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Phonological Processing in Temporal and Frontal Lobes During Speech Recognition

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Distinct levels of phonological processing in speech recognition?

The goal of our study was to identify levels of phonological processing during word recognition. Psycholinguistic factors: *phonotactic probability* and *density* may modulate sublexical and lexical-phonological processing load, selectively affecting related neural networks.

Phonological neighborhood density → Lexical processes (access, competitive activation)

Phonotactic probability → Sublexical processes (segmentation, learning)

Earlier fMRI studies modulated phonological processing load using density, but found contradictory patterns. (Okada & Hickok, 2006; Prahbakaran et al., 2006.)

Irvine Phonotactic Online Dictionary (IPhOD)

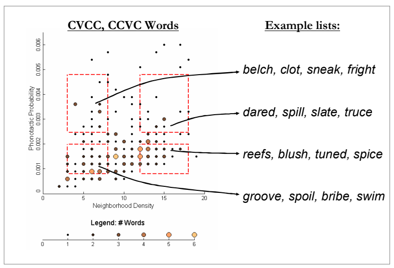
Phonological Neighborhood Density: Competition

How many words share all but one phoneme?

Phonotactic Probability: Facilitation

How many other words contain the same phoneme pairs?

Both measures were described in Vitevitch & Luce (1999).



Stimuli: 4 word lists presented over headphones

100 (CVCC, CCVC) words, 25 per condition. Lists were homogeneous in (high/low) density and phonotactic probability. Bootstrapping algorithm selected words according to behavioral data, recording duration, and Kucera-Francis word frequency; condition order optimized with Genetic Algorithm (Wager & Nichols, 2003).

Participants and Task

Participants: UCI students (12 male, 9 female, mean age = 22)

Right-Handed, native English speakers, free of neurological disease, normal hearing by self-report.

Task: listen, press a button if the list contained pseudowords.

Regular Trial Example: *belch, clot, sneak, fright* (no press)

Catch Trial Example: *doves, henth, yorm, teased* (button press)

* Note: catch trials were excluded from imaging analysis.

Each run: 24 trials (6 per cond) + 2 catch trials; 4.5 min.

8 total runs; session took one hour.

Jittered block design: 8.4, 10.5, 12.6 sec

Imaging Protocol

3T Philips MRI at the Research Imaging Center, UCI. All images AC-PC oriented. Anatomical volumes: 1mm^3 isomorphic, T1 weighted sequence. Functional volumes: [2.3x2.3x3mm] voxels, 34 slices, whole brain coverage, interleaved slices, zero gap.

Other EPI specs: TR=2.1s, TE=26ms; FA=90; FOV=200; 130 volumes per run; SENSE headcoil; Cogent 2000 synchronized sound delivery through Resonance Technologies headphones.

Preprocessing

SPM5: slice-timing correction, realignment, co-registration, normalization to MNI, spatial smoothing (6mm FWHM Gaussian). De-trended with Linear Model of the Global Signal (Macey et al., 2004).

Two extra nuisance variables: one vector identified extreme whole-volume intensity shifts, another detected large numbers of coincident extreme voxel values based on timecourses (*method used in* Vaden, Muftuler, Hickok, 2009).

Group Analysis:

1. Phonological Neighborhood Density

Where did activity significantly correlate with the number of neighbors (positively or negatively)?

2. Phonotactic Probability

Did activity systematically change with respect to sublexical processing load?

3. Individual factors (Wilson, Isenberg, Hickok, 2009)

Task Performance

Summary. Mean percent correct = 0.86 (SD = 0.11), Hit Rate = 0.71 (0.20), False Alarms = 0.14 (0.12), A' = 0.77 (0.05), A' ranged [0.74, 0.99].

4 subjects exceed 2 SD from mean FA, Misses, A', removed from analyses.

Density Effects: False Alarms (N.S.)

High (7.38) > Low (5.18).

$F(1,16) = 3.62, p = 0.075$.

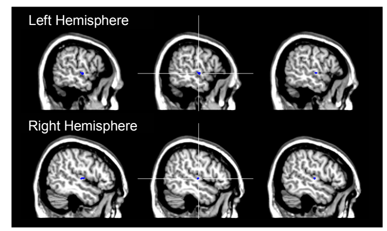
Phonotactic Effects: False Alarms

High (7.65) > Low (5.18).

$F(1,16) = 8.07, p = 0.012$.

DxP Interaction (N.S., $p = 0.42$)

Neuroimaging Results



Neighborhood density (top)

Left pSTS, right pSTG negatively correlated with density values.

Phonotactic probability (bottom)

Left inferior frontal gyrus positively correlated with phonotactic values.

Thresholded $t(16) = 2.92$, $p < 0.005$, M.C. corrected at cluster level (10 vxls), $p < 0.001$. SVC corrected using 10mm radius sphere at *a priori* ROIs (SMG/AG, STS/STG).

Conclusions

Further evidence that spoken word recognition involves distinct phonological processes

Identical words correlated with activity in different regions, depending on lexical or sublexical focus.

Replicated Okada & Hickok (2006), density effects in bilateral posterior superior temporal lobes.

IFG activity also modulated with sublexical frequency measures in production tasks (Papoutsi et al., 2009).

This highlights different aspects of speech perceptual activity, parametrically traced to separate networks.

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CCVC/CVCC words used in the fMRI experiment

Low Dens. Low Phon.	Low Dens. High Phon.	High Dens. Low Phon.	High Dens. High Phon.
beeps	blush	bags	brig
blob	churned	belch	brim
bribe	cliff	block	clan
crawl	clutch	blot	crass
crouch	crib	brook	crate
cube	daunt	broom	creep
curved	gleam	clot	dared
cute	plush	float	dipped
flag	probe	flock	dunk
frog	prune	fright	fond
groove	realm	hurled	freak
jammed	reefs	lagged	gram
jolt	scotch	muse	greet
junk	sleeve	popped	grill
mute	sludge	roamed	hoots
pledge	smug	shield	jarred
quiz	snug	slash	lids
shelf	tenth	slop	meld
sniff	thumbed	snack	scare
spoil	torch	sneak	slate
spoon	trash	spice	spear
swim	trot	spike	spill
thirds	trout	swell	tread
vault	tuned	tank	truce
verbs	zoned	yank	vex