Morphological Recomposition: An MEEG Study

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1 Introduction

From words and to sentences and beyond, language has a fascinating ability to compose basic units to express new and complex meanings. Much research has been done in the past thirty years investigating the mechanisms of word recognition. The understanding how words are organized and arranged has been a lively and contentious topic within the field of language research. Morphemes are smallest pairing of a sound to a meaning wherein the word 'walker' would consist of two morphemes, 'walk' and '-er'. The field tends to be split over lexical storage, i.e. whether morphologically complex words, words with more than morpheme, are stored as solitary units irrespective of internal structure (list-memory approach, e.g. 'WALKER'), or as stems (basis for word-formation) and computed with other morphemes (morphemic approach, e.g. 'WALK' + '-ER').

1.1 Morphological decomposition

The field has begun to converge on a morphemic approach to word storage. Taft & Forster (1975) proposed some of the earliest models in lexical storage of affixed words. Using lexical decision (Meyer & Schvaneveldt, 1971) to test the predictions of their model, they proposed that the lexicon is arranged by word frequency and that stems of derived words are stored as lexical items. Marslen-Wilson et al. (1994) detailed a more comprehensive model of the mental lexicon in which they claim that this morphemic organization is semantically constrained. They found that words with possible morphemic constituents (e.g. depart + -ment for department) did not prime their constituent embedded word (e.g. depart) when their word forms did not contribute to its meaning.

More recent work from Rastle et al. (2004) has propelled the field to reassess the semantic constraint claim. To test this claim, they used the lexical property of semantic transparency to determine the accessibility of possible embedded morphemes. Semantic transparency describes how well a word's constituent word forms (morphemes) contribute to its overall meaning. A word is considered semantically transparent if the constituent meanings contribute to the overall meaning (e.g. audit + -or for auditor) whereas a word is considered semantically opaque if there are no meaningful contributions from its possible word forms (e.g. audit + -tion for audition). To disentangle the effects of semantic constraints on morpheme segmentation, Rastle et al. used a masked priming paradigm to test whether there is an earlier stage in word recognition that parses word forms on the basis of their representation in the lexicon, their lexicality. Their premise for using priming is that when an item is primed, its representation has been activated leading to faster time in reactivation. Masked priming allows for this activation to occur at a subliminal level. The results revealed that there was faster and equal amounts of priming of the complex word on its constituent word form for both semantically opaque (e.g. BROTHER-broth) and transparent complex words (e.g. DARKNESS-dark) but not for simple words with a possible embedded word but no legal affixes (e.g. BROTHEL-broth). They concluded that these results reflect a process of morpho-orthographic decomposition where words are parsed into possible word forms regardless of semantic transparency. Transparent and opaque complex words alike would go through this process, but simple words would not be broken down further if the results would lead to illegal affixes.

1.2 Morphological composition

Since these findings there have been more convergent results inline with these findings, yet little progress has been made in determining if the word forms parsed in decomposition are recombined for word recognition or if decomposition is merely an automatic but not necessary for word recognition. If decomposition feeds into word recognition, there are some necessary steps in processing, i.e. lexical access and recomposition, that are needed to reach this stage (Meunier & Longtin, 2007). Lexical access involves the retrieval of the stored representation in memory for each of the word forms. Recomposition would involve the combination of the lexical meanings of the word forms.

There are proposals for a general binding mechanism for basic composition proposed by Bemis & Pylkkänen (2011) that may play a role at the word-level. The lateral anterior temporal lobe (LATL) and the ventromedial prefrontal cortex are involved in various semantic combinatorial computations, i.e. minimal composition and enriched composition, respectively (Bemis & Pylkkänen, 2011; Pylkkänen & McElree, 2007). In the minimum composition study, Bemis & Pylkkänen (2011) found that two composable items, an adjective-noun phrase, revealed more activation in the LATL and vmPFC than two non-composable items, a random letter string and word. This was taken as evidence of the most basic of combinatorial processing. Thus, a model of complex word recognition requires at least these three stages of process: parsing into basic units (decomposition), access of their meanings (lexical access) and the recomposition of these word forms with their meaning (Stockall & Marantz, 2006; Taft, 2004).

1.3 Time-course of word recognition

A morphological composition-based model would propose that complex words would be represented as a construction of its morphemes bound together in some systematic manner. Research in electrophysiology and magnetic physiology has begun indexing these stages in visual word recognition by identifying the time-course of these cognitive processes. EEG studies first show letter frequency effects starting around 100ms (N1 on n-gram frequencies: Hauk et al., 2006). MEG studies show activation peaking around 170ms after the presentation of a stimulus (M170 on morphological decomposition: Solomyak & Marantz, 2010). These decomposition effects appear in the same window but peak somewhat later in EEG, at around 250ms (N250: Morris et al., 2007). Their source generator has been localized to the left fusiform gyrus (Dehaene et al., 2010; Solomyak & Marantz, 2010).

After these word forms are activated, their lexical access tends to occur between 250-350ms with activation in the superior temporal gyrus (Pylkkänen & Marantz, 2003). Although there is little to no research on how word forms are recomposed, we propose that their recombination uses the same basic combinatorial areas, specifically LATL and orbitofrontal cortex, proposed by Bemis & Pylkkänen (2011). This combinatorial process tends to occur from 184 to 255ms in the LATL (Bemis & Pylkkänen, 2011) suggesting that the composition of these word form works in parallel with their access. Classic models of language comprehension implicated the pars triangularis (left inferior frontal gyrus (LIFG); Broca's area) in syntactic construction of words, which may also be a candidate for a composition area. Although some of these areas interact with each other to form a general speech processing network, it is still unclear how well this model extends to the areas involved in visual word recognition.

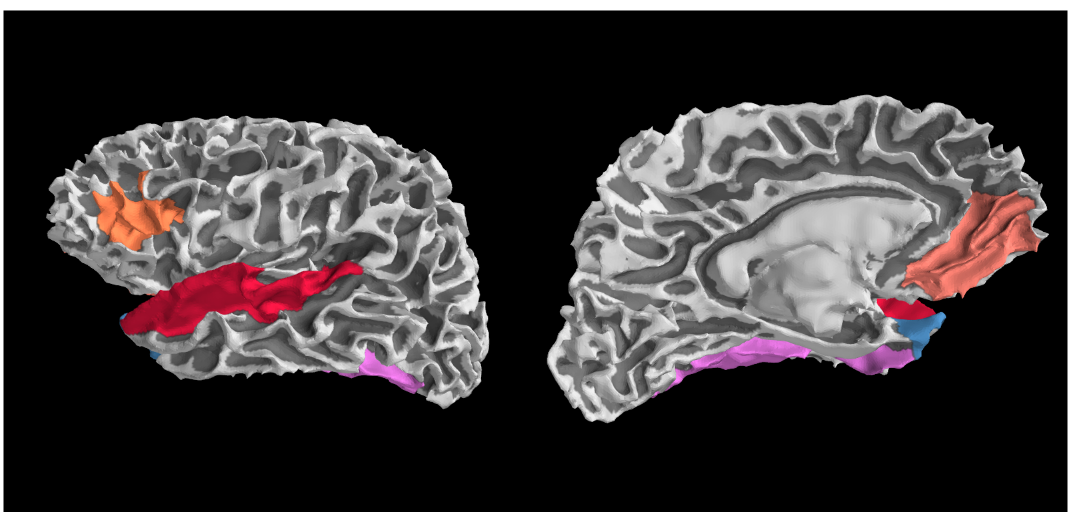


Figure 1: Selected Regions of Interest (Lateral View)

Figure 2: Selected Regions of Interest (Sagittal View)
Five ROIs were defined in this study: Fusiform Gyrus "orchid purple", Temporal Pole "steel blue", Pars Triangularis "coral orange", Superior Temporal Gyrus "crimson red", Orbitofrontal Gyrus "salmon pink"

To test the contribution of these areas to word recognition, we look to the priming literature. Research on priming shows that semantic priming yields suppression, decrease of cortical activity, when there is a semantic relationship between the prime and target (Fiebach et al., 2005; Matsumoto et al., 2005). The markers of this suppression are decreased brain wave amplitudes in the related condition for MEG and EEG, and smaller hemodynamic BOLD effect for fMRI, all of which localize to the superior temporal gyrus. Given the effects on cortical deactivation due to semantic priming, and the areas associated with its processing, our model of word recognition can make strong predictions about the time-course and localization of the stages of visual complex word recognition. Our study aims to test each stage using simultaneous MEEG, combining techniques from both the EEG and MEG literature. Both EEG and MEG are known for the great temporal resolution as these methodologies can record brainwave activity millisecond by millisecond. Because magnetic flux tends to conserve its field pattern as it travels through different media in a systematic way, MEG has the added feature of source localization. The use of EEG will help corroborate our findings in a different recording modality using the same population under the exact same conditions. It will also allow our results to relate directly back to the large body of cognitive electrophysiological research.

1.4 Experiment Paradigm

Compound words provide a rich testing bed for assessing these predictions because they are a subclass of complex words with the unique property of having only free (unbounded) morphemes as their constituents. Spatially unified bi-morphemic compounds were used in this study. Compounds tend to have a modifier-head relationship where the modifier specifies a particular relationship with the head. For example, “doll” in “dollhouse” is the modifier of the head “house” where it describes the type of house, one that is for dolls. This relationship requires a composition of meaning from these morphemes. The degree to which this relationship of these morphemes can compose is of great interest to models of word recognition because it provides insight to the structure of mental lexicon and informs how composition can be observed within the word level. Since the morphemes of a compound are unbounded, they can be used in a priming paradigm to see how their meanings contribute to compound’s procession to word recognition. To do this, a partial repetition-priming and semantic-priming paradigm variant (partial priming) is used to test the effect of a constituent on its overall word (Brooks & Gordon, prep). These compounds will be compared to orthographic simple words that have embedded words within them but have no morphological complexity (e.g. HATCH-hatchet) to test whether any effects are due to orthography only (form priming). Novel compounds whose constituents are randomly concatenated simple words (e.g. LADY-ladyfork) will be tested to observe newly formed modifier-head relationship in the context of composition (for full design, see 2.2 on page 9). We implement a word naming task to obviate the need for non-words associated with lexical decision while making each trial part of the experimental design. Word naming has shown behavioral effects consistent with lexical decision (Neely, 1991) for naming latency and reaction time, respectively.

1.5 A Morphological Composition-based Model

Since our model of word recognition predicts there to be this stage of morphological decomposition, we expect to see decomposition effects in fusiform gyrus for the M170 where the opaque, transparent and novel compounds are segmented but not the orthographics. Since transparent and opaque compounds are morphologically complex, these segmentation effects would be consistent with the literature on decomposition (Solomyak & Marantz, 2010; Stockall & Marantz, 2006). Novel compounds should pattern with the opaque and transparent compounds since the novels share morphological structure consistent with these existing compounds. The morphological decomposition model strongly predicts that segmentation occurs in the absence of semantics, which would lead to novel compounds' segmentation. Because orthographics are not morphologically complex, segmentation should not occur for them. Expectedly, the same pattern of effects should be observed in the N250 time window where opaque, transparent, and novel compounds are decomposed but not the orthographics.

Following the segmentation of these compounds, their constituent word forms will go through lexical access retrieving their semantic and syntactic information (Taft, 2004). Because no segmentation is expected for orthographics, they will proceed directly through to lexical access fully intact. Lexical access will provide each of these word forms with all of their possible senses and instructions on how to compose (Rodd, 2004). We propose that for the compounds, when their word forms combine with their fellow counterpart, their compositional meaning will be a "lock-and-key" relationship where the first constituent word form's sense coheres with the second constituent word form's sense. For example, "carwash" is composed of "car" and "wash", but "wash" has several meanings and grammatical functions, most critically the verb "wash" and the noun "wash". The noun meaning of "wash" will be indexed using its modifier "car" to obtain the compositional meaning of "carwash".

In previous studies using semantic priming on complex words, there were interacting effects of priming such that there was facilitation of word recognition for semantically transparent words but competition and interference effects for semantically opaque ones (Brooks & Gordon, prep; Rastle et al., 2000a). This could be explained in the context of this "lock-and-key" relationship. In a paradigm where the complex word is the prime and its constituent is the target (e.g. DARKNESS-dark Rastle et al., 2000a), the modifier sense is determined by its relationship with head. This sense is activated above and beyond any of its other senses. By definition, this sense is congruous with the target for transparent complex words, therefore the residual activation speeds up the recognition of the target. Conversely, this sense is incongruous for target constituent because it is not the target's default meaning. As for the orthographics, no composition would take place and word recognition would be achieved. The constituents of the novel compounds won't have a preset "lock-and-key" relationship between them. Therefore, a relationship will be generated using the lexical properties of modifiers.

Our aim is to test whether these patterns of effects over time-course of word recogntion. Previous studies have demonstrated cortical deactivation for semantic priming (Fiebach et al., 2005; Matsumoto et al., 2005). We predict that the semantically transparent compounds, the ones whose meaning is composite of its constituent parts, would experience cortical deactivation when its word forms are recombined due to the ease in lexical access facilitated through priming (ROAD-roadside). In contrast, we predict that the opposite pattern of activation will occur for semantically opaque compounds, ones whose meanings are not determined by the composition of their parts, since priming will activate a sense of one of the constituents that is not related to the overall meaning (HOG-hogwash). These effects are expected to appear in M250/M350 and N400[1] since these time windows have been implicated for composition effects (Bemis & Pylkkänen, 2011). Prior studies suggest that the naming latency effects will show similar patterns to the brain activity. Compounds should interact across levels of semantic transparency and priming, while the orthographic simple words should not exhibit any effect (Feldman et al., 2004; Rastle et al., 2000a). Our study seeks to parsimonious answer the question of the role of morphological decomposition and recomposition in visual complex word recognition to provide a perspective of the organization on the mental lexicon.

2 Methods

2.1 Stimuli

311 compounds were compiled from prior studies (see Appendix) and were normed using a semantic relatedness survey administered through Amazon Mechanical Turk. The semantic relatedness survey asked participants to rate on a Likert scale from 1 to 7 how related the meaning of the one of compounds' constituents is to the compound itself where "1" was not related and "7" was very related. 20 participants were randomly given only one constituent per compound to judge.

[1]Pylkkänen & Marantz, 2003 suggested that the N400 is actually a complex component consisting of three peaks, M250, M350a and M350b.

We defined constituents as semantically opaque (e.g. deadline) with a score between 1 to 3 and semantically transparent (e.g. dollhouse) between 5 to 7. Compounds were considered fully opaque if their summed ratings were 1-6 and fully transparent if 10-14. For example, the opaque compound 'deadline' received a summed rating of 3.76 with 'dead' contributing a transparency rating of 1.44 and 'line' contributing a rating of 2.32. Similarly, the compound 'dollhouse' received a summed rating of 11.79 with 'doll' contributing a transparency rating of 6.47 and 'house' contributing a rating of 5.32. Sixty compounds were selected for each category. This method of semantic transparency norming is consistent with prior studies (See Appendix).

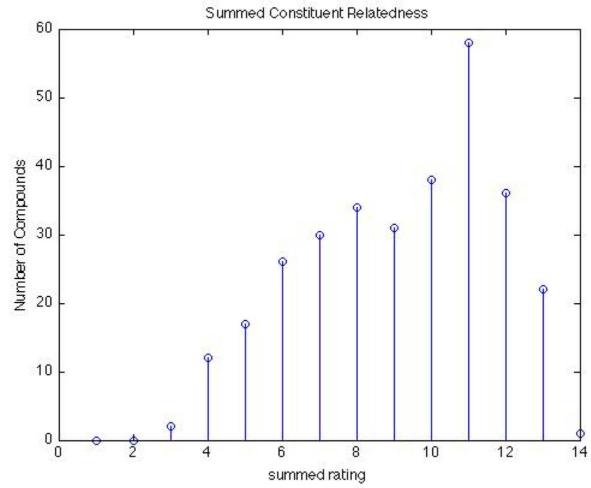


Figure 3: Distribution of Combined Semantic Relatedness Judgments

An analysis of naming latencies was conducted for the compounds collected in the Amazon Mechanical Turk survey using the English Lexicon Project results (Balota et al., 2007). It suggested a trend toward significance such that transparent compounds had a shorter latency [$t(130) = -1.77$, $p = .08$]. As a control, words with no possible internal morphological construction were added to ensure that the priming effects were not due to orthography (form priming). These orthographic simple words were pooled from several studies (see Appendix) with the restriction that they have a word embedded in them, but they, themselves are mono-morphemic (e.g. HATCH-hatchet). These orthographics were selected to have their embedded words have overlapping punctuation with them (e.g. HATCH-hatchet vs. CORD-cordial). Sixty orthographics were selected for this study: thirty of them having the embedded words at the beginning of the word (e.g. HATCH-hatchet) while thirty others with the embedded words at the end (LOG-dialog).

In addition, we included novel compounds to look at composition effects for words with possible morphological structure but with no overall meaning. Sixty novel compounds were generated using the remaining compounds from the relatedness survey. The constituents of the novel compound were randomly selected from the pools of remaining constituents, respectively. Since these constituents are words that are likely to be compounded with others, they make good candidates for novel word formation. To prevent the random formation of an existing word, the word frequency of these compounds were checked using the English

Lexicon Project's word frequencies (Balota et al., 2007).

2.2 Experiment Design

This study contrasted four different word types, each with 60 items: transparent, opaque, orthographics, and novel compounds. These word types were compared in two types of priming, repetition and partial (constituent). For the repetition priming condition, the full compound was shown as both the prime and the target as compared to the constituent priming where the constituent of word (in this study, first-constituent only) is used as a prime for its whole word target. These priming conditions were compared to their unrelated controls. These conditions were latin-squared and blocked such that each word appeared in each of the condition per block. To account for any possible long-lag priming effects, we factored in block order into our design producing a completely within-subjects, fully factorial design: Word Type (4) × Constituency (2) × Priming (2) × Block Order (4).

	Transparent		Opaque		Novel		Orthographic	
	prime	target	prime	target	prime	target	prime	target
control	doorbell	teacup	heirloom	hogwash	keybook	winecloud	brothel	spinach
identity	teacup	teacup	hogwash	hogwash	winecloud	winecloud	spinach	spinach
control	door	teacup	heir	hogwash	key	winecloud	broth	spinach
constituent	tea	teacup	hog	hogwash	wine	winecloud	spin	spinach

Table 1: Design Matrix

2.3 Procedure

Prior to the experiment, each participant was capped with an EasyCap 29-channel passive scalp electrode system placed with electrodes arranged according to the international 10/20 system. The impedances were measured and corrected to below 10 kΩ. The participant then had their head shape digitized using the Polhemus Fastrak system. Along with head shape, five head position marker coils are digitized to co-register the participant's head inside the MEG helmet where this coordinate space is later transformed to each participant's MRI space. The participant was then tested in a magnetically-shielded chamber, which is integrated with an active shielding system.

The study used a partial priming word naming task. In this task, a fixation cross first appears followed by a prime then a target. All of the visual presentations are 300 ms with an inter-stimulus interval of 600ms. The task is for the participant to read aloud the target word from the onset on the screen. Audio was sampled from the presentation of the target to the activation of a voice trigger (see Appendix). Their production was recorded from the point a voice trigger is activated. Each participant was presented with 960 trials: 60 words in each of four word types counterbalanced for each of the four condition.

MEG data were collected using a 157-axial gradiometer MEG system (Kanazawa Institute of Technology, Nonoichi, Japan) sampling at 1000 Hz with a low-pass filter at 200 Hz and a notch filter at 60 Hz. Naming latencies were computed as the time of the target presentation to the activation of the voice trigger. Voice recordings were recorded for 700 ms after the activation of the sound trigger to capture the word production.

Blink detection was determined from an SR-Research Eyelink 1000 arm-mounted eye-tracker. The epochs were baseline corrected using the pre-stimulus time interval of 200ms.

2.4 Participant Recruitment

Participants were recruited from the New York City community. There were five right-handed, native English speakers, all having normal or corrected-to-normal vision. Due to an irrecoverable co-registration error, only three participants MEG data survived the source estimation.

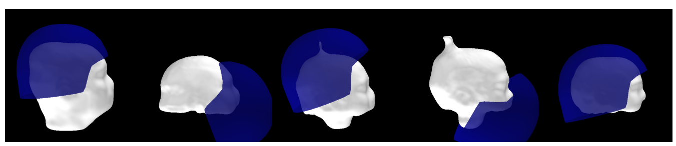


Figure 4: MEG Subject Head Placement

2.5 Analysis

For behavioral results, the effects on naming latency from the participants' word production were analyzed using a repeated-measures ANOVA. Naming latencies were defined as the duration from the visual onset of the target stimulus to the activation of the voice trigger marked by a sound threshold.

For the MEG brain responses, the MEG signal was recorded using a DC recording with a low-pass filter of 200Hz and a notch filter of 60Hz. During on-line recording, three axial gradiometers measured the magnetic fields away from the participant's head but within the dewar. The brain response MEG signal was then processed using a continuously adjusted least squares method (CALM) based on these gradiometers to reduce lower frequency noise from the environment (Adachi et al., 2001). Lastly, the signal then has a low-pass filter applied at 30Hz.For both the MEG and EEG brain responses, the data were epoched with a baseline of 200ms prior to the onset of the target stimulus to 400ms for MEG and to 500ms for EEG post-stimulus presentation. Trials were rejected using the Eyelink blink detection. Additionally, MEG trials were rejected if the signal's amplitude exceeded a threshold of 3pT throughout the epoch. Since our analyses were interested in the local brain activity of these regions of interests: fusiform gyrus, temporal pole, superior temporal gyrus, pars triangularis, and orbitofrontal cortex, we conducted a cortically-constrained L2 minimum-norm current estimate using the software package, MNE (Martinos Center for Biomedical Imaging). Due to an existing noise problem that has been characterized with a particular topography across a score of participants, a principal component analysis was conducted to remove this component from the data.

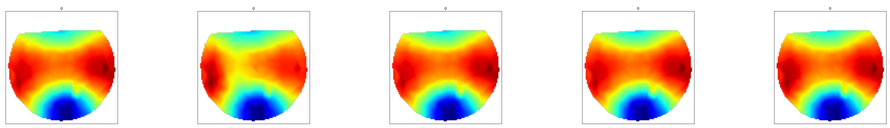


Figure 5: PCA across subjects

A noise covariance matrix was computed to correlate sensors with each other in the presence of ambient noise. To prevent correlating ambient noise and brain response, we used a 400 ms epoch window centered on the presentation of the fixation cross. This allows for the computation on recorded data that is individually tuned. The sensor locations are then transformed into MRI space to have these sources in a common space. Using the covariance matrix, the MEG sensor coordinate transformation, and the MRI, a forward model is computed to estimate the how cortical source activity would be realized at an MEG sensor. Our MRIs are parcellated into 5124 icosahedron sources. Since this forward model is generally well-understood, we can generate an inverse operator and apply it to the MEG data to solve the sensor-to-source problem. Our event-related fields (ERFs) were defined based on the previous work and are generally accepted time windows: 100-200ms (M170), 200-300ms (M250), 300-400ms (M350), all post-stimulus presentation (Pylkkänen & Marantz, 2003).

The EEG data was analyzed using a cluster-based sensor approach (Morris et al., 2007). Since our electrode cap differed slightly from prior work, we adjusted the clusters to reflect comparable areas. Electrodes were classified into four clusters: outer (Fp1, Fp2, O1, O2, F7, F8, P7, P8), midlateral (F3, F4, P3, P4, FC5, FC6, CP5, CP6), inner (C3, C4, FC1, FC2, CP1, CP2), and midline (Fz, FCz, Cz, CPz, Pz, POz).

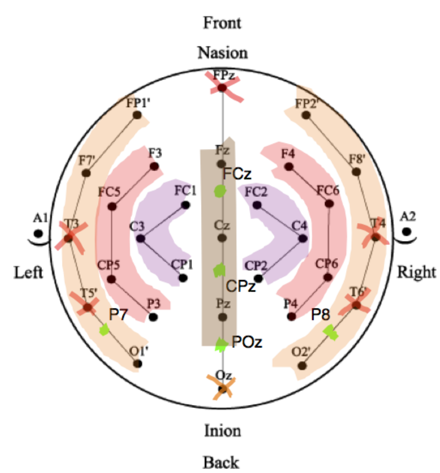


Figure 6: EEG Electrode Arrangement

There were two windows of interests for the event-related potentials (ERPs) in this study: 200-300ms (N250) and the 300-500ms (N400), all post-stimulus presentation.

3 Results

3.1 Behavioral

For the behavioral results, in the repetition priming condition, latency analyses revealed that there is a significant effect in priming such that naming latencies were shorter for the target when it was primed [$F_1(1,4) = 47.64$, $p = .00$]. There was also an significant effect of word type [$F_1(3,4) = 4.12$, $p = .03$] and block order [$F_1(3,4) = 7.71$, $p = .05$]. There was no significant interaction between word type and priming [$F_1(1,4) = 2.38$, $p = .12$]

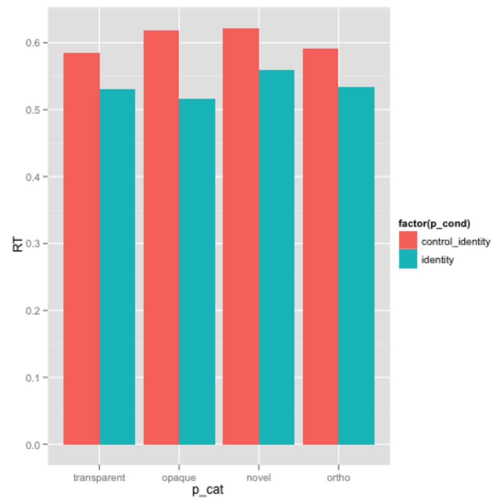


Figure 7: Repetition Priming on Naming Latency

For the partial priming condition, analyses revealed that there is a significant effect in priming such that naming latencies were shorter for the target when it was primed [$F_1(1,4) = 11.87$, $p = .02$]. There was also an significant effect of block order [$F_1(1,4) = 10.20$, $p = .03$], but there was only a trend toward an interaction effect of word type and priming [$F_1(1,4) = 2.83$, $p = .08$] such that naming latency are faster for transparent, opaque and novel compounds but not for the orthographic simple words.

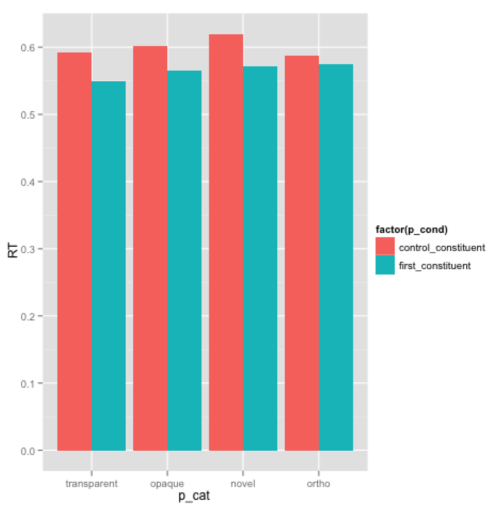


Figure 8: Partial Priming on Naming Latency

3.2 MEG

Due to the anomalous co-registration error, non-removable environmental noise, and the sparse participant sample, there is not enough statistical power to reliably test our predictions. However, we can observe the trends in the data for our regions of interest. Below, repetition priming is referred to as RP and partial priming, PP.

3.2.1 Left Fusiform Gyrus

There appears to be a trend of decreased activation in the repetition condition beginning in the M170 window expanding to the M250.

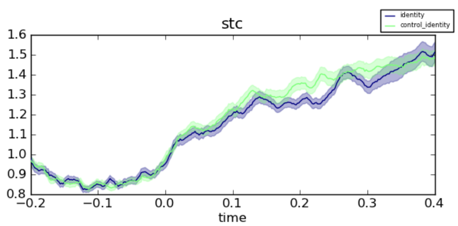
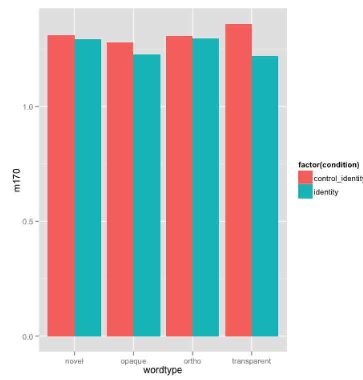


Figure 9: Grand Averages of RP Activation

Figure 10: M170 RP Activation per Word Type



Here, there is an interaction pattern in the partial priming condition between word type and priming. Novel and opaque compounds pattern together with more activation in the primed condition whilst transparent compounds show a decrease in activation.

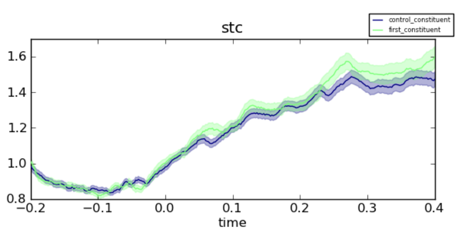
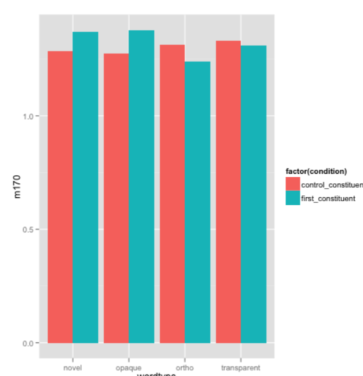


Figure 11: Grand Averages of PP Activation

Figure 12: M170 PP Activation per Word Type



3.2.2 Temporal Pole

There appears to be a trend of decreased activation in the repetition condition peaking around the M250 window.

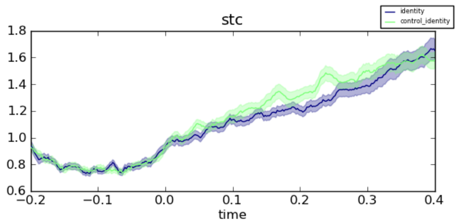


Figure 13: Grand Averages of RP Activation

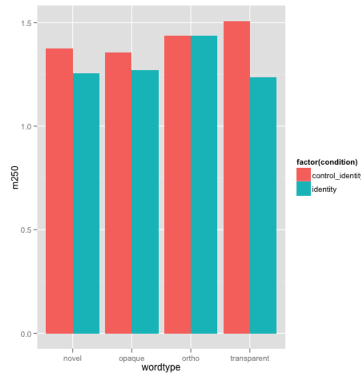


Figure 14: M250 RP Activation per Word Type

Here, there is an interaction pattern in the partial priming condition between word type and priming. Novel and opaque compounds pattern together with more activation in the primed condition.

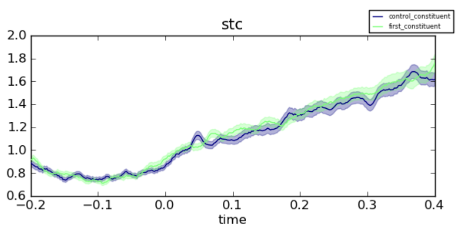


Figure 15: Grand Averages of PP Activation

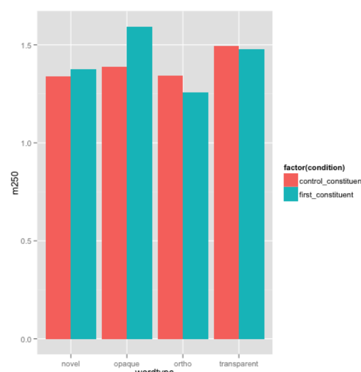


Figure 16: M250 PP Activation per Word Type

3.2.3 Orbitofrontal Cortex

There appears to be a trend of decreased activation in the repetition condition beginning around 200ms within the M250 window.

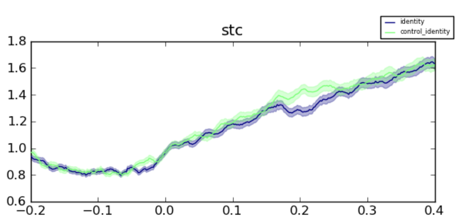


Figure 17: Grand Averages of RP Activation

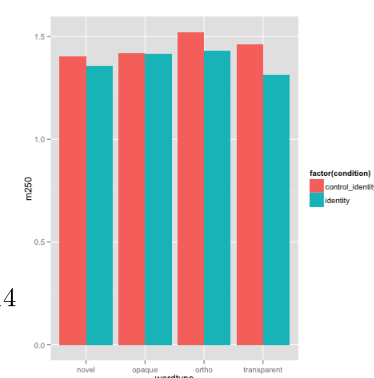


Figure 18: M250 RP Activation per Word Type

Here, there is an interaction pattern in the partial priming condition between word type and priming. Opaque compounds show more activation in the primed condition than any word type. Transparent compounds have the opposite pattern of activation showing a decrease in activation when primed.

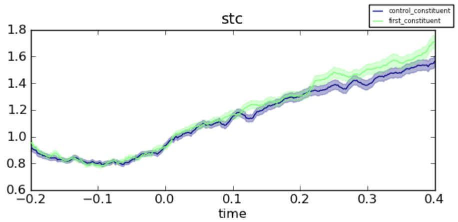


Figure 19: Grand Averages of PP Activation

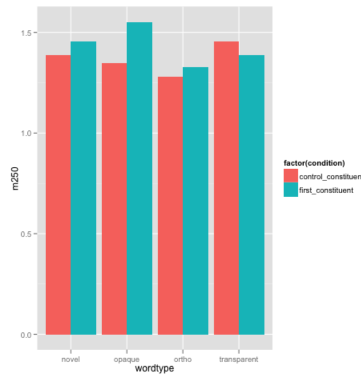


Figure 20: M250 PP Activation per Word Type

3.2.4 Superior Temporal Gyrus

There appears to be a trend of an interaction in the repetition condition where transparent compounds exhibit decreased activation the M250 window.

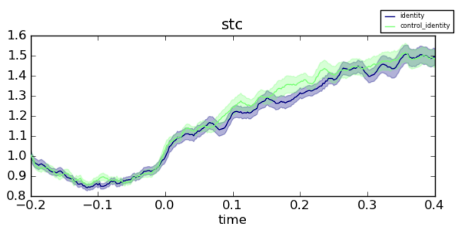


Figure 21: Grand Averages of RP Activation

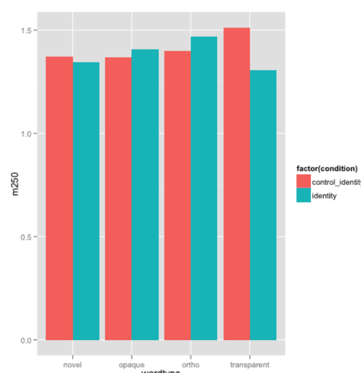


Figure 22: M250 RP Activation per Word Type

Here in the partial priming condition, opaque compounds pattern show a increase of activation in the primed condition.

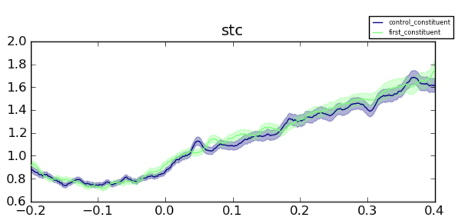


Figure 23: Grand Averages of PP Activation

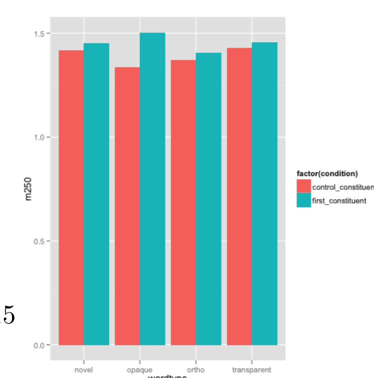


Figure 24: M250 PP Activation per Word Type

3.2.5 Pars Triangularis

In the repetition condition, there appears to be a sustained deactivation beginning around the M170 window while overlapping the M250. Transparent compounds tend to have the strong effect from this repetition.

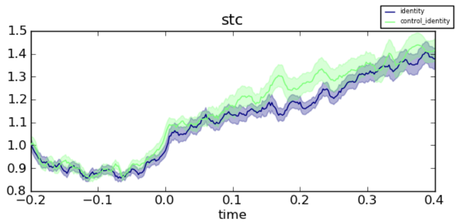
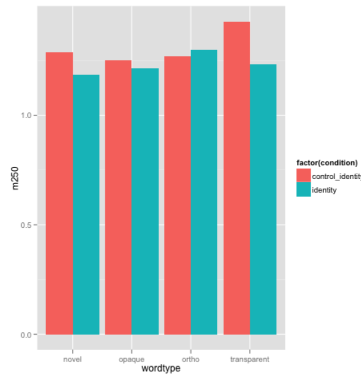


Figure 25: Grand Averages of RP Activation

Figure 26: M250 RP Activation per Word Type



Here, there is an interaction pattern in the partial priming condition between word type and priming. Novel and opaque compounds have again patterned together with more activation in the primed condition. There appears to be less activation for the transparent compounds when primed and nearly no effect on the orthographic simple words.

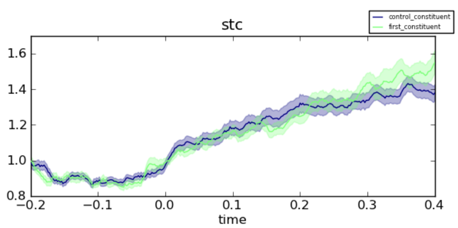
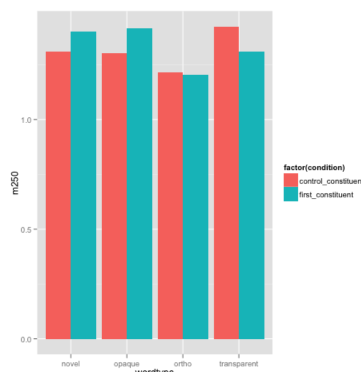


Figure 27: Grand Averages of PP Activation

Figure 28: M250 PP Activation per Word Type

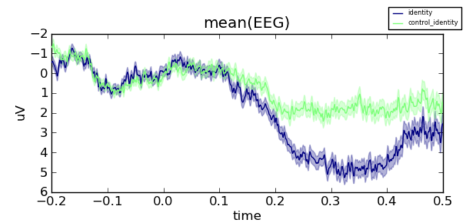


3.3 EEG

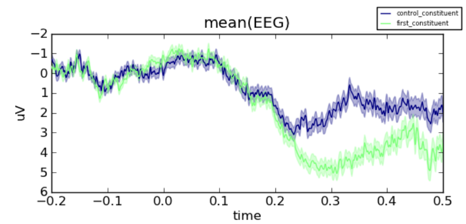
Analyses revealed a pattern of surprising results. The task yielded a component that was centered between the two time regions of interests, N250 and N400. This component appears to be a P300 with opposite field pattern polarity than was expected. The priming manipulation yields strong amplitude modulations irrespective of word type. Thus, the following analyses will investigate the P300 effects.

3.3.1 Outer cluster

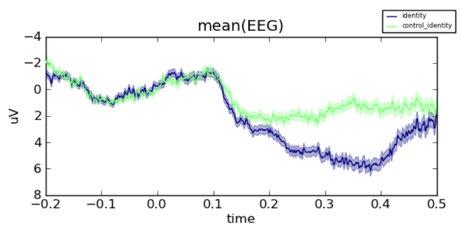
Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 16.20, p = .03]$. No other effect was significant.



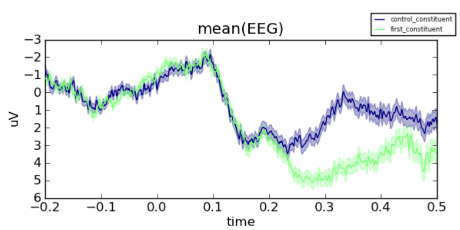
A significant priming was also found for the partial priming condition, $[F_1(1,4) = 122.36, p = .00]$. No other effect was significant.



3.3.2 Midlateral cluster



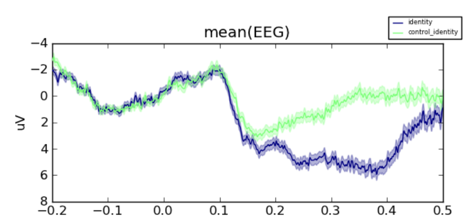
Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 14.37, p = .03]$.



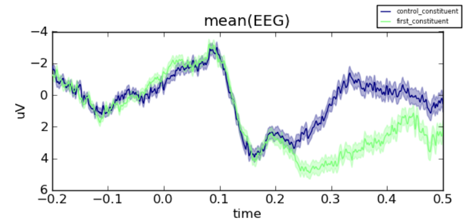
A significant priming was also found for the partial priming condition, $[F_1(1,4) = 55.15, p = .01]$. No other effect was significant.

3.3.3 Inner cluster

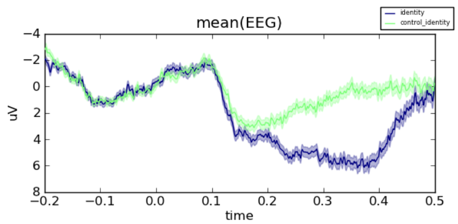
Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 16.72, p = .03]$.



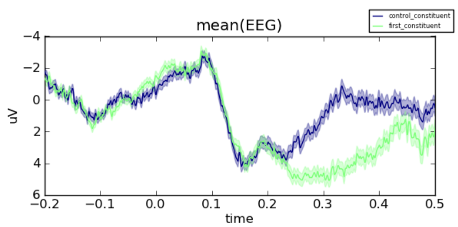
A significant priming was also found for the partial priming condition, $[F_1(1,4) = 40.21,\ p = .01]$. No other effect was significant.



3.3.4 Midline cluster



Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 18.96,\ p = .02]$. In addition, a borderline significant condition by block order interaction was found, $[F_1(1,4) = 3.88,\ p = .05]$.



A significant priming was also found for the partial priming condition, $[F_1(1,4) = 35.68,\ p = .01]$. No other effect was significant.

4 Discussion

4.1 Behavioral

The word naming latency effect is largely consistent with the masked priming literature on word recognition demonstrating the interaction where complex words pattern together having a reduced latency due to priming while priming simple words do not any effects on latency due to priming (McCormick et al., 2008; Morris et al., 2007; Rastle et al., 2004; Taft, 2004). However, these priming effects are not consistent with the effects demonstrated in the semantic priming literature. Here, there is an interaction among the complex words such that transparent complex words have a faster reaction time but opaque complex words have a lower reaction time compared to baseline (Rastle et al., 2000a). This effect is rather surprising because it suggests that there is no effect of semantic transparency on naming latency. This effect also departs from the predicted pattern from the English Lexicon Project analysis where there was a difference in the naming latency for transparent and opaque compounds. Naming latency effects may not be sensitive enough to reveal any semantic transparency difference. Because the naming latency effects pattern with the lexical decision effects in previous work, this suggests that morphological decomposition has occurred in the recognition process. That is, complex words do show this automatic segmentation, which is consistent with the proposed morphological composition model of word recognition.

4.2 MEG

The MEG results on repetition priming showed some patterns consistent with the predictions for the fusiform gyrus: there was decreased activity for across all word types when a word was repeated, which is a consistent finding (Fiebach et al., 2005). For partial priming, there was a pattern of an interaction where opaque compounds had more cortically activation than transparent which showed reduced activation. This semantic transparency effect may be attributable to SOA where prolonged conscious awareness may cause the increased brain activity of opaque compounds since the meaning of its prime is incongruous with its meaning.

For the temporal pole, pars triangularis, superior temporal gyrus, and orbitofrontal cortex, there was a pattern of an interaction such that primed opaque compounds lead to more activity. All areas but the superior temporal gyrus showed patterns of decreased activity for transparent compounds when they were primed. The effects in these regions correspond in time and in location to previously defined regions of composition (Bemis & Pylkkänen, 2011; Pylkkänen & McElree, 2007). These patterns are consistent with the composition model where meaning integration has different effects across the dimensions of semantic transparency. That is, transparent compounds have decreased activity when primed, which is consistent with semantic priming studies (Matsumoto et al., 2005). However, opaque compounds have increased activation when primed. These results fit in with the morphological composition model where there would be a decrease in activation if there is a semantic relationship between the prime and target.

4.3 EEG

The EEG results revealed an unexpected component that strongly signaled an effect with priming. The P300 component has been associated with anticipation of an infrequent but expected stimulus (Verleger et al., 1994). Since our task operated on overt semantic priming where our stimulus-onset asynchrony is 600ms, it may have led participant to anticipate our prime trials more than a more subtle, covert prime. The choice of SOA came from composition studies where priming was not used, leading the composition to be less obvious (Bemis & Pylkkänen, 2011), but given the task, a faster SOA may be more appropriate. Studies investigating differential semantic processes during word recognition have used times half as long as the ones in composition studies (Rastle et al., 2000b). The current SOA may also be problematic because it has a prolonged conscious representation, which may confound the subprocesses typically associated with word recognition. This would perhaps decrease the possibility of strategic behavior. This P300 effect may have shrouded the ERP components of interests since its time window overlaps both the N250 and the N400 windows.

Conclusions

There appears to be evidence that there are stages of processing in visual word recognition that reflects morphological-based parsing and computation. The behavioral effects from word naming demonstrate a pattern of results consistent with the existing literature on the early stages of visual word recognition. Source estimates over the time-course of recognition revealed key patterns of activation consistent with predictions from a morphological composition-based theory of word recognition. Activation in the fusiform reflect automatic segmentation in morphologically complex words that leads to lexical access. These processes are followed by a stage of composition where constituents of a word are recombined in a "lock-and-key" fashion to construct the meaning of the overall word. This study informs our understanding of what information is stored in the mental lexicon. Word forms are the lexical entry of choice for providing the meaning and the instruction for constructing more complex words. The combination of these word forms yields new meaning from the basis of established ones. This consistency of composition across different levels of processing: phrase-level (Bemis & Pylkkänen, 2011) and word-level, may provide insight to whether there is a general binding principle that governs all levels of language construction.

Critically, a new SOA would be the most informative of the semantic nature of morphological composition. Evidence from behavioral studies point to a shorter SOA than our current study as it "allows conscious appreciation of the primes, yet may be so brief as to minimise strategic behaviour" (Rastle et al., 2000a). An increase of participants would yield enough power to effectively evaluation the significance of the pattern of results. The concurrent measures of EEG and MEG provided equally informative and different sources of information.

Since this dataset provides a rich source of information regarding word processing, an analysis of acoustic duration will inform our notion of lexical integrity. Evidence in the word production literature suggests that giveness, the relative activation of an item, of a discourse entity may lead to acoustic reduction in their pronunciation (Kahn & Arnold, prep). Since priming leads to an activation effect in word recognition, partial priming of the constituent should lead to facilitation of the phonological code of that constituent within its compound. If this holds true, there should be an acoustic reduction for compounds when partially primed but no reduction for orthographics. This would add more evidence that discounts the lexical integrity hypothesis assumption that words are a solitary and indivisible unit (Lapointe, 1980). These analyses will broaden our understanding of the architecture of the mental lexicon and how composition integrates word forms and gives rise to new meaning.

5 Appendix

The compounds were pooled from Drieghe et al. (2010); Fiorentino & Poeppel (2007); Fiorentino & Fund-Reznicek (2009); Juhasz et al. (2003). The semantic relatedness norming procedure was replicated over the pooled list of compounds. The ratings were largely consistent with the prior work. The orthographic simple words were pooled from Rastle et al. (2004) and Balota et al. (2007).

Psychtoolbox monitors the audio throughout the recording session. Latency times are measured from the presentation of the target screen to onset of the voice trigger: when the acoustic noise exceeds the set threshold (0.1), it sends a trigger to the MEG, the EEG and presentation computer to mark the beginning of speech and naming latency times.

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