INTERRELATIONSHIP OF ENGLISH CONSONANTS*

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A confusion-predicting model, based on distinctive feature relationships of English consonants, was proposed. Comparisons of the three different sets of classifications of interconsonantal relationships, offered by Miller and Nicely,[1] extended by Singh and Black[2] (MN ext. SB), by Halle[3] (H), and by Wickelgren[3] (W) were made to investigate which of these three systems approximated more closely the phonemic realization of English consonants. Errors in each distinctive feature category and combination of categories were compared to test the independence of features from the phonemic contexts. The distinctive feature system used for further analysis of data was MN ext. SB. Arbitrarily selected features were voicing, frication, duration, liquid, glide, retroflex, and place of articulation. Presence of a feature, for example, voicing, in the model was denoted by V^1 and its absence by V°. Similar notations followed for the other features except for place of articulation. Four places of articulation were chosen to characterize 22 consonants of English denoted by P^1, bilabial; P^2, alveolar; P^3, palatal; and P^4, velar. These were coded into a multi-category channel rather than into four idependent channels.[4]

The phoneme (s) may be characterized by $V^0F^1\,D^1\,L^0G^0R^0P^2$, indicating that voicing, liquid, glide, and retroflex are not present while frication and duration are present at the alveolar place of articulation; the phoneme (g) may be characterized by $V^1F^0D^0L^0G^0R^0P^4$, indicating that frication, duration, liquid, glide, and retroflex are not present while voicing is present at the velar place of articulation.

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[1] G. A. Miller and P. E. Nicely, "An Analysis of Perceptual Confusion among some English Consonants," *J. Acoust. Soc. Am.* 27, 338—352 (1955).

[2] Sadanand Singh and J. W. Black, "Study of Twenty-Six Intervocalic Consonants as Spoken and Recognized by Four Language Groups," *J. Acoust. Soc. Am.* 39, 372—387 (1966).

[3] Wayne A. Wickelgren, "Distinctive Features and Errors in Short-Term Memory for English Consonants," *J. Acoust. Soc. Am.* 39, 388—398 (1966).

[4] Sadanand Singh, "Crosslanguage Study of Perceptual Confusion of Plosive Phonemes in Two Conditions of Distortion," *J. Acoust. Soc. Am.* 40, 635—656 (1966).

Table of Quotients of Distinctive Features of English Consonants.

	k	t	p	ʃ	s	θ	f	h	dʒ	g	d	b	ʒ
k	U	P^2	P^3	$F^{-1}PD^{-1}$	$F^{-1}P^2D^{-1}$	$F^{-1}P^2$	$F^{-1}P^3$	F^{-1}	$V^{-1}F^{-1}P$	V^{-1}	$V^{-1}P^2$	$V^{-1}P^{-3}$	$V^{-1}F^{-1}P^{-1}D$
t		U	P	$F^{-1}P^{-1}D^{-1}$	$F^{-1}D^{-1}$	F^{-1}	$F^{-1}P$	$F^{-1}P^{-2}$	$V^{-1}F^{-1}P^{-1}$	$V^{-1}P^{-2}$	V^{-1}	$V^{-1}P$	$V^{-1}F^{-1}P^{-1}D^{-1}$
p			U	$F^{-1}P^{-2}D^{-1}$	$F^{-1}D^{-1}P^{-1}$	$F^{-1}P^{-1}$	F^{-1}	$F^{-1}P^{-3}$	$V^{-1}F^{-1}P^{-2}$	$V^{-1}P^{-3}$	$V^{-1}P^{-1}$	V^{-1}	$V^{-1}F^{-1}P^{-2}D^{-1}$
ʃ				U	P	PD	P^2D	$P^{-1}D$	$V^{-1}D$	$V^{-1}FP^{-1}D$	$V^{-1}FPD$	$V^{-1}FP^2D$	V^{-1}
s					U	D	PD	$P^{-2}D$	$V^{-1}P^{-1}D$	$V^{-1}FP^{-2}D$	$V^{-1}FD$	$V^{-1}FPD$	$V^{-1}P^{-1}$
θ						U	P	P^{-2}	$V^{-1}P^{-1}$	$V^{-1}FP^{-2}$	$V^{-1}F$	$V^{-1}FP$	$V^{-1}P^{-1}D^{-1}$
f							U	P^{-3}	$V^{-1}P^{-2}$	$V^{-1}FP^{-3}$	$V^{-1}FP^{-1}$	$V^{-1}F$	$V^{-1}P^{-2}D^{-1}$
h								U	$V^{-1}P$	$V^{-1}F$	$V^{-1}FP^2$	$V^{-1}FP^3$	$V^{-1}PD^{-1}$
dʒ									U	$P^{-1}F$	FP	FP^2	D^{-1}
g										U	P^2	F^3	$PF^{-1}D^{-1}$
d											U	P	$P^{-1}F^{-1}D^{-1}$
b												U	$P^{-2}F^{-1}D^{-1}$
ʒ													U
z													
ð													
v													
l													
r													
j													
w													
tʃ													
m													

	z	ð	v	l	r	j	w	tʃ	m
k	$V^{-1}F^{-1}P^2D^{-1}$	$V^{-1}F^{-1}P^2$	$V^{-1}F^{-1}P^3$	$V^{-1}P^2L^{-1}$	$V^{-1}P^2R^{-1}L^{-1}$	$V^{-1}PG^{-1}$	$V^{-1}P^3G^{-1}$	$F^{-1}P$	$F^{-1}G^{-1}P^3$
t	$V^{-1}F^{-1}D^{-1}$	$V^{-1}F^{-1}$	$V^{-1}F^{-1}P$	$V^{-1}L^{-1}$	$V^{-1}R^{-1}L^{-1}$	$V^{-1}P^{-1}G^{-1}$	$V^{-1}PG^{-1}$	$F^{-1}P^{-1}$	$F^{-1}G^{-1}P$
p	$V^{-1}F^{-1}P^{-1}D^{-1}$	$V^{-1}F^{-1}P^{-1}$	$V^{-1}F^{-1}$	$V^{-1}P^{-1}L^{-1}$	$V^{-1}P^{-1}R^{-1}L^{-1}$	$V^{-1}P^{-2}G^{-1}$	$V^{-1}G^{-1}$	$F^{-1}P^{-2}$	$F^{-1}G^{-1}$
ʃ	$V^{-1}P$	$V^{-1}PD$	$V^{-1}P^2D$	$V^{-1}PL^{-1}DF$	$V^{-1}PR^{-1}L^{-1}FD$	$V^{-1}FG^{-1}D$	$V^{-1}G^{-1}FP^2D$	D	$DG^{-1}P^2$
s	V^{-1}	$V^{-1}D$	$V^{-1}PD$	$V^{-1}L^{-1}DF$	$V^{-1}R^{-1}L^{-1}FD$	$V^{-1}FP^{-1}G^{-1}D$	$V^{-1}G^{-1}FPD$	$P^{-1}D$	$DG^{-1}P$
θ	$V^{-1}D^{-1}$	V^{-1}	$V^{-1}P$	$V^{-1}L^{-1}F$	$V^{-1}R^{-1}L^{-1}F$	$V^{-1}FP^{-1}G^{-1}$	$V^{-1}G^{-1}FP$	P^{-1}	$G^{-1}P$
f	$V^{-1}P^{-1}D^{-1}$	$V^{-1}P^{-1}$	V^{-1}	$V^{-1}L^{-1}P^{-1}F$	$V^{-1}R^{-1}L^{-1}P^{-1}F$	$V^{-1}FP^{-2}G^{-1}$	$V^{-1}G^{-1}F$	P^{-2}	G^{-1}
h	$V^{-1}P^2D^{-1}$	$V^{-1}P^2$	$V^{-1}P^3$	$V^{-1}L^{-1}P^2F$	$V^{-1}R^{-1}L^{-1}P^2F$	$V^{-1}FPG^{-1}$	$V^{-1}G^{-1}FP^3$	P	$G^{-1}P^3$
dʒ	PD^{-1}	P	P^2	FPL^{-1}	$FPR^{-1}L^{-1}$	FG^{-1}	FP^2G^{-1}	V	$G^{-1}P^2V$
g	$P^2F^{-1}D^{-1}$	P^2F^{-1}	P^3F^{-1}	P^2L^{-1}	$P^2K^{-1}L^{-1}$	PG^{-1}	P^3G^{-1}	$PF^{-1}V$	$F^{-1}G^{-1}P^3V$
d	$F^{-1}D^{-1}$	F^{-1}	PF^{-1}	L^{-1}	$K^{-1}L^{-1}$	$P^{-1}G^{-1}$	PG^{-1}	$P^{-1}F^{-1}V$	$F^{-1}G^{-1}PV$
b	$P^{-1}F^{-1}D^{-1}$	$P^{-1}F^{-1}$	F^{-1}	$P^{-1}L^{-1}$	$P^{-1}R^{-1}L^{-1}$	$P^{-2}G^{-1}$	G^{-1}	$P^{-2}F^{-1}V$	$F^{-1}G^{-1}V$
ʒ	P	PD	P^2D	$PFDL^{-1}$	$PFDR^{-1}L^{-1}$	FDG^{-1}	P^2FDG^{-1}	VD	$DG^{-1}P^2V$
z	U	D	PD	FDL^{-1}	$FDR^{-1}L^{-1}$	$P^{-1}FDG^{-1}$	$PFDG^{-1}$	$P^{-1}VD$	$DG^{-1}PV$
ð		U	P	FL^{-1}	$FR^{-1}L^{-1}$	$P^{-1}FG^{-1}$	PFG^{-1}	$P^{-1}V$	$G^{-1}PV$
v			U	$P^{-1}FL^{-1}$	$P^{-1}FR^{-1}L^{-1}$	$P^{-2}FG^{-1}$	FG^{-1}	$P^{-2}V$	$G^{-1}V$
l				U	R^{-1}	$P^{-1}G^{-1}L$	$PG^{-1}L$	$P^{-1}LF^{-1}V$	$F^{-1}G^{-1}LFV$
r					U	$P^{-1}G^{-1}LR$	$PG^{-1}LR$	$P^{-1}LF^{-1}VR$	$F^{-1}G^{-1}LPRV$
j						U	P^2	$GF^{-1}V$	$F^{-1}P^2V$
w							U	$P^{-2}GF^{-1}V$	$F^{-1}V$
tʃ								U	$G^{-1}P^2$
m									U

V=voicing, F=frication, P=place, D=duration, R=retroflex, L=liquid, G=glides, U=unity.

Now the phonemes $(s):(g) = \dfrac{V^0F^1D^1L^0G^0R^0P^2}{V^1F^0D^0L^0G^0R^0P^4} = V^{-1}FDP^{-2}$

The inverse is $VF^{-1}D^{-1}P^2$. Thus, the ratio contains four features including an extra loading on the place category. Table 1 describes all the interconsonantal relationships of English in similar fashion. This is based on the MN ext. SB system of classification. One novel feature in this table is that once the first row has been obtained, and the relationship of (k) to the rest of the phonemes in the row has been computed, the subsequent relationships can be generated by following algebraic multiplication. For example, in order to find the relationship between (t) and (p) denoted by (t, p) the following relations are used: $(k, p) = (k, t)\,(t, p)$. Thus $(t, p) = (k, t)^{-1}(k, p) = p^{-2}p^3 = p$.

Native speakers of Hindi and English, 22 in each group, comprised the experimental subject. They recorded 22 pre- and 22 post-vocalic English consonants. Twentytwo native auditors each of Hindi and English responded to them in five S/N ratio (—8, —4, 0, +4, +8 dB) and five signal level (35, 30, 25, 20, 15 dB) conditions. Although the stimulus was never included in the response-choice, all remaining

consonants (21) were paired with each other using ABX. All listeners did not hear all speakers; however, they heard all consonants in each condition of distortion.

The four confusion matrices relating to the prevocalic stimuli and four to the post-vocalic ones were analyzed for speakers and auditors. Rank-correlations were obtained between the eight confusion matrices and the three interconsonantal relationships. The responses to each of the 22 stimulus consonants were ranked from high to low and the number of distinctive feature differences from low to high on the assumption that with fewer differences between the two sounds, greater confusion occurs.

The error responses to the 22 pre- and 22 postvocalic consonants of English in four speaking-listenig conditions were correlated with the three different systems of classifying interconsonantal relationships. To formulate a comparable response-predicting model bases on H and W systems, their respective notations were used.

Out of 528 rank-correlation values 270 were found significant either at the .05 or .01 level, *df*. 20. In pre-vocalic conditions, 157 of 264 were significantly correlated as compared to 113 in the post-vocalic condition. A greater number of significant rank correlations were found in the listening modes (158 of 264) than in the speaking modes

(112 of 264). The greater number of phonemes correlated with the model based on MN ext. SB system than on H system. The lowest number of significant rank correlations were obtained with W systems. The numbers were MN ext. SB 108, H 90, and W 72, each of 176 possible correlations.

The consonants that were commonly unpredictable in all the 4 speaking-listening conditions using MN ext. SB classification in prevocalic position were */z r/* and postvocalic */dlj/*; using H system-prevocalic */hzðlr/* and postvocalic */θhðlrj/*; and using W system — prevocalic */hzj/* and postvocalic */bʒvrhwjld/*.

The predictability of the distinctive feature model based on MN ext. SB was tested further by comparing the scores in each of seven distinctive feature classifications and also in the feature combination categories of two's, three's, four's, and five's. The X^2 comparisons of the scores within a given category of feature showed no significance either in pre- or post-vocalic stimulus conditions. They were as follows: voicing, df 15; place, 17; frication, 9; duration, 7; retroflex, 1; liquid, 1; glide, 3; and combinations of two's df 109; three's 127; four's 105; and five's, 45 in both experiments. Thus, of a given feature or combination of features contrasting one pair of phonemes did not yield significantly different frequencies of errors as compared to contrasting another pair of phonemes.

DISCUSSION

Black:

I infer that your interesting procedure is based on an assumption that one distinctive feature equals another in aural effect. Hence the 50 per cent of significant correlations must be encouraging: But may not the remaining 50 per cent of non-significant correlations suggest further explorations of this basic assumption?

Singh:

Ad Black: It has been demonstrated earlier that all distinctive features do not preserve in errors equally. The results of the present study show that the error in a given distinctive feature category (inspite of the fact that they were from different phonemic contexts) did not yield significantly different results.

The fact that 50% of the consonants correlated with the model is self revealing that the present number of distinctive features is not adequate to characterize all consonants of English with significant perceptual relevance.