The neural basis of obligatory decomposition of pseudo-affixed words: Tracking the "broth" in "brother"

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Introduction

Purpose: Explore the influence of word form properties on the M170 response from the inferior temporal lobe (IT, including the VWFA) during early stages of pseudo-affixed word recognition.

What is the role of the IT in visual word recognition? Does the IT obligatorily decompose potentially morphologically complex words, and if so, at what stage of processing?

Competing views of the M170 IT response
• Letter and symbol string recognition (Tarkiainen et al., 1999).
• Lexical access (Pulvermüller, 2001).

Current views
• Visual word form recognition via orthographic word form properties (Cohen et al., 2002).
• Visual word form recognition via morphological properties as reflected in the MEG M170 response (Solomyak & Marantz, 2009a, 2009b).
• Obligatory decomposition suggested by masked priming results (Rastle et al., 2004).

Our approach: Examine brain responses to word form properties of pseudo-affixed words during a lexical decision task with simultaneous MEG.

Findings support an obligatory decomposition model of visual word recognition where every word is decomposed based on visual word forms of stem and affix. Additionally, whole word form representations may be available for words like *brother* whose decomposition would be ineffective in achieving lexical access.

Design

Stimuli
• Filler items (n=420) & non-words (n=571)
• Pseudo-affixed monomorphemic words (n=78) from the *English Lexicon Project*
• (5-8 letters, 1-3 syllables)

Four pseudo-affixes: *-al* (n=10), *-er* (n=53), *-ic* (n=8), *-ion* (n=7)

-al	-er	-ic	-ion
final formal	adder after barber beaker bother brother butcher	antic magic	bunion legion
legal marshal	cocker drawer fiber flicker flower former gaffer glower guilder hunger hunker	manic panic	lotion notion
metal rational	lager larder lather leger luster mister muster mutter number offer paper ponder	pubic runic	ration
sandal several	pucker render scamper shoulder shower skewer sober solder tamper temper	rustic tactic	scullion
vestal withal	titer tuber tucker turner wander welter whisker wicker wither		trillion

Stimulus Variables

Variable	Definition	Example
Surface frequency (SF)	summed frequency of whole word form	frequency of *brother*
Base frequency (BF)	frequency of base as a whole word	frequency of *broth*
Transition probability (TP)	probability of the whole word form given the base	given *broth*, probability of *brother*

$$\text{TP of } brother = \frac{\text{frequency of } brother}{\text{frequency of } broth + \text{frequency of } brother}$$

Higher TP = greater parsing difficulty = greater brain activation

Analysis

• Native English speakers (n=11) completed a visual lexical decision task (word vs. non-word) of ~1000 trials randomized over five blocks with rests in between.

• MEG data were acquired continuously throughout the experiment.

MRI and MEG Data
Structural MRIs were acquired during a separate session. MRIs were reconstructed via FreeSurfer to cortically constrain MEG data. Inverse solutions were computed for data in MNE (MGH/HMS/MIT Athinoula A. Martinos Center for Biomedical Imaging, Charleston, MA). Minimum-norm solutions were averaged over subjects and visualized on a standard brain to identify regions of interest (ROIs) based on activity peaks in the averaged data.
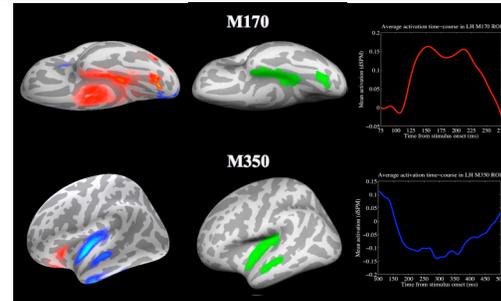
From left: (1) LH activation from non-word trials, projected on standard inflated cortical surface, (2) average activity within each ROI across all non-word trials and all subjects, (3) mean activity in each ROI from non-word trials.

Regions of Interest (ROIs)
M170: based on ~150ms and ~210ms peaks in positive activity in inferior temporal area.

M350: based on ~225ms, ~275ms, and 355ms peaks in negative activity in superior temporal and Sylvian Fissure region.

ROIs were employed in separate correlational analyses with stimulus variables.

Time-course analyses
M170: activity over 140-220ms
M350: activity over 220-320ms

Results

Variable	M170	M350
TP	positive effects over 164-208ms (Σr =4.5852 for 45 time points, p < 5.0e-04*)	X
SF	positive effects on activity averaged over 150-200ms, (r = .0915, p < .024)	X
BF	X	positive effects over 239-259ms (Σr =2.2432 for 21 time points, p < .0303*).

*p = .05 significance level following correction for multiple comparisons

Restrictive M170 ROI Analyses

• More anterior regions of the temporal lobe are associated with more abstract computation (Vinckier et al., 2007).
• Post-hoc analysis divided the M170 ROI based on anatomy into two restricted ROIs, one more anterior than the other.

anterior   posterior
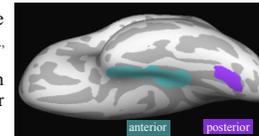
Variable	Anterior	Posterior
TP	positive effects over 168-208ms (Σr =4.32 for 31 time points, p < .001*)	X
SF	positive effects on activity averaged over 150-180ms, (r = .0821, p < .0424).	positive effects on activity averaged over 150-180ms, (r =.0895, p < .027).
BF	X	X

*p = .05 significance level following correction for multiple comparisons

Transition probability effects restricted to the anterior region; Supports the "anteriorness-abstractness" prediction.
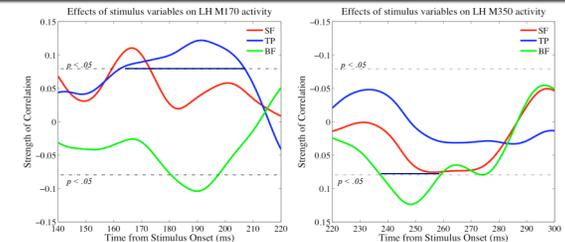
Conclusion

For *brother* words, the M170 response is modulated by TP from base to affix and SF of the whole word form, while the M350 response is modulated by frequency of the base. These results suggest the following:

1) Words are obligatorily decomposed based on statistical relations between stems and affixes.
2) Pseudo-affixed word recognition involves dual-routes where full form representations are available.
3) Lexical entries become relevant at a later response and play no role in decomposition.

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