Morphological paradigm effects on phonetic realization

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Abstract

Previous studies have shown phonetic variation can be lexically conditioned (Wright, 1997; Munson and Solomon, 2004; Munson, 2007; Scarborough, 2006). Morphological paradigms have also been implicated in phonetic variation (Steriade, 2000; Kuperman et al., 2007). This paper investigates the nature of morphological paradigm effects on vowel production in German verbs. We report the results of a production experiment showing that, while paradigmatic complexity affects vowel dispersion, the effect is mediated by word frequency.

Key words: German, morphology, complexity, variation

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1. Introduction

Temporal and spectral vowel reduction is a hallmark of systemic variation in speech production (Lieberman et al., 1967). In recent years, a growing number of studies have focused on this reduction and the factors thought to influence it. One of the most robustly attested effects is that of frequency: word frequency is often correlated with phonetic reduction (Hooper, 1976; Bybee, 2001; Jurafsky et al., 2002; Munson and Solomon, 2004). For example, high-frequency words such as *memory* are much more likely to reduce their unstressed vowel to schwa than low-frequency words such as *mammary*. Frequency effects on reduction have also been shown to manifest themselves in speech error rates, independent of phonetic complexity (Goldrick and Larson, 2008).

Other lexical statistics have been shown to affect phonetic realization as well. The similarity of lexical items, as measured by lexical neighborhood density (the number of phonologically similar words in the lexicon), has also been shown to play a role in reduction, with low-density forms tending to be reduced compared to high-density forms (Wright, 1997; Munson and Solomon, 2004; Munson, 2007). At the semantic level, word predictability has been shown to correlate with phonetic reduction as well: words which are in some sense predictable tend to be temporally and spectrally reduced relative to words which are unpredictable in a given context (Lieberman, 1963; Clopper and Pierrehumbert, 2008). In this paper, we examine a further type of predictability, that imposed by morphological paradigm relations.

The idea that morphological paradigm relations themselves may influence phonetic realization is of course nothing new. Hooper (1976) provided historical examples of high-frequency paradigms retaining morphophonemic irregularities longer than low-frequency paradigms. Working within Optimality Theory (Prince and Smolensky, 2004 [1993]), Steriade (2000) proposed a set of Paradigm Uniformity constraints to enforce the observed invariance of a sound pattern within a given paradigm, e.g. tapping/flapping in English. Yu (2007) has argued for paradigmatic effects on tonal realization in Cantonese, based on the differing phonetic realizations of a phonologically identical mid-rising tone in morphologically derived and lexical environments.

To date, however, no previous work has directly addressed the question of whether speakers are sensitive to *intra*paradigmatic differences in complexity, despite the considerable psycholinguistic evidence which has been marshaled to argue that the complexity of morphological paradigms affects reaction times in lexical decision tasks (Baayen et al., 2006; Hay, 2001; Kostić, 1991, 1995; Kostić et al., 2003; Moscoso del Prado Martín et al., 2004a,b). In addition to the empirical results, this line of work has also produced a variety of ways to measure complexity. Building on the earlier work of Kostić and colleagues (1991, 1995, 2003), Moscoso del Prado Martín et al. (2004b) propose an information-theoretic measure of morphological complexity, INFLECTIONAL ENTROPY, which they show correlates closely with observed reaction time data.

If paradigmatic complexity exerts measurable influence over reaction times in lexical decision tasks, it may prove to be a useful means of characterizing the influence of paradigm complexity on phonetic reduction as well. In this study, we investigate the degree to which paradigmatic complexity affects phonetic realization by examining the effects of frequency, neighborhood density, and inflectional entropy on vowel reduction in Standard German. German is an ideal language in which to test the influence of morphology on speech production due to its rich and productive verbal morphology. In addition, previous work on Germanic languages has revealed other types of morphological effects on phonetic production. Pluymaekers et al. (2006) demonstrate that the variable phonetic realization of the cluster /xh/ in the Dutch suffix *-igheid* can be at least partially accounted for by particular morphological structure of Dutch. Since this structure is language-dependent, the authors argue that the effects cannot simply be ascribed to low-level articulatory processes. Similarly, Kuperman et al. (2007) show that the acoustic duration of Dutch interfixes is tied to the predictability of a word's morphological paradigm structure. The long history of work on the phenomenon of incomplete neutralization in German and Dutch provides further evidence that morphological factors may play a role in both the production and perception of phonetic variation in those languages (Fourakis and Iverson, 1984; Port and O'Dell, 1985; Port and Crawford, 1989; Jessen, 1998; Piroth and Janker, 2004; Warner et al., 2004).

2. Experiment

We designed a production experiment to investigate the effect of paradigmatic complexity on vowel dispersion in Standard German. While Standard German has both 'strong' and 'weak' verbs, only the 'weak' verbs, which inflect in a uniform fashion, were considered here (Table 1).

	PAST		PRESENT	
	SING	PLUR	SING	PLUR
1st	machte	machten	mache	machen
2nd	machtest	machtet	machst	macht
3rd	machte	machten	macht	machen
Part.	gemacht		machend	
Inf.	machen			

Table 1: Inflectional paradigm for the weak German verb *machen* 'to make, do'.

The goal of the experiment was to test for the effect of paradigmatic complexity on phonetic realization, independent of frequency and similarity (neighborhood density). Phonetic variation was measured in terms of vowel dispersion $\bar{D}$, the average Euclidean distance in the F1 $\times$ F2 Bark space for all tokens $\mathcal{P}$ from center Q of the vowel space (Bradlow et al., 1996; Wright, 1997):

$$\bar{D}(P,Q) = \frac{\displaystyle\sum_{P\in\mathcal{P}} \sqrt{(p_x - q_x)^2 + (p_y - q_y)^2}}{|\mathcal{P}|}, \tag{1}$$

where

$$q_x = \frac{\sum_{p_x\in\mathcal{P}} f1(p_x)}{|\mathcal{P}|}; q_y = \frac{\sum_{p_y\in\mathcal{P}} f2(p_y)}{|\mathcal{P}|} \tag{2}$$

While a variety of metrics exist for measuring neighborhood density, the most commonly used method in language studies is LEVENSHTEIN DISTANCE, which considers the number of operations (insertions, deletions, or additions) required to transform one string into another. Following previous work in this area, the number of neighbors of a word (or lemma) w is considered to be all those words (or lemmas) in the corpus with a Levenshtein distance of 1 from w.

Following Moscoso del Prado Martín et al. (2004b), paradigmatic complexity of a verbal paradigm $\mathscr{P}$ was measured as the inflectional entropy H:

$$H(\mathscr{P}) = -\sum_{x\in\mathscr{P}} p(x|\mathscr{P})\log_2 p(x|\mathscr{P}) \cong -\sum_{x\in\mathscr{P}} \frac{F(x)}{F(\mathscr{P})}\log_2\frac{F(x)}{F(\mathscr{P})} \tag{3}$$

$$\approx H_i = -\sum_i p_i \log_2(p_i) \tag{4}$$

Here, i ranges over all inflectional variants; p_i is the relative frequency of an inflected form in its paradigm. The inflectional entropy $H(\mathscr{P})$ represents the number of bits necessary to represent the paradigm $\mathscr{P}$ in an optimal encoding scheme. H_i is greater when (a) there are many attested inflectional forms of a lemma, and (b) when the probabilities of those variants are similar to one another. By combining surface and base frequency into a single measure, inflectional entropy avoids the collinearity problems which characterize the relationship between many lexical variables (Baayen et al., 2006, 2008), making it easier to assess the influence of intraparadigmatic complexity independent of raw frequency. In short, inflectional entropy provides a convenient way to measure *relative frequency* within and between paradigms.

By way of example, consider Table 2, which shows the corpus frequency counts for the verbs *machen* 'to do' and *heissen* 'to name'. The lemma *machen* has multiple frequent surface realizations, translating into high entropy (low predictability). The lemma *heissen*, on the other hand, has just one highly frequent

	PAST		PRESENT		PAST		PRESENT	
	SING	PLUR	SING	PLUR	SING	PLUR	SING	PLUR
1st	1223	302	174	**3128**	0	0	35	**102**
2nd	4	1	51	0	0	0	0	0
3rd	1223	302	31	**3128**	0	0	1141	**102**
Part.	1762		12		0		0	
Inf.	**3128**				**102**			
	machen 'to do'				*heissen* 'to name'			

Table 2: CELEX corpus counts for *machen* ($F(\mathscr{P}) = 8089, H(\mathscr{P}) = 2.227$), *heissen* ($F(\mathscr{P}) = 1278, H(\mathscr{P}) = 0.583$). Gray/bold counts show sum of all forms of the cells they appear in, i.e. 302 indicates a total of 302 occurrences of the surface string *machten* in the corpus. This is because CELEX does not provide morphological disambiguation for surface-identical forms.

surface realization, the third singular present form *heisst*; since any given instance of the lemma *heissen* is likely to be this form, it has high predictability, hence low entropy.

To see the independence of frequency and entropy more generally, consider Table 3, which shows verbs from the Mannheim section of German CELEX sorted first by entropy (from low to high) and then by frequency. As can be seen, it is possible for both low-frequency verbs like *stöbern* 'rummage' and high-frequency verbs like *stellen* 'stand' to have high inflectional entropy, and the reverse is true as well, as seen in a comparison of e.g. *feiern* 'celebrate' and *einen* 'unify'.

2.1. Stimuli

The set of German weak verbs in CELEX containing the vowels /a ɛ ɪ/ were first binned by frequency, neighborhood density, and inflectional entropy (high and low). Bins were based on the value of a variable relative to the median (3rd quantile) of that variable. Two verbal infinitives containing each of the three vowels were then selected from the resulting eight bins (high frequency, high density, high entropy; high frequency, high density, low entropy; etc.). The actual stimuli used are given in the Appendix. Where possible, items in each set were also matched for voicing, place, and manner of articulation of the consonants preceding and following the root vowel.

Lemma	Gloss	F	H	Lemma	Gloss	F	H
fasen	'bevel'	1145	0.038	hupfen	'skip'	1	2.81
modern	'decay'	64	0.149	glucken	'cluck'	1	2.81
missen	'miss'	21	0.418	nuscheln	'mumble'	1	2.66
riefen	'call'	35	0.457	dudeln	'tootle'	2	2.434
murmeln	'babble'	148	0.495	kapseln	'encapsulate'	2	2.434
währen	'continue'	1256	0.573	neiden	'begrudge'	2	2.434
heissen	'be named'	1278	0.588	kribbeln	'prickle'	3	2.625
stammeln	'stammer'	44	0.62	pellen	'peel'	3	2.73
feiern	'celebrate'	43	0.76	schlittern	'slither'	4	2.3
zwicken	'pinch'	5	1.305	zwitschern	'twitter'	4	1.983
stöbern	'rummage'	8	2.58	fragen	'ask'	2461	2.195
forschen	'research'	44	2.616	führen	'lead'	2518	2.35
rasen	'speed'	76	2.616	glauben	'believe'	2804	2.121
äussern	'express'	669	2.617	suchen	'seek'	2892	2.277
kribbeln	'prickle'	3	2.625	meinen	'think'	2991	2.317
röcheln	'rattle'	3	2.625	zeigen	'show'	3142	2.314
heulen	'howl'	43	2.643	stellen	'place'	4171	2.351
quatschen	'gab'	5	2.65	machen	'do'	8089	2.227
nuscheln	'mumble'	1	2.66	einen	'unify'	11715	0.911
glucken	'cluck'	1	2.81	sagen	'say'	12159	2.096

Table 3: Some German verbs sorted by entropy (H) and Mannheim corpus frequency (F).

2.2. Procedure

6 native speakers of Standard German were recorded while performing a self-paced reading task. Subjects were visually presented with a digit and a verbal infinitive, and were asked to read aloud the verb displayed in its 3rd singular ("er/sie/es") form. For example, if the verb displayed was *lachen* 'laugh', participants would read *es lacht* 'it laughs'. Each stimulus appeared 5 times, with stimulus order randomized within and across participants. Responses were recorded using the internal microphone of a MacBook Pro laptop at 24 bits, 44.1KHz using Logic Pro 8. Recordings were made in the isolation booth at the University of Chicago Phonology Laboratory.

2.3. Analysis

Recordings were analyzed using the Praat software package (Boersma and Weenink, 2008). The relevant stressed vowel portions of each recording were manually delimited using both waveform and spectrograms as guides. Vowel onset was taken to be the onset of clear formant structure, and vowel offset was taken as the clear onset of the following consonant. Since in most cases the following consonant was an obstruent, vowel offset could be consistently determined. Vowel F1 and F2 formants were then extracted from these sections at eleven equally spaced timepoints.

3. Results

The effect of lexical factors on dispersion was analyzed using a linear mixed-effects model (Pinheiro and Bates, 2000). This model has the advantage of allowing us to model truly random effects (i.e., non-repeatable treatments such as subject). Our model included both SUBJECT and WORD as random effects. WORD was chosen as a random effect because all the lexical measurements used as predictors are characteristic of individual words; there is no guarantee that all the relevant item-specific properties are actually captured by the predictors used in the model (Baayen et al., 2008).

After model criticism, the final model included 8 fixed-effect predictors and an interaction term in addition to the random effects. The fixed-effect predictors included in the final model were NUCLEUS, ONSET, CODA, DURATION, TIMESTEP, (log) WORD FREQUENCY, (log) LEMMA FREQUENCY, and ENTROPY. The interaction term was FREQUENCY:ENTROPY. NUCLEUS, ONSET, and CODA were significant predictors for a few values, but this was expected: these factors (along with DURATION) were included mainly as controls, to insure that undue explained variance was not being attributed to the predictors of interest. Table 4 shows the output of the model, fitted in R (R Development Core Team, 2008) using functions contained in the `languageR` package. The model estimates (in column 1) are extremely similar to the mean estimates across 100,000 Markov Chain Monte Carlo (MCMC) samples (column 2). The addition of both the SUBJECT ($\chi^2 = 1552.7$) and WORD ($\chi^2 = 251.34$) terms were highly significant ($p < 0.001$ in both cases).

Figure 1 shows the partial effects of the numeric predictors together with the 95% posterior confidence intervals, illustrating the small but significant effects on dispersion of all predictors except neighborhood density (which did not reach significance). Figure 1 also shows the rather surprising interaction between frequency and inflectional entropy. The effect of inflectional entropy is seen to vary with frequency: for low-frequency forms, increasing entropy had a dispersive effect, but for high-frequency forms, increasing entropy had an antidispersive effect.

	Estimate	MCMCmean	HPD95lower	HPD95upper	pMCMC	Pr(>|t|)
(Intercept)	-0.8379	-0.8387	-2.0976	0.4790	0.1829	0.1664
NucleusE	-0.7150	-0.7155	-0.9002	-0.5302	**0.0000**	**0.0000**
NucleusI	0.0454	0.0451	-0.1629	0.2488	0.6445	0.6374
Codab	0.0078	0.0073	-0.4241	0.4360	0.9718	0.9692
Codaf	-0.3682	-0.3679	-0.9347	0.2181	0.1912	0.1718
Codah	0.2768	0.2765	-0.0696	0.6127	0.1035	0.0826
Codaj	0.0977	0.0973	-0.4432	0.6231	0.7006	0.6953
Codak	0.2202	0.2210	-0.1297	0.5817	0.2004	0.1851
Codal	0.0774	0.0779	-0.2246	0.3831	0.5871	0.5852
Codam	0.0504	0.0505	-0.3303	0.4292	0.7774	0.7771
Codan	0.3401	0.3411	-0.1548	0.8677	0.1733	0.1564
Codap	0.5399	0.5410	-0.0120	1.0864	0.0524	**0.0359**
Codar	0.0361	0.0366	-0.3543	0.4233	0.8424	0.8420
Codat	0.0356	0.0357	-0.2433	0.3063	0.7842	0.7819
Codav	0.0587	0.0594	-0.2637	0.3919	0.7010	0.7025
Codaz	0.1315	0.1313	-0.2320	0.4947	0.4487	0.4374
OnsetJ	-0.2806	-0.2805	-0.6820	0.1181	0.1531	0.1329
OnsetN	0.0108	0.0103	-0.3818	0.4001	0.9595	0.9530
OnsetS	-0.2677	-0.2673	-0.7121	0.1909	0.2214	0.2032
Onsetf	-0.3505	-0.3509	-0.7412	0.0470	0.0765	0.0567
Onsetk	-0.1105	-0.1109	-0.4863	0.2627	0.5302	0.5273
Onsetl	-0.1829	-0.1827	-0.7209	0.3647	0.4782	0.4701
Onsetm	-0.3208	-0.3211	-0.6952	0.0536	0.0871	0.0670
Onsetn	-0.4199	-0.4208	-0.8695	0.0273	0.0652	0.0448
Onsetp	-0.4450	-0.4452	-0.8293	-0.0428	**0.0312**	**0.0155**
Onsetr	-0.5317	-0.5321	-1.1058	0.0389	0.0657	0.0465
Onsets	-0.1710	-0.1720	-0.7319	0.3779	0.5130	0.5100
Onsett	-0.3744	-0.3751	-0.7332	-0.0120	**0.0425**	**0.0267**
Onsetx	0.0023	0.0019	-0.4473	0.4498	0.9934	0.9912
Density	-0.0749	-0.0748	-0.3461	0.2044	0.5695	0.5632
Duration	0.0011	0.0011	0.0007	0.0015	**0.0000**	**0.0000**
Timestep	0.0241	0.0241	0.0218	0.0263	**0.0000**	**0.0000**
Freq	1.4141	1.4165	0.3055	2.5223	**0.0152**	**0.0066**
Entropy	0.5821	0.5825	0.0519	1.1323	**0.0366**	**0.0220**
Freq:Entropy	-0.5957	-0.5966	-1.0964	-0.0944	**0.0219**	**0.0114**

Table 4: Fixed effects MCMC simulation results, 100,000 runs.

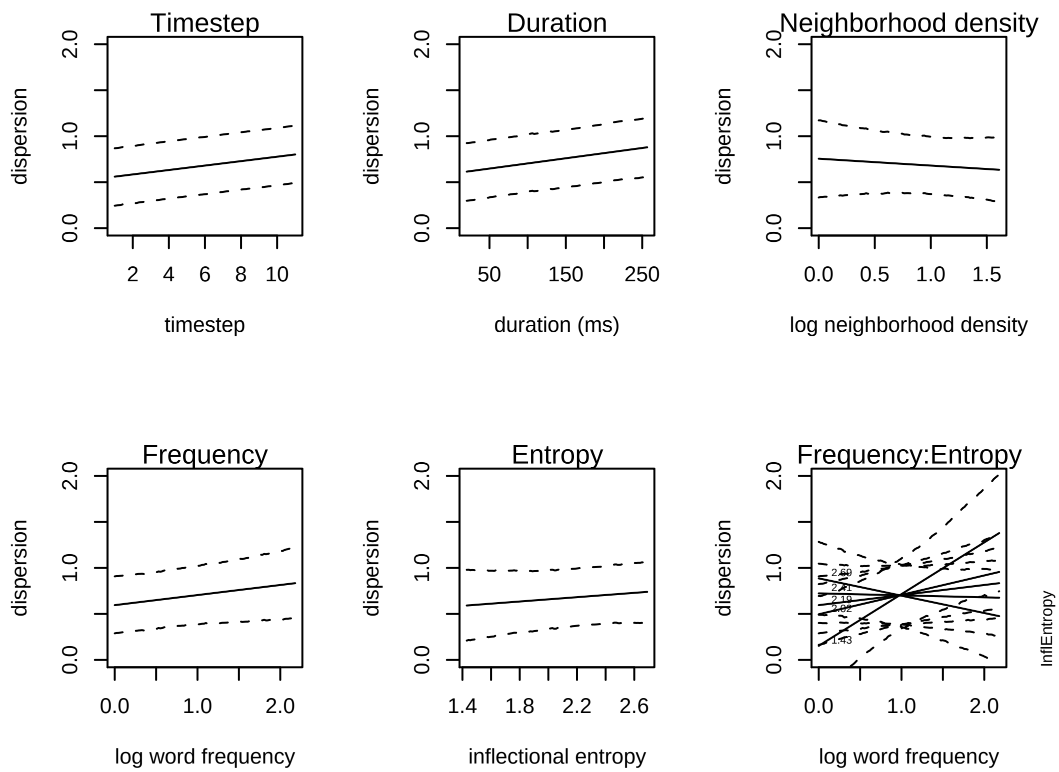

Figure 1: Partial effects of the numeric predictors for vowel dispersion. Dotted lines show MCMC-based 95% highest posterior density (HPD) intervals based on 100,000 samples.

4. Discussion

The partial effect of inflectional entropy was dispersive; that is, as entropy increased, so did dispersion. This finding is consistent with previous work which found spectral reduction in high predictability contexts (Lieberman, 1963; Scarborough, 2006). High-frequency items were also produced as reduced relative to low-frequency ones. However, the effect sizes were extremely small, which can be better understood in light of the interaction effect.

One line of explanation for these results is that talkers are listener-oriented (Lindblom, 1990). On this view, low-frequency, high-entropy forms would need to be clearly articulated to avoid listener confusion. Low-frequency, low-entropy forms, despite occurring fairly rarely, are at least predictable within their paradigms, and thus might be expected to withstand some reduction as a result; a similar line of reasoning might be advanced to explain reduction in high-frequency, high-entropy forms. But this approach fails to answer the question of why high-frequency, low-entropy forms appear to be hyperarticulated: from a listener-oriented standpoint, these forms are predicted to be the most reduced, yet the reverse appears to be true.

An alternative (not necessarily inconsistent with the first) explanation is that the interaction is highlighting a sound change in progress, which is targeting more autonomous forms. In reviewing the experimental literature on the effects of frequency on morphological complex forms, Bybee (2001) develops the argument that high-frequency forms have a tendency to become autonomous, to such an extent that their behavior can no longer be predicted solely on the basis of their frequency. The interaction observed here may indicate that the degree of autonomy may be related to inflectional entropy: if high-frequency forms from low-entropy paradigms are more likely to become autonomous (since the inflected form is highly predictable given the lemma, the paradigm itself is exerting comparatively little influence on the form), but the same may not be true for forms from high-entropy paradigms (which may bear stronger connections to related words in the paradigm). The expanded (unreduced) vowel spaces associated with frequent, predictable verbs may be a precursor to these forms breaking away from their paradigms and becoming strong verbs, as happened for a short time in the 1800s with the verb *fragen* 'to ask', which developed the forms *fragen frug gefragen* on apparent analogy with *tragen* 'to carry' (Stedje, 1994).

This type of development of strong verbs from weak in Germanic is, however, an exceedingly rare phenomenon, and weak verbs which develop strong forms are often highly unstable (indeed, in modern German *fragen* has reverted to weak verb status). The reverse situation, whereby strong verbs become weak, is much more common (e.g. *gebacken*, the semi-strong past participle of *backen* 'to bake', is gradually being replaced with *gebackt*), and also usually attributed to the effects of analogy. If inflectional entropy does indeed provide some measure of autonomy, it may prove to be a useful diagnostic in determining which strong forms are more likely that others to be so influenced.

The lack of a significant effect of neighborhood density was unexpected given the findings of previous researchers (Wright, 1997; Munson and Solomon, 2004; Munson, 2007; Scarborough, 2006). At no point in the process of model assessment did this predictor emerge as significant. One possibility is that the range in density values may have been too constrained, relative to the range in values for frequency and entropy. Low-density verbs were those with 1 to 10 immediate neighbords, while high-density verbs had from 11 to 41. Low-frequency verbs, on the other hand, were those with a Mannheim corpus frequency between 1 and 5, whereas some high-frequency verbs had frequencies as high as 150. In other words, the median split by neighborhood density may not have sufficiently separated the two groups.

5. Conclusions

Paradigmatic complexity, measured by inflectional entropy, exerts a measurable influence on vowel dispersion in Standard German. The influence is independent of other factors, but the magnitude of the effect is mediated by frequency: dispersion is correlated with entropy in low-frequency paradigms and varies inversely with entropy in high-frequency paradigms. Further work is necessary to unravel the source of this unusual interaction, as well as to better understand the ramifications of intraparadigmatically-influenced phonetic variation on phonological and morphological change in Germanic more generally.

A. Stimuli

These tables show the frequency (F), neighborhood density (D), and inflectional entropy (H) of the verbs used in the study, along with the bin (high/low) they were assigned to for each predictor.

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W	3sg gloss	$F(W)$	$D(W)$	$H(W)$	FBIN	DBIN	HBIN
flattert	‘jitters’	10	3	2.34	hi	lo	hi
hackt	‘chops’	5	34	2.32	lo	hi	hi
haftet	‘guarantees’	34	20	1.43	hi	hi	lo
jammert	‘moans’	6	5	1.87	hi	lo	lo
klappt	‘works out’	38	22	1.96	hi	hi	lo
kracht	‘crashes’	5	10	2.19	lo	lo	lo
krankt	‘suffers’	5	10	1.55	lo	lo	lo
lacht	‘laughs’	76	30	2.28	hi	hi	hi
prasselt	‘crackles’	1	3	2.58	lo	lo	hi
sackt	‘sinks’	2	29	1.83	lo	hi	lo
sammelt	‘collects’	23	10	2.27	hi	lo	hi
spannt	‘strains’	10	9	1.70	hi	lo	lo
stapft	‘trudges’	4	15	2.05	lo	hi	lo
wacht	‘is awake’	8	25	2.58	hi	hi	hi
zapft	‘draws, taps’	1	6	2.26	lo	lo	hi

Table 5: /a/ stimuli

W	3sg gloss	$F(W)$	$D(W)$	$H(W)$	FBIN	DBIN	HBIN
bäckt	‘bakes’	1	41	2.69	lo	hi	hi
bellt	‘barks’	3	18	2.12	lo	hi	lo
fletscht	‘snarls’	2	5	2.33	lo	lo	hi
hemmt	‘blocks’	16	16	2.46	hi	hi	hi
kläfft	‘yaps’	1	6	2.65	lo	lo	hi
klemmt	‘grips’	2	11	2.10	lo	hi	lo
meldet	‘informs’	150	13	2.29	hi	hi	hi
quetscht	‘squashes’	2	7	2.18	lo	lo	lo
schlendert	‘stroll’	5	4	2.19	lo	lo	lo
schleppt	‘carries’	19	10	2.51	hi	lo	hi
schreckt	‘frightens’	6	19	1.63	hi	hi	lo
schwemmt	‘sweeps’	2	11	2.29	lo	hi	hi
schwenkt	‘swivels’	10	6	2.09	hi	lo	lo
senkt	‘sinks’	34	10	2.02	hi	lo	lo
stemmt	‘stems’	4	17	2.51	lo	hi	hi
trennt	‘parts’	33	17	2.04	hi	hi	lo
wechselt	‘changes’	31	3	2.56	hi	lo	hi

Table 6: /ɛ/ stimuli

W	3sg gloss	$F(W)$	$D(W)$	$H(W)$	FBIN	DBIN	HBIN
billigt	‘endorses’	11	9	2.43	hi	lo	hi
blinkt	‘blinks’	6	6	2.15	hi	lo	lo
filmt	‘films’	2	5	2.28	lo	lo	hi
flickt	‘mends’	2	17	1.95	lo	hi	lo
kickt	‘kicks’	2	25	2.33	lo	hi	hi
kippt	‘topples’	8	16	2.10	hi	hi	lo
mischt	‘mixes’	18	16	2.46	hi	hi	hi
nippt	‘sips’	1	9	1.85	lo	lo	lo
stiftet	‘donates’	10	5	2.30	hi	lo	hi
tickt	‘ticks’	5	25	2.23	lo	hi	hi
tippt	‘types’	5	23	1.95	lo	hi	lo
widmet	‘devotes’	23	1	2.03	hi	lo	lo
zischt	‘sizzles’	6	12	1.74	hi	hi	lo
zittert	‘trembles’	35	13	2.41	hi	hi	hi
zwirbelt	‘twirls’	1	5	2.57	lo	lo	hi
zwitschert	‘twitters’	2	2	1.98	lo	lo	lo

Table 7: /ɪ/ stimuli

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