languages, allowing the comparison of different environments within each language.

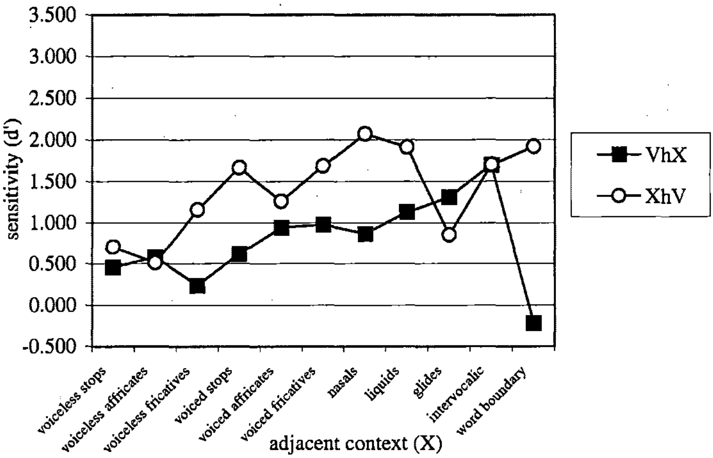
(37) *Sensitivity (d') by environment for Turkish*



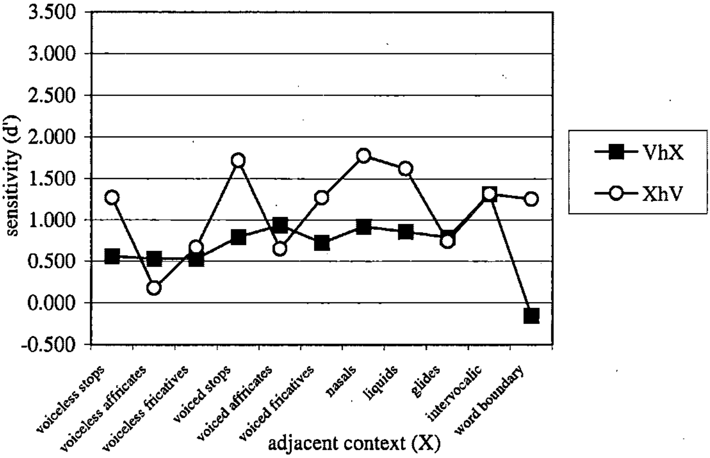
(38) *Sensitivity (d') by environment for Arabic*



(39) *Sensitivity (d') by environment for English*



(40) *Sensitivity (d') by environment for French*



Sensitivity is significant for word-initial vs. word-final environments for all four groups of speakers. For Arabic, sensitivity before a voiceless affricate is significantly higher than sensitivity after a voiceless affricate (p = .003). Sensitivity after a nasal is significantly higher than sensitivity before a nasal (p = .024). Sensitivity after a voiced stop is nearly significantly higher than before a voiced stop (p = .065). For English subjects, sensitivity is significantly higher after five different types of consonants than before them: voiceless fricatives (p < .001), voiced stops (p < .001), voiced fricatives (p = .017), nasals (p < .001), and liquids (p = .013). For French subjects, sensitivity is significantly higher after four different types of consonants than before them: voiceless stops (p = .008), voiced stops (p = .002), nasals (p = .014), and liquids (p = .014), and sensitivity before a voiced stop is nearly significantly higher than after a voiced stop (p = .077).

Sensitivity after a sonorant is significantly higher (p < .05) than before a sonorant for Arabic, English, and French subjects. This is consistent with the prediction that prevocalic [h] is more salient.

The prediction that [h] is more salient after a voiceless stop is not borne out in the results of this experiment. The only significant difference is in the French subjects, for whom [h] is significantly more salient (p = .008) after the voiceless stop than before. This may be because prevocalic [h] is generally much more salient for English and French subjects. Particularly in the English results, while there is a great difference between before and after most consonants, the difference is much smaller for voiceless stops and voiceless affricates. This may be an effect of aspiration that is not large enough to overcome the effect of prevocalicity.

Sensitivity is significantly higher before a voiceless affricate than after only for Arabic subjects ($p = .003$). However, since there is no similar difference for voiceless stops, this may not be entirely attributable to aspiration.

Sensitivity after liquids and nasals is significantly higher than after voiceless stops for English subjects ($p < .001$), but not for French subjects. Only sensitivity after liquids is higher for Arabic subjects ($p = .005$), although sensitivity after nasals is nearly significantly higher than after voiceless stops ($p = .060$). Sensitivity after liquids and nasals is significantly higher ($p < .05$) than after voiceless affricates for all groups of subjects, and significantly higher than after voiceless fricatives for all groups of subjects with one exception. Sensitivity after nasals is only marginally higher than after voiceless fricatives for Arabic subjects ($p = .107$).

Word-initial [h] is not significantly more salient than intervocalic [h] for any group of subjects, but it is significantly more salient ($p < .001$) than word-final [h] for all groups of subjects. The effect of intervocalic voicing may not be enough to significantly impede perception, but word-final [h] suffers for being prepausal.

Sensitivity after a voiced stop is significantly higher than sensitivity after a voiceless stop for English subjects ($p = .001$), but not quite significant for French ($p = .138$) or Arabic subjects ($p = .061$). Aspiration does have an effect, but the effect is different for different groups of subjects. Aspiration is discussed further in §5 and §6.

Sensitivity before a sonorant is significantly higher ($p < .05$) than before a voiceless fricative for all groups of subjects, except that sensitivity before a nasal is not significantly higher for Arabic subjects. The effect of fricative noise appears to be present universally.

Sensitivity after a voiceless fricative is significantly higher than before a voiceless fricative for English subjects ($p < .001$), but not for any other group of subjects. This may be a result of the English prevocalic [h] rather than the salience of prevocalic [h], because the difference is only significant for English subjects.

4.3. Summary

The results show a striking difference between different groups of subjects. Turkish and Arabic subjects were very sensitive to [h] in most environments, and English and French subjects were considerably less sensitive, particularly in non-prevocalic environments, and English subjects were more sensitive than French subjects in prevocalic environments. (35) and (36) show that there is no environment where English or French subjects were more sensitive to [h] than Turkish or Arabic subjects. In fact, the difference in sensitivity between each of the two "[h]-sensitive" groups (Turkish and Arabic) and each of the two "non-sensitive" groups (English and French) is significant for all of the 21 environments.

Another salient aspect of these results is that despite differences in overall sensitivity between the different groups, the patterns of relative perceptibility are very similar across languages, and the lines tend to parallel each other. This is especially apparent in (36) and in the charts for English and French (39 & 40).

5. Considerations for aspirated stops

Aspirated stops are of special importance in this study because of the perceptual similarity between [h] and stop aspiration. Examining how subjects responded to aspirated stops is informative, and also raises some questions about experiment design.

Arabic subjects had higher sensitivity to [h] after voiceless stops than Turkish subjects, and French subjects had higher sensitivity than English subjects. Apparently the two pairs of languages differ in this respect for different reasons. Recall that the sensitivity measure d' is a function of correct identification rate and false alarm rate. Therefore there are two ways a d' can be lowered, either by lowering the correct identification rate, or by raising the false alarm rate.

In the case of Turkish and Arabic, the Turkish subjects had a slightly higher false alarm rate and a slightly lower correct identification rate. This is consistent with the previous explanation that the sensitivity of Turkish speakers in this environment is lowered by the fact that [h] is not contrastive in this environment.

Compared to Arabic and Turkish, the differences between English and French can be accounted for in another way. French does not have aspirated stops anywhere except word-finally (Valdman 1976). The French subjects had a higher false alarm rate after aspirated stops, which is understandable given that aspirated stops can be perceived as unaspirated stops followed by [h]. The difference in sensitivity is due to the fact the French subjects had a much higher correct identification rate (see Appendix D). The correct identification rate of the English subjects (30.36%) was lower than after any other consonant. The reason for this may be that the Turkish aspirated stops in the stimuli are not as heavily aspirated as English aspirated stops (Lewis 1967). To an English speaker, a stop with a comparatively short voice onset time followed by an [h] is not as likely to be perceived as having an [h], if the combined duration of the aspiration and the [h] is short enough to be simply the aspiration of a stop. (41) shows the VOT for all of the voiceless stop foil stimuli (intervocalic voiceless stops with no [h]) and the voiceless stop + [h] stimuli, along with the [h] identification rate for each group of stimuli. ([h] identification rate for the voiceless stop + [h] stimuli is the correct identification rate and [h] identification rate for the foil stimuli is the false alarm rate)

(41) *[h] identification rate for voiceless stops with and without [h]*

	VOT		[h] identification rate			
	average	range	Arabic	Turkish	French	English
voiceless stop + [h]	86 ms	51-115 ms	85.42%	83.55%	53.57%	30.36%
voiceless stop (foil)	44 ms	19-62 ms	10.42%	9.87%	11.90%	7.76%

In a study of noncoronal stop perception, Volaitis and Miller (1992) found that for a fast speech rate, English-speaking subjects found labial stops produced with VOTs up to 87.15 ms and velar stops with VOTs up to 92.10 ms to be "normal" voiceless stops, and stops with higher VOTs were "exaggerated" voiceless stops. Many of the voiceless stop + [h] stimuli in this study, which were produced by a speaker of Turkish, fall within the range that Volaitis and Miller found to be acceptable voiceless stops for English listeners

6. Experiment 3: English listeners

As mentioned in the previous section, providing subjects with a partial transcription removes the possibility of confusing an aspirated stop with an unaspirated stop followed by [h]. The English subjects in Experiment 2 may have had a low [h] identification rate after voiceless stops because they were aware that the stops in those stimuli were [p], [t], and [k], not [b], [d], and [g]. A long VOT was allowable without alarm because the voiceless stop could account for the VOT. If there were a possibility that the stops could be voiced, aspiration would be an indication that there was an [h]. In Ovcharova's (1999) study, subjects were not given a partial transcription, and this problem did not arise. To check the results of the previous experiment, another experiment was run, with a task more similar to Ovcharova's.

6.1. Methods

6.1.1. Subjects

The subjects in this experiment were 17 female and five male Ohio State University undergraduates, aged 18-27, all native speakers of American English who did not participate in the first experiment. The results of one Greek-English bilingual speaker were not included.

6.1.2. Procedures

Procedures were similar to the previous experiment. However, instead of seeing the partial transcription and clicking on the screen where [h] was heard, subjects were asked to choose between two responses: "h" if there was an [h] in the stimulus, and "Ø" if there was not. Stimuli and other procedures were unchanged. See Appendix E for a sample screen view.

6.1.3. Data analysis

Because d' is not measurable without false alarm rates, only the correct identification rate was calculated. The correct identification rates (C/I) for each environment were averaged. They were then compared to two different rates from the English subjects in Experiment 2: the C/I rate, where [h] was reported in the correct position, and the total identification (T/I) rate, where [h] was reported in a stimulus containing [h], even if it was reported in the wrong place. This second measure is more similar to the C/I rate for the present experiment, where subjects simply reported whether or not they heard [h].

6.2. Results and discussion

In all environments, the correct identification rates from Experiment 3 were lower than or similar to the other two rates, as expected, since the responses contributing to the C/I rate for each environment are a subset of the responses contributing to the T/I rate. The T/I rate for the partial transcription task was virtually the same as or higher than the C/I rate for the task without transcription in all but four environments: after voiceless stops, after voiceless affricates, after liquids, and after glides. In the case of the stops and affricates, this means that subjects were less likely to report hearing an [h] if they knew a voiceless stop or affricate was in the stimulus and accounted for at least part of what they heard.

(42) *Identification rates after obstruents for both experiments*

Context		Experiment 2 C/I Rate		Experiment 2 T/I Rate	Experiment 3 C/I rate
voiceless stop	[p, t, k]	51.79%	>	46.43%	30.36%
voiceless affricate	[tʃ]	51.79%	>	47.02%	35.71%
voiceless fricative	[f, s, ʃ]	67.86%	<	70.24%	62.50%
voiced stop	[b, d, g]	64.29%	<	74.40%	63.10%
voiced affricate	[dʒ]	58.93%	<	64.29%	57.14%
voiced fricative	[v, z, ʒ]	66.67%	<	73.81%	63.10%

6.3. Summary

For Experiment 2, this means that the identification rates and in particular the false alarm rates for stimuli containing an [h] following a voiceless stop or affricate were likely lower than they would have been if the voiceless stop and affricate were not transcribed. As a result, true sensitivity to [h] following a voiceless stop or affricate is probably lower than the results indicate, and aspiration may have more of an effect on [h] perception than Experiment 2 was able to show.

7. Discussion: the influence of phonology on perception

If phonology had no influence on perception, the results for all four groups of subjects should be the same. They are clearly not the same, and they are not the same for a number of reasons.

In general, Turkish and Arabic sensitivity is very high, in fact nearly perfect, reaching a ceiling level and thus making comparison of the two languages and the different environments difficult. Several environments had zero false alarms,[7] and for Turkish subjects, five environments (before nasals, liquids, and voiced fricatives and affricates, and after liquids) had correct identification rates above 98%. Arabic subjects had correct identification rates of 100% for before liquids and glides. For Turkish and Arabic subjects, detecting [h] in these environments is too easy for the results to show anything more than that detection is easy. Noise could be added to the signal to make the task more difficult, but noise can affect stimuli in unexpected ways, and it is important for the experiments in this study to be run without noise. However, replicating the experiments with noise may prove to be informative as well.

In contrast to the high sensitivity of Turkish and Arabic subjects, the opposite problem presents itself in the results of the English and French subjects. The level of sensitivity is very low for many environments, particularly postvocalic environments, so that comparison between environments is difficult because they are all about as low as they can be. Zero d' is chance performance, and the results for English and French are very near zero for several environments.

One approach to analyzing these results is to recognize that in general, Turkish and Arabic subjects perform near the ceiling and English and French subjects perform near the floor. Where there is a deviation from these low and high patterns, there may be a more specific effect to explain. Four factors appear to determine how the phonology of a language affects sensitivity to [h]. They are the presence of [h] in the language, familiarity with [h] in specific environments, the presence of non-prevocalic [h] in the language, and the contrastiveness of [h] in specific environments.

7.1. Presence of [h]

Of the four languages in the study, the one language which does not have [h], i.e., French, is the language whose subjects showed the least sensitivity to [h]. Thus, whether or not a language has [h] as a possible sound is a factor that contributes to sensitivity of [h].

[7] d' is undefined when the false alarm rate or correct identification rate is zero or one. In the event that the false alarm rate or the correct identification rate for any subject was zero or one, the total was adjusted by an amount equal to half of one error or correct identification. For example, 8/8 becomes 7.5/8 and 0/8 becomes 0.5/8.

7.2. Familiarity with [h] in specific environments

One factor that appears to determine [h] sensitivity is familiarity. Turkish and Arabic are both languages with [h] in many environments, as compared to English and French, and Turkish and Arabic subjects had higher sensitivity to [h] than English and French subjects in every environment. Being exposed to a language with [h] in many environments causes a listener to be more sensitive to the presence of [h] in those environments.

7.3. Non-prevocalic [h]

The dichotomy between the two groups of languages (Turkish and Arabic as opposed to English and French) is most striking in the non-prevocalic environments in (35). Generally, the rift is between the languages with [h] in many environments and languages with [h] in fewer environments, but in this case the rift is between languages that have [h] before consonants (Turkish and Arabic) and languages that do not allow [h] before consonants (English and French). The split is not so severe in (36), which shows prevocalic environments, because English has [h] in these environments. English subjects were significantly more sensitive to [h] in a number of prevocalic environments than French subjects, because English has prevocalic [h], and thus English speakers are more familiar with it.

Similarly, Turkish, Arabic, and English all have prevocalic [h], but Turkish and Arabic subjects were nevertheless more sensitive to [h] in prevocalic environments, although English subjects were more sensitive than French subjects. Apparently the skill of perceiving non-prevocalic [h] is transferable to prevocalic [h] (and not available to English speakers). Being able to perceive [h] when it is not followed by a vowel makes listeners even more able to perceive it when it is followed by a vowel. Listeners must have the ability to recognize [h] using a smaller number of cues, and their increased ability to utilize these cues benefits their [h] perception even in environments where more cues are present.

The fact that French subjects were more sensitive to prevocalic [h] than to postvocalic [h] is supportive of the hypothesis that [h] should be generally more perceptible before vowels than after, because the onset of the vowel is more salient than the offset. This may in part explain the difference in sensitivity of prevocalic and postvocalic [h] for English subjects, although the lack of non-prevocalic [h] in English is likely responsible. Nevertheless, this is a likely reason for the smaller difference between lowest and highest sensitivity in (38). The unfamiliarity of French subjects in particular is partially compensated for by the acoustical advantage claimed by prevocalic consonants. As measured in this experiment, Arabic and Turkish subjects are nearly maximally sensitive to [h] in many prevocalic and postvocalic environments, and perhaps do not need the auditory advantage afforded by prevocalic [h].

7.4. Contrast

Another factor contributing to sensitivity is contrast. While the sensitivity of Turkish and Arabic listeners is virtually the same in nearly all environments, it does differ in three environments: after voiceless stops, after voiceless fricatives, and after voiced fricatives. Two of these are environments where [h] can be deleted in Turkish. This is not the case with all of the environments where [h] deletes in Turkish, but perhaps these are the weakest in terms of acoustic cues, as opposed to other environments where the cues may be robust enough to overcome the lack of native language contrast.

When there is optional [h] deletion, the contrast between [h] and the lack of [h] is not meaningful. In Arabic, where this contrast is typically maintained, listeners are more sensitive to its presence or absence. In Turkish, where this contrast is often neutralized, it is less necessary for listeners to be sensitive to [h] in these environments in order to recognize words. Thus, a lack of contrast leads to a lack of sensitivity.

The four factors will be addressed further in the next section, where they are important in the model for predicting d'.

8. Discussion: the influence of perception on phonology

If perception influences phonology in Turkish [h] deletion, the environments where deletion is observed would be expected to be perceptually weak universally. The first experiment showed that for Turkish subjects, sensitivity before and after each type of consonant is consistent with deletion patterns. The results for Arabic, English, and French subjects are supportive.

Constructing a universal perceptibility scale (uninfluenced by phonology) for [h] environments based on the results from the four languages is difficult because the relative salience of [h] environments is different for each group of subjects. Developing a model of sensitivity may help to isolate the universal and language-specific factors and indicate what might be universal.[8]

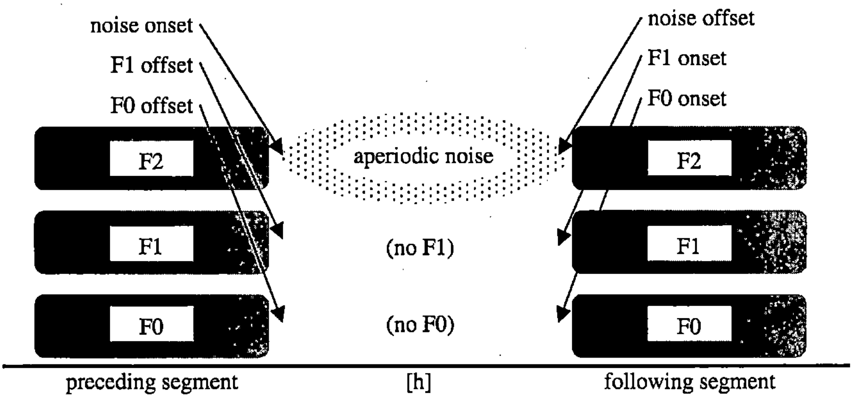
In Experiments 1 and 2, sensitivity (d') was computed as a function of normalized correct identification and false alarm rates. In this section a model for predicting d' will be proposed, based on what are hypothesized to be the factors that determine the sensitivity of a speaker of a given language to the presence of [h] in a given environment. In this study, subjects speaking four different languages were tested in 21 different phonetic environments. This gives 84 possible combinations of environments and languages. For each of the 84 cases, phonetic and language-specific factors are relevant.

Ten variables were considered. Six variables are based on phonetic cues proposed in §2, noise onset, noise offset, F1 offset, F1 onset, F0 offset, and F0 onset.

[8] See Mielke (to appear a) for a more detailed discussion of the influence of perception on phonology.

These cues are illustrated in (44). Four language-specific variables are based on the factors discussed in §7: presence of [h], non-prevocalic [h], familiarity, and contrast.

(43) *Universal (phonetic) variables*



The values of the phonetic variables are determined by environment regardless of language. Each environment receives a value of zero or one for each of the six variables, depending on whether that cue to [h] is present in the environment.

(44) *Universal (phonetic) variables*

Environment			F0 offset	F0 onset	F1 offset	F1 onset	noise onset	noise offset
vls stop	__	vowel	0	1	0	1	0	1
vls affricate	__	vowel	0	1	0	1	0	1
vls fricative	__	vowel	0	1	0	1	0	1
vcd stop	__	vowel	1	1	0	1	1	1
vcd affricate	__	vowel	1	1	0	1	0	1
vcd fricative	__	vowel	1	1	0	1	0	1
sonorant	__	vowel	1	1	1	1	1	1
glide	__	vowel	0	0	1	1	1	1
#	__	vowel	0	1	0	1	1	1
vowel	__	vowel	0	0	1	1	1	1
vowel	__	vls stop	1	0	1	0	1	1
vowel	__	vls affricate	1	0	1	0	1	1
vowel	__	vls fricative	1	0	1	0	1	0
vowel	__	vcd stop	1	1	1	0	1	1
vowel	__	vcd aff	1	1	1	0	1	1
vowel	__	vcd fricative	1	1	1	0	1	0
vowel	__	sonorant	1	1	1	1	1	1
vowel	__	glide	0	0	1	1	1	1
vowel	__	#	1	0	1	0	1	1

The language-specific variables receive a value of zero or one depending on the phonology of each language. "Presence of [h]" is 1 for Turkish, Arabic, and English, which have /h/ in their inventories, and 0 for French which does not. "Non-prevocalic [h]" is 1 for Turkish and Arabic, which permit [h] in non-prevocalic environments, and 0 for English and French, which do not. "Familiarity" is 1 for those environments where [h] is allowed in a language, so it is 1 for most environments in Turkish and Arabic, and for prevocalic environments in English, and 0 for all environments in French. "Contrast" is 1 for the subset of environments with a value of 1 for "Familiarity" that have a meaningful contrast between [h] and its absence in those environments.

(45) *Language specific variables*

Variable	Turkish	Arabic	English	French
Presence of [h]	1	1	1	0
Non-prevocalic [h]	1	1	0	0
Familiarity[9]	0 or 1	0 or 1	0 or 1	0 or 1
Contrast	0 or 1	0 or 1	0 or 1	0 or 1

The ten variables are summarized in (46)

[9] Values of familiarity and contrast variables depend on environment.

(46) *Variables hypothesized to be factors in determining sensitivity*

Variable		Description	Value
Universal (phonetic) variables	F0 onset	The transition from [h] to the following segment is marked by the onset of voicing.	0 or 1
	F0 offset	The transition from the preceding segment into [h] is marked by the offset of voicing.	0 or 1
	F1 onset	The transition from [h] to the following segment is marked by the onset of the F1 resonance.	0 or 1
	F1 offset	The transition from the preceding segment into [h] is marked by the offset of the F1 resonance.	0 or 1
	Noise onset	The transition from the preceding segment into [h] is marked by the onset of aperiodic noise.	0 or 1
	Noise offset	The transition from [h] to the following segment is marked by the offset of aperiodic noise.	0 or 1
Language-specific variables	Presence of [h]	The language has [h] in its consonant inventory	0 or 1
	Non-prevocalic [h]	The language has [h] in non-prevocalic position.	0 or 1
	Familiarity	The language has [h] in the environment in question.	0 or 1
	Contrast	The presence of [h] is contrastive in the environment in question.	0 or 1

A stepwise linear regression was performed, and six of the ten variables were found to have a significant contribution to d'. Whether or not a language has [h] in non-prevocalic position was found to be the largest contributing factor to sensitivity in general, as this is the difference between the two languages with very high sensitivity and the two languages with very low sensitivity. Four of the other five significant variables are phonetic. In all three sets of cues, the onset of the resonance or noise is significant, which is consistent with the predictions based on Wright (1996) and Fujimura et. al (1978) that the onset of a stimulus would be more important for [h] perception than the offset of the same stimulus. This holds true even though the onset of noise occurs at the beginning of [h] and the onset of F0 and F1 occur at the end of [h]. The offset of F0 is also significant, as well as whether or not [h] is contrastive in the environment.

(47) *Stepwise linear regression: variables with a significant contribution to d'*

Variable		Coefficient	T	P
a.	Non-prevocalic [h]	1.363	14.627	<.001
b.	F0 onset	.413	3.554	.001
c.	Contrast	.349	3.609	.001
d.	Noise onset	.323	3.648	.010
e.	F1 onset	.453	3.717	<.001
f.	F0 offset	.256	2.120	.037

The formula for predicting sensitivity based on these variables is given in (48).

(48) *Formula for predicting d'*

$$d' = 1.363a + .413b + .349c + .323d + .453e + .256f$$

where: a = 1 if the language has non-prevocalic [h]; otherwise a = 0
b = 1 if the onset of voicing is at the end of [h]; otherwise b = 0
c = 1 if [h] is contrastive in the environment; otherwise c = 0
d = 1 if aperiodic noise begins at the beginning of [h]; otherwise d = 0
e = 1 if the F1 resonance begins at the end of [h]; otherwise e = 0
f = 1 if the offset of voicing is at the beginning of [h]; otherwise f = 0

Based on the four phonetic cues that have been found to be significant variables, the ranking in (49) is a basic universal perceptibility scale. The coefficients found in (48) are multiplied by the universal phonetic variables for each environment, giving a predicted d' for each environment. These environments can then be ranked by predicted d', giving a universal perceptibility scale. In reality, language-specific factors would influence d' as well. In this model, that would not affect the ranking.

(49) *Predicted d' (excluding language-specific variables, i.e., for a = 0 & c = 0)*

Environment	**Cues**								**Predicted d'**
	F0 onset		**noise onset**		**F1 onset**		**F0 offset**		
sonorant __ V	.413	+	.323	+	.453	+	.256	=	1.445
V __ sonorant	.413	+	.323	+	.453	+	.256	=	1.445
vcd stop __ V	.413	+	.323	+	.453	+	.256	=	1.445
# __ V	.413	+	.323	+	.453	+	0	=	1.189
vcd aff __ V	.413	+	0	+	.453	+	.256	=	1.122
vcd fric __ V	.413	+	0	+	.453	+	.256	=	1.122
V __ vcd aff	.413	+	.323	+	0	+	.256	=	0.992
V __ vcd stop	.413	+	.323	+	0	+	.256	=	0.992
V __ vcd fric	.413	+	.323	+	0	+	.256	=	0.992
vls aff __ V	.413	+	0	+	.453	+	0	=	0.866
vls fric __ V	.413	+	0	+	.453	+	0	=	0.866
vls stop __ V	.413	+	0	+	.453	+	0	=	0.866
V __ V	0	+	.323	+	.453	+	0	=	0.776
glide __ V	0	+	.323	+	.453	+	0	=	0.776
V __ glide	0	+	.323	+	.453	+	0	=	0.776
V __ vls stop	0	+	.323	+	0	+	.256	=	0.579
V __ vls aff	0	+	.323	+	0	+	.256	=	0.579
V __ vls fric	0	+	.323	+	0	+	.256	=	0.579
V __ #	0	+	.323	+	0	+	.256	=	0.579

With this hypothetical universal scale, it is possible to compare these environments to the deletion environments, and evaluate Hypothesis 1, that [h] is less perceptible in the environments were it deletes in Turkish.

(50) *Comparison of Turkish [h] deletion environments to perceptibility scale for Turkish and hypothesized universal scale*

Perceptibility scale based on Turkish (Experiment 1)

Environment	Deletion
liquid __ V	
nasal __ V	
V __ vcd stop	
V __ vcd fric	
V __ liquid	YES
vls aff __ V	YES
V __ nasal	YES
V __ vcd aff	
vcd stop __ V	
V __ vls stop	
V __ vls aff	
vcd fric __ V	
V __ vls fric	YES
# __ V	
V __ vls aff	
V __ V	YES
vls stop __ V	YES
V __ glide	
V __ vls fric	YES
glide __ V	
V __ #	YES

more perceptible ↔ **less perceptible**

Perceptibility scale based on six phonetic factors

Environment	Turkish Deletion
liquid __ V	
nasal __ V	
V __ liquid	YES
V __ nasal	YES
vcd stop __ V	
# __ V	
vcd aff __ V	
vcd fric __ V	
V __ vcd aff	
V __ vcd stop	
V __ vcd fric	
vls aff __ V	YES
vls fric __ V	YES
vls stop __ V	YES
V __ V	YES
glide __ V	
V __ glide	
V __ vls stop	
V __ vls aff	
V __ vls fric	YES
V __ #	YES

In both rankings, there is a tendency for the deletion environments to be the environments where [h] is less perceptible, but based on these rankings it is not the case that all of the deletion environments are less salient than all of the non-deletion environments. The fact that some of the deletion environments are the environments where [h] is less salient, but that deletion environments do not seem to be exclusively the least salient environments, can be explained in a number of ways.

First, the way sensitivity was measured in the experiments did not duplicate the way sensitivity is used in everyday conversation. No noise was added to the stimuli, and the quiet environment that was created in the sound booth is not very similar to real-world listening conditions. For the Turkish and Arabic subjects, detecting [h] was very easy in most environments, particularly for the ones found to be most salient, and therefore the environments found to be least confusable in the controlled environment of the sound booth may not be particularly relevant in conversation.

Second, two listeners who differ in their sensitivity to [h] may attend to different cues. The model of sensitivity advanced in this paper assumes that all subjects are using the cues in the same way. For example, the coefficients for F0 offset, F1 offset, and noise onset may need to be higher for speakers of languages with non-prevocalic [h] than they are for speakers of languages without non-prevocalic [h], because these speakers have more experience utilizing these cues exclusively to recognize [h]. The above model of sensitivity does not allow this. See Mielke (to appear a) for a more sophisticated model of sensitivity.

Third, there may be non-perceptual factors involved. Environments for deletion may be generalized in ways that may not match the results of the experiments (see also Cole and Iskarous 2001). Perception *influences* phonology, after all. It does not replace phonology.

9. Conclusion

These experiments have demonstrated a bi-directional relationship between perception and phonology. The influence of phonology on perception is seen in the widely varying performances of subjects with different language backgrounds. The ability of listeners to detect [h] depends on where [h] is allowed in the native language and how it is used.

The influence of perception on phonology is seen in the asymmetrical pattern of [h] deletion in Turkish. Not only does the asymmetry match the patterns of perceptibility in the majority of environments Turkish, it matches patterns of perceptibility in Arabic, English and French, which are not influenced by Turkish phonology.

The goal of this paper has been to show that perception and phonology are related. The example of Turkish [h] deletion makes this relationship quite clear, and the fact that perception is important in this phonological phenomenon shows that this relationship indeed exists. This is not to claim that perception can explain everything in phonology, but that along with other factors, the influence of perception on phonology is not to be overlooked.

Appendix A - Examples of the distribution of [h]

The following lists of words show the distribution of [h] as claimed in (39).

A.1 - Turkish

Context			Example	Context			Example
vls stop	__	vowel	şüphe	vowel	__	vls stop	kahpe
vls aff	__	vowel	meçhul	vowel	__	vls aff	ahçı
vls fric	__	vowel	ishak	vowel	__	vls fric	ahşap
vcd stop	__	vowel	tedhiş	vowel	__	vcd stop	ahbap
vcd aff	__	vowel	--	vowel	__	vcd aff	mahcup
vcd fric	__	vowel	mazhar	vowel	__	vcd fric	mahzur
nasal	__	vowel	imha	vowel	__	nasal	köhne
liquid	__	vowel	merhum	vowel	__	liquid	ihlal
glide	__	vowel	meyhane	vowel	__	glide	ihya
#	__	vowel	hayır	vowel	__	#	sabah
vowel	__	vowel	şahin				

Source: Kornrumpf (1979), Oflazer (1994)

A.2 - Arabic

Context			Example	Context			Example
vls stop	__	vowel	məthaf	vowel	__	vls stop	muhtaram
vls aff	__	vowel	--	vowel	__	vls aff	--
vls fric	__	vowel	shur	vowel	__	vls fric	wæhʃ
vcd stop	__	vowel	rəbha	vowel	__	vcd stop	rəhba
vcd aff	__	vowel	--	vowel	__	vcd aff	--
vcd fric	__	vowel	mežhud	vowel	__	vcd fric	lehža
nasal	__	vowel	minha	vowel	__	nasal	məhna
liquid	__	vowel	marhaba	vowel	__	liquid	məlul
glide	__	vowel	tˤajha	vowel	__	glide	jəhja
#	__	vowel	həʒʒæm	vowel	__	#	tˤah
vowel	__	vowel	bæhit				

Source: Harrell (1966), M. Alaoui (p.c.)

A.3 - English

Context			Example	Context			Example
vls stop	__	vowel	knighthood	vowel	__	vls stop	--
vls aff	__	vowel	beachhead	vowel	__	vls aff	--
vls fric	__	vowel	fishhook	vowel	__	vls fric	--
vcd stop	__	vowel	bloodhound	vowel	__	vcd stop	--
vcd aff	__	vowel	hedgehog	vowel	__	vcd aff	--
vcd fric	__	vowel	hogshead	vowel	__	vcd fric	--
nasal	__	vowel	inherit	vowel	__	nasal	--
liquid	__	vowel	forehand	vowel	__	liquid	--
glide	__	vowel	keyhole	vowel	__	glide	--
#	__	vowel	help	vowel	__	#	--
vowel	__	vowel	vehicular				

Appendix B – Stimuli for experiments 1-3[10]

Context	Target Stimuli				Foil Stimuli	
	Before Context		After Context			
voiceless stops	ühpe[11]	yhpɛ[12]	üphe	yphɛ	opa	oːpa
	ahte	ahtɛ	athe	athɛ	ita	iːta
	ahkum	ahkum	akhum	akhum	eka	ɛːka
	ohpa	ohpa	opha	opha	üta	yːta
	ahtı	ahtɯ	athı	athɯ	üpe	ypɛ
	ühkü	yhky	ükhü	ykhy	ekü	ɛky
	ehpe	ɛhpɛ	ephe	ɛphɛ	epe	ɛpɛ
	ihta	ihta	itha	itha	atı	atɯ
voiced stops	ühbe	yhbɛ	übhe	ybhɛ	oba	oːba
	ahde	ahdɛ	adhe	adhɛ	ida	iːda
	ahgum	ahgum	aghum	aghum	ega	ɛːga
	ohba	ohba	obha	obha	üda	yːda
	ahdı	ahdɯ	adhı	adhɯ	übe	ybɛ
	ühgü	yhgy	üghü	yghy	egü	ɛgy
	ehbe	ɛhbɛ	ebhe	ɛbhɛ	ebe	ɛbɛ
	ihda	ihda	idha	idha	adı	adɯ

[10] The majority of these nonwords are from Ovcharova (1999). All stimuli were recorded new for this study, and additional nonwords were added for environments not included in Ovcharova's study.
[11] The first column is Turkish orthography, as the stimuli were presented on screen (without "h"s).
[12] The second column is IPA transcription.

voiceless fricatives	ihsa	ihsa	isha	isha	isa	isa
	ahşe	ahʃɛ	aşhe	aʃhɛ	öşe	œ:ʃɛ
	ahfa	ahfa	afha	afha	afa	afa
	ehfe	ɛfhɛ	efhe	ɛfhɛ	ıse	ɯsɛ
	öhşüt	œhʃyt	öşhüt	œʃhyt	aşe	aʃɛ
	ahşı	ahsɯ	aşhı	aʃhɯ	afa	a:fa
	ıhse	ɯhsɛ	ıshe	ɯshɛ	ofe	o:fɛ
	ühfe	yhfɛ	üfhe	yfhɛ	öse	œ:ʃɛ
voiced fricatives	ihza	ihza	izha	izha	ova	ova
	ahje	ahʒɛ	ajhe	aʒhɛ	izo	izo
	ahva	ahva	avha	avha	aze	azɛ
	ehve	ɛhvɛ	evhe	ɛvhɛ	aza	a:za
	öhjüt	œhʒyt	öjhüt	œʒhyt	eje	ɛʒɛ
	ahjı	ahʒɯ	ajhı	aʒhɯ	aja	a:ʒa
	ıhze	ɯhzɛ	ızhe	ɯzhɛ	ive	i:vɛ
	ühve	yhvɛ	üvhe	yvhɛ	öze	œ:zɛ
voiceless affricates	ahça	ahtʃa	açha	atʃha	içi	itʃi
	uhçu	uhtʃu	uçhu	utʃhu	eçi	ɛ:tʃi
	ihçi	ihtʃi	içhi	itʃhi	ıçı	ɯ:tʃɯ
	ehçi	ɛhtʃi	açhı	atʃhɯ	içe	i:tʃɛ
	ühçü	yhtʃy	üçhü	ytʃhy	aça	a:tʃa
	ehçe	ɛhtʃɛ	eçhe	ɛtʃhɛ	uçu	utʃu
	ihça	ihtʃa	içha	itʃha	eçe	ɛtʃɛ
	öhçe	yhtʃɛ	öçhe	œtʃhɛ	öçe	œtʃɛ
voiced affricates	ahca	ahdʒa	acha	adʒa	ici	idʒi
	uhcu	uhdʒu	uchu	udʒu	eci	ɛ:dʒi
	ihci	ihdʒi	ichi	idʒi	ıcı	ɯ:dʒɯ
	ehci	ɛhdʒi	achı	adʒɯ	ice	i:dʒɛ
	ühcü	yhdʒy	üchü	ydʒy	aca	a:dʒa
	ehce	ɛhdʒɛ	eche	ɛdʒɛ	ucu	udʒu
	ihca	ihdʒa	icha	idʒa	ece	ɛdʒɛ
	öhce	œhdʒɛ	öche	œdʒɛ	öcc	œdʒɛ

nasals	ahmı	ahmɯ	omha	omha	ena	ɛ:na
	öhmü	œhmy	ömhü	œmhy	eme	ɛ:me
	ehna	ɛhna	enha	ɛnha	ömü	œmy
	ehme	ɛhmɛ	emhe	ɛmhɛ	anu	anu
	ohnu	ohnu	anhe	anhɛ	emi	ɛmi
	ihma	ihma	emho	ɛmho	emi	ɛ:mi
	ehne	ɛhnɛ	inha	inha	ame	a:mɛ
	ahme	ahmɛ	onhu	onhu	ina	ina
liquids	ihla	ihla	ilha	ilha	iri	i:ri
	ihri	ihri	irhi	irhi	ile	i:lɛ
	ihle	ihlɛ	ilhe	ilhɛ	ara	ara
	ahra	ahra	arha	arha	ila	ila
	ihra	ihra	ilhi	ilhi	ere	ɛrɛ
	ühlü	yhly	arha	arha	oru	o:ru
	ihru	ihru	urha	urha	ira	i:ra
	ohlü	ohly	alhi	alhi	ela	ɛla
glides	uhya	uhja	uyha	ujha	ıya	ɯ:ja
	ehye	ɛhjɛ	eyhe	ɛjhɛ	öyu	œ:ju
	uhye	uhjɛ	uyhe	ujhɛ	ayu	a:ju
	öhya	œhja	öyha	œjha	öyö	œ:jœ
intervocalic	tahan	tahan	köhen	kœhɛn	taan	ta:an
	rohum	rohum	keher	kɛhɛr	loum	lo:um
	muhan	muhan	lohum	lohum	muan	mu:an
	tihir	tihir	sahal	sahal	köen	kœ:ɛn
word-initial	halam	halam	hemon	hɛmon	alam	alam
	hürin	hyrin	helir	hɛlir	ürin	yrin
	holan	holan	holar	holar	olan	olan
	helor	hɛlor	honen	honen	elir	ɛlir
word-final	rulah	rulah	ralah	ralah	rala	rala:
	nulah	nulah	nelih	nɛlih	nula	nula:
	maloh	maloh	mulih	mulih	luna	luna:
	amah	amah	ralih	ralih	muna	muna:

Nontarget Stimuli							
apte	aptɛ	ökne	œ	ımsa	ɯmsa	ırtı	ɯrtɯ
atke	atkɛ	öfte	tfe	ufta	ufta	umku	umku
opta	opta	itka	itka	örme	œrmɛ	opsa	opsa
esta	ɛsta	anka	anka	ilka	ilka	üptü	ypty
ibra	ibra	ümke	ymkɛ	üske	yskɛ	amsa	amsa
ekme	ɛkmɛ	iska	iska	amba	amba	ekse	ɛksɛ
utpe	utpɛ	onra	onra	ölte	œltɛ	olga	olga
arte	artɛ	atra	atra	ustu	ustu	ufsa	ufsa
avpı	avpɯ	elke	ɛlkɛ	arsa	arsa	adra	adra
ayka	ayka	onle	onlɛ	ıftı	ɯftɯ	afka	afka
ekle	ɛklɛ	üktü	ykty	arte	artɛ	alda	alda
ente	ɛntɛ	üspü	yspy	opke	opkɛ	upsu	upsu
ıvza	ɯvza	armı	armɯ	imdi	imdi	erbe	ɛrbɛ
omde	omdɛ	asre	asrɛ	ekme	ɛkmɛ	ilne	ilnɛ
olne	olnɛ	ölne	œlnɛ	ipli	ipli	itke	itkɛ
ikti	ikti	önke	œnkɛ	isti	isti	urnu	urnu
laban	laban	begin	bɛgin	poter	potɛr	atke	atkɛ
rapan	rapan	tüküs	tykys	falat	falat	utpe	utpɛ
kulun	kulun	seten	sɛtɛn	apte	aptɛ	arte	artɛ

Appendix C – Table of sensitivity results (Experiments 1 and 2)

Context		Turkish	Arabic	English	French
before voiceless stop	V __ [p, t, k]	2.583	2.500	0.455	0.561
before voiceless affricate	V __ [tʃ]	2.558	2.698	0.581	0.530
before voiceless fricative	V __ [f, s, ʃ]	2.423	2.449	0.236	0.529
before voiced stop	V __ [b, d, g]	2.861	2.656	0.621	0.793
before voiced affricate	V __ [dʒ]	2.769	2.773	0.945	0.938
before voiced fricative	V __ [v, z, ʒ]	2.841	2.837	0.977	0.721
before nasal	V __ [n, m]	2.838	2.696	0.867	0.923
before liquid	V __ [l, r]	2.841	2.972	1.127	0.860
before glide	V __ [j]	2.155	2.221	1.311	0.790

after voiceless stop	[p, t, k] __ V	2.233	2.573	0.705	1.270
after voiceless affricate	[tʃ] __ V	2.274	2.109	0.513	0.175
after voiceless fricative	[f, s, ʃ] __ V	2.144	2.621	1.155	0.666
after voiced stop	[b, d, g] __ V	2.707	2.893	1.664	1.715
after voiced affricate	[dʒ] __ V	2.838	2.613	1.262	0.650
after voiced fricative	[v, z, ʒ] __ V	2.426	2.728	1.683	1.268
after nasal	[n, m] __ V	2.964	3.004	2.072	1.773
after liquid	[l, r] __ V	3.028	2.903	1.911	1.620
after glide	[j] __ V	1.777	2.126	0.853	0.740
intervocalic	V __ V	2.248	2.256	1.699	1.317
word-initial	# __ V	2.376	2.310	1.919	1.252
word-final	V __ #	0.734	0.550	-0.220	-0.156

Appendix D - Response rates

The following tables show the average response rates for each type of stimulus in experiments 1 and 2. Correct responses are in boldface.

D.1 - Turkish

Context	[h] Location	Response			
voiceless stop		initial	before	after	final
	before	0.00%	**92.48%**	1.50%	1.50%
	foil	0.00%	6.58%	9.87%	10.53%
	after	0.66%	0.00%	**83.55%**	1.32%
voiced stop		initial	before	after	final
	before	0.00%	**95.39%**	1.97%	0.00%
	foil	0.00%	1.97%	0.66%	3.95%
	after	0.00%	1.32%	**89.47%**	1.32%
voiceless fricative		initial	before	after	final
	before	0.66%	**88.82%**	2.63%	1.32%
	foil	0.00%	9.21%	5.92%	0.66%
	after	0.00%	4.61%	**76.97%**	1.32%
voiced fricative		initial	before	after	final
	before	0.00%	**98.03%**	1.32%	0.00%
	foil	0.00%	5.26%	1.97%	0.00%
	after	0.66%	7.89%	**81.58%**	0.66%
voiceless affricate		initial	before	after	final
	before	0.66%	**99.34%**	0.00%	0.00%
	foil	0.00%	14.29%	3.01%	1.50%
	after	0.00%	1.32%	**80.26%**	1.32%

voiced affricate		initial	before	after	final
	before	0.00%	**99.34%**	0.00%	0.00%
	foil	0.00%	7.24%	0.66%	5.92%
	after	0.00%	0.66%	**95.39%**	0.00%
nasal		initial	before	after	final
	before	0.00%	**98.68%**	0.00%	0.00%
	foil	0.00%	5.92%	0.00%	2.63%
	after	0.00%	0.00%	**96.71%**	0.00%
liquid		initial	before	after	final
	before	0.00%	**99.34%**	0.66%	0.00%
	foil	0.00%	6.58%	0.00%	3.95%
	after	0.00%	1.32%	**98.68%**	0.00%
glide		initial	before	after	final
	before	0.00%	**98.68%**	1.32%	0.00%
	foil	0.00%	5.26%	1.32%	3.95%
	after	0.00%	14.47%	**77.63%**	0.00%
intervocalic		initial	intervoc.	post	final
	intervocalic	0.00%	**97.74%**	0.00%	0.00%
	foil	0.00%	15.79%	0.00%	0.00%
word-initial		initial	before	after	final
	initial	**92.11%**	0.00%	0.00%	0.00%
	foil	2.63%	0.00%	0.00%	0.00%
word-final		initial	before	after	final
	final	0.00%	0.66%	0.66%	**42.11%**
	foil	0.00%	1.32%	0.00%	9.21%

D.2 - Arabic

Context	**[h] Location**	**Response**			
voiceless stop		initial	before	after	final
	before	1.19%	**92.86%**	0.00%	1.19%
	foil	4.17%	9.38%	1.04%	10.42%
	after	2.08%	0.00%	**85.42%**	4.17%
voiced stop		initial	before	after	final
	before	2.08%	**93.75%**	0.00%	0.00%
	foil	6.25%	6.25%	1.04%	1.04%
	after	0.00%	0.00%	**95.83%**	3.13%
voiceless fricative		initial	before	after	final
	before	2.08%	**89.58%**	1.04%	2.08%
	foil	0.00%	8.33%	2.08%	16.67%
	after	3.13%	2.08%	**87.50%**	1.04%

voiced fricative		initial	before	after	final
	before	2.08%	**95.83%**	1.04%	0.00%
	foil	3.13%	3.13%	0.00%	13.54%
	after	1.04%	1.04%	**89.58%**	2.08%
voiceless affricate		initial	before	after	final
	before	1.04%	**95.83%**	0.00%	0.00%
	foil	2.38%	5.95%	1.19%	11.90%
	after	1.04%	0.00%	**72.92%**	6.25%
voiced affricate		initial	before	after	final
	before	3.13%	**95.83%**	0.00%	0.00%
	foil	0.00%	5.21%	1.04%	11.46%
	after	1.04%	0.00%	**86.46%**	4.17%
nasal		initial	before	after	final
	before	3.13%	**91.67%**	0.00%	0.00%
	foil	2.08%	3.13%	0.00%	4.17%
	after	1.04%	0.00%	**97.92%**	1.04%
liquid		initial	before	after	final
	before	0.00%	**100.00%**	0.00%	0.00%
	foil	2.08%	3.13%	0.00%	3.13%
	after	0.00%	5.21%	**94.79%**	0.00%
glide		initial	before	after	final
	before	0.00%	**100.00%**	0.00%	0.00%
	foil	0.00%	4.17%	0.00%	0.00%
	after	0.00%	4.17%	**91.67%**	2.08%
intervocalic		initial	intervoc.	post	final
	intervocalic	0.00%	**94.05%**	4.76%	0.00%
	foil	4.17%	10.42%	0.00%	0.00%
word-initial		initial	before	after	final
	initial	**93.75%**	1.04%	2.08%	0.00%
	foil	8.33%	2.08%	0.00%	0.00%
word-final		initial	before	after	final
	final	0.00%	1.04%	1.04%	**46.88%**
	foil	0.00%	2.08%	0.00%	22.92%

D.3 - English

Context	[h] Location	Response			
voiceless stop		initial	before	after	final
	before	5.44%	**24.49%**	14.29%	6.12%
	foil	3.57%	10.71%	7.74%	9.52%
	after	2.98%	7.74%	**30.36%**	5.36%

voiced stop		initial	before	after	final
	before	7.74%	**28.57%**	11.31%	2.38%
	foil	5.95%	8.33%	8.33%	9.52%
	after	2.38%	6.55%	**63.10%**	2.38%
voiceless fricative		initial	before	after	final
	before	2.98%	**11.90%**	29.17%	5.36%
	foil	2.98%	4.17%	23.81%	2.98%
	after	0.60%	1.79%	**62.50%**	5.36%
voiced fricative		initial	before	after	final
	before	7.14%	**35.71%**	8.93%	2.38%
	foil	5.36%	4.17%	7.74%	7.14%
	after	2.98%	2.38%	**63.10%**	5.36%
voiceless affricate		initial	before	after	final
	before	5.95%	**31.55%**	25.00%	4.17%
	foil	1.36%	10.88%	17.69%	2.72%
	after	3.57%	4.17%	**35.71%**	3.57%
voiced affricate		initial	before	after	final
	before	5.36%	**41.07%**	22.62%	3.57%
	foil	3.57%	8.93%	15.48%	1.19%
	after	1.79%	2.38%	**57.14%**	2.98%
nasal		initial	before	after	final
	before	7.14%	**45.83%**	2.98%	3.57%
	foil	9.52%	16.67%	2.38%	2.98%
	after	7.14%	10.71%	**70.83%**	0.00%
liquid		initial	before	after	final
	before	10.12%	**39.88%**	10.71%	4.17%
	foil	4.76%	3.57%	5.36%	5.95%
	after	4.17%	10.12%	**68.45%**	2.98%
glide		initial	before	after	final
	before	3.57%	**60.71%**	9.52%	7.14%
	foil	3.57%	9.52%	1.19%	0.00%
	after	4.76%	23.81%	**38.10%**	4.76%
intervocalic		initial	intervoc.	post	final
	intervocalic	0.68%	**82.99%**	1.36%	0.00%
	foil	5.95%	20.24%	1.19%	0.00%
word-initial		initial	before	after	final
	initial	**78.57%**	2.98%	1.19%	0.00%
	foil	4.76%	4.76%	3.57%	8.33%
word-final		initial	before	after	final
	final	8.33%	9.52%	5.36%	**14.88%**
	foil	5.95%	8.33%	0.00%	13.10%

D.4 - French

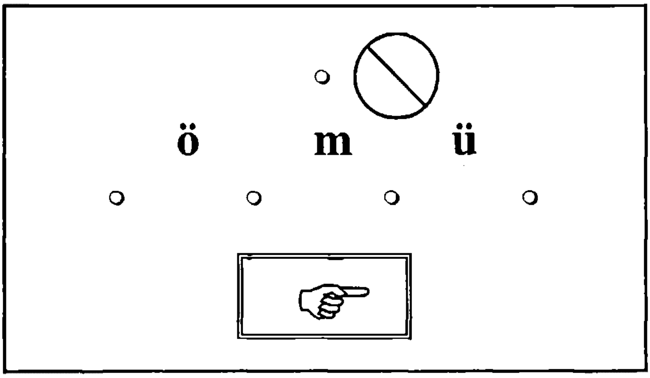
Context	[h] Location	Response			
voiceless stop		initial	before	after	final
	before	23.13%	**28.57%**	14.97%	4.08%
	foil	18.45%	8.93%	11.90%	3.57%
	after	12.50%	3.57%	**53.57%**	8.33%
voiced stop		initial	before	after	final
	before	28.57%	**35.71%**	14.88%	3.57%
	foil	16.07%	9.52%	8.93%	3.57%
	after	10.71%	5.36%	**65.48%**	5.36%
voiceless fricative		initial	before	after	final
	before	25.60%	**26.79%**	11.90%	1.19%
	foil	16.07%	8.93%	11.90%	5.95%
	after	15.48%	5.36%	**33.93%**	7.14%
voiced fricative		initial	before	after	final
	before	30.36%	**30.95%**	8.33%	2.98%
	foil	10.12%	7.74%	4.76%	4.76%
	after	13.10%	5.36%	**46.43%**	9.52%
voiceless affricate		initial	before	after	final
	before	24.40%	**36.31%**	22.62%	2.98%
	foil	14.29%	18.37%	19.73%	4.08%
	after	12.50%	6.55%	**26.79%**	4.17%
voiced affricate		initial	before	after	final
	before	23.81%	**41.07%**	20.24%	1.19%
	foil	8.93%	10.71%	23.21%	1.19%
	after	8.93%	4.17%	**44.64%**	4.76%
nasal		initial	before	after	final
	before	29.17%	**41.07%**	7.74%	2.98%
	foil	12.50%	10.71%	4.17%	4.76%
	after	18.45%	8.33%	**61.90%**	0.60%
liquid		initial	before	after	final
	before	24.40%	**31.55%**	19.05%	4.76%
	foil	5.95%	4.17%	2.98%	4.76%
	after	13.69%	8.93%	**55.95%**	4.17%
glide		initial	before	after	final
	before	29.76%	**51.19%**	11.90%	1.19%
	foil	16.67%	16.67%	2.38%	2.38%
	after	15.48%	16.67%	**33.33%**	5.95%
intervocalic		initial	intervoc.	post	final
	intervocalic	3.40%	**82.99%**	4.76%	2.04%
	foil	3.57%	36.90%	1.19%	0.00%

word-initial		initial	before	after	final
	initial	**56.55%**	2.38%	7.74%	8.33%
	foil	4.76%	2.38%	9.52%	5.95%
word-final		initial	before	after	final
	final	5.95%	5.95%	9.52%	**14.88%**
	foil	8.33%	3.57%	3.57%	10.71%

Appendix E - Sample screen views

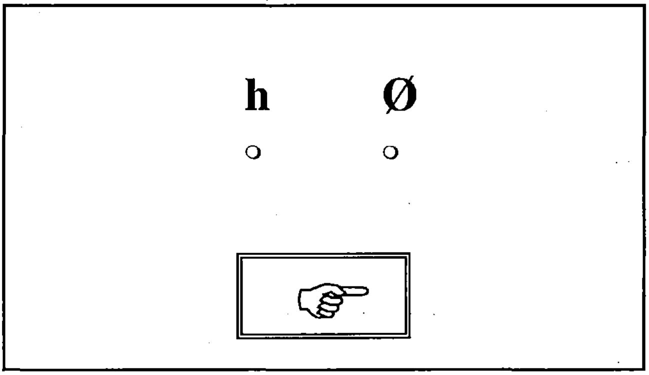
E.1 - Experiment 1 & 2 screen view

Subjects were instructed to click on a radio button beneath the part of the transcription where an [h] was heard, or to click on the top button (next to the large "Ø") if no [h] was heard.



E.2 - Experiment 3 screen view

Subjects were instructed to click on a radio button beneath the "h" if an [h] was heard, or to click on the button beneath the "Ø" if no [h] was heard.



References

Bladon, Anthony. 1986. Phonetics for hearers. In G. McGregor (ed.), *Language for Hearers*. Oxford: Pergamon, pp. 1-24.

Borowsky, T. 1986. Topics in the Lexical Phonology of English. PhD dissertation, University of Massachusetts.

Casagrande, Jean. 1984. *The Sound System of French.* Georgetown University Press. Washington, D.C.

Cole, Jennifer, and Khalil Iskarous. 2001. Contextual effects of consonant place identification: implications for a theory of phonologization. In E. Hume and K. Johnson (eds.) *The Role of Speech Perception in Phonology.* New York: Academic Press.

Fujimura, O., M. J. Macchi & L. A. Streeter, 1978. Perception of Stop Consonants with Conflicting Transitional Cues: A Cross-linguistic Study, *Language and Speech*, Vol 21, Part 4, 1978.

Green, David M. & John A. Swets, 1966. Signal detection theory and psychophysics. New York: Wiley.

Hammond, Michael 1999. The Phonology of English: A Prosodic Optimality-Theoretic Approach. Oxford University Press.

Harrell, Richard S. 1966. *A Dictionary of Moroccan Arabic: Arabic-English.* Georgetown University Press, Washington, D.C.

Heath, Jeffrey. 1987. *Ablaut and Ambiguity: Phonology of a Moroccan Arabic Dialect.* SUNY Press.

Hume, Elizabeth & Keith Johnson. 2001. A Model for the Interplay of Speech Perception and Phonology. In E. Hume and K. Johnson (eds.) *The Role of Speech Perception in Phonology.* New York: Academic Press.

Hura, S.L., Lindblom, B. & R. Diehl. 1992. On the role of perception in shaping phonological assimilation rules. *Language & Speech* 35, 59-72.

Jensen, John T. 1993. *English Phonology.* John Benjamins Publishing Company. Amsteram/Philadelphia.

Johnson, Keith. 1997. *Acoustic & Auditory Phonetics.* Blackwell. Oxford.

Keating, Patricia A. 1988. Underspecification in phonetics. *Phonology 5.* 275-292.

Kohler, K. 1990. Segmental reduction in connected speech: Phonological facts and phonetic explanations. In W.J. Hardcastle & A. Marchal (eds.) *Speech Production and Speech Modeling* (pp. 69-92). Dordrecht: Kluwer Academic Publishers.

Kornrumpf, H.-J. 1979. *Langenscheidt's Universal Dictionary: Turkish-English, English-Turkish.* Kangenscheidt. Berlin and München.

Lewis, G. L. 1967. *Turkish Grammar.* Clarendon Press. Oxford.

MacMillan, Neil A. and Douglas Creelman, 1991. *Detection Theory: A User's Guide.* Cambridge. New York.

Mielke, Jeff. 2000. A perceptual account of Turkish [h] deletion. Paper presented at the Montreal-Ottawa-Toronto Workshop on Phonology, York University.

Mielke, Jeff. to appear a. Directional asymmetry in Turkish [h] deletion: a perceptual account.

Mielke, Jeff. to appear b. Crosslinguistic patterning of laryngeal consonants.

Oflazer, Kemal. 1994. PC-Kimmo Turkish Lexicon. European Corpus Initiative.

Ohala, J. 1992. Alternatives to the Sonority Hierarchy for Explaining Segmental Sequential Constraints. *Chicago Linguistics Society: Papers from the Parasession on the Syllable.* Chicago: CLS. 319-338.

Ovcharova, Olena 1999. A perception-based study of consonant deletion in Turkish. Poster presented at the ICPhS satellite meeting "The Role of Speech Perception Phenomena in Phonology"

Sezer, Engin. 1986. An autosegmental analysis of compensatory lengthening in Turkish. in L. Wetzels & E. Sezer, eds. *Studies in Compensatory Lengthening.* Dordrecht. Foris Publications.

Steriade, Donca. 1997. Phonetics in Phonology: The Case of Laryngeal Neutralization. ms. UCLA.

Steriade, Donca. 2001. Directional asymmetries in place assimilation: a perceptual account. In E. Hume and K. Johnson (eds.) *The Role of Speech Perception in Phonology.* New York: Academic Press.

Valdman, Albert. 1976. *Introduction to French Phonology and Morphology.* Newbury House Publishers. Rowley, Massachusetts.

Volaitis, Lydia E., and Joanne L. Miller. 1992. Phonetic prototypes: Influence of place of articulation and speaking rate on the internal structure of voicing categories. *JASA* 92 (2), pt. 1.

Winer, B. J. 1971. *Statistical Principles in Experimental Design.* McGraw-Hill: New York.

Wright, R. 1996. Consonant Clusters and Cue Preservation in Tsou. PhD dissertation. UCLA.

Zawadowski, Y. N. (1978) *The Maghrib Arabic Dialects.* Central Department of Oriental Literature. Moscow.