# Morphological Recomposition: An MEEG Study

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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-on priming shows that semantic priming yields suppression, or 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 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.

Confused. Isn't this a version of semantic constraint mentioned earlier?

# 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.

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

published paper : Neuron : Ranganath

## 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



why naming? ?

(production)

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.

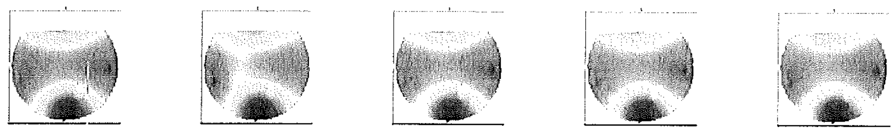


Figure 5: PCA across subjects

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).

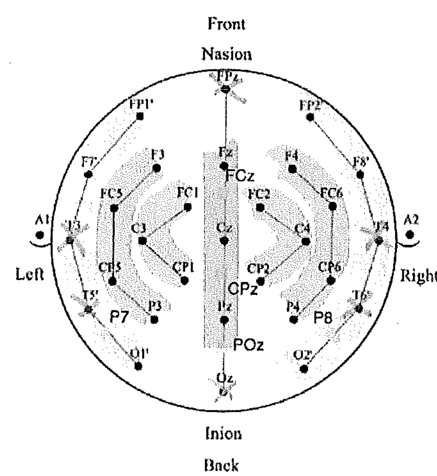



Figure 6: EEG Electrode Arrangement

## 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.

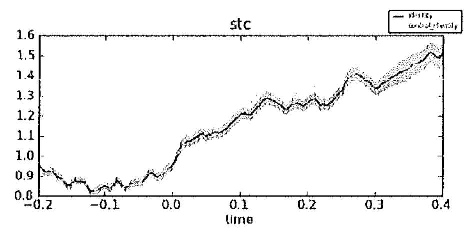



Figure 9: Grand Averages of RP Activation

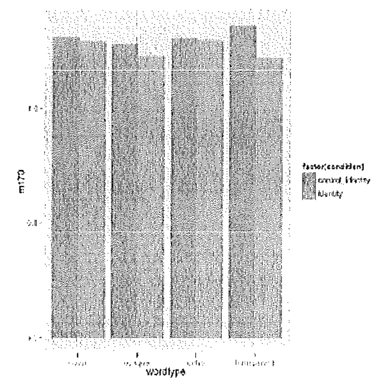


Figure 10: M170 RP Activation per Word Type

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.

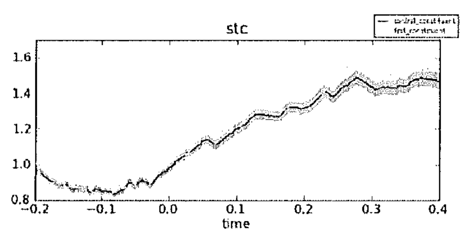



Figure 11: Grand Averages of PP Activation

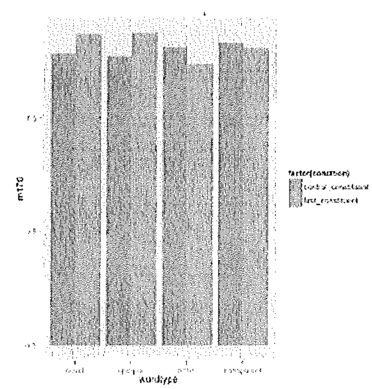


Figure 12: M170 PP Activation per Word Type

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.

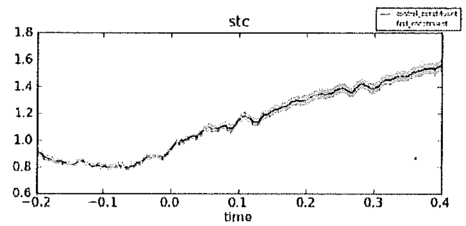



Figure 19: Grand Averages of PP Activation

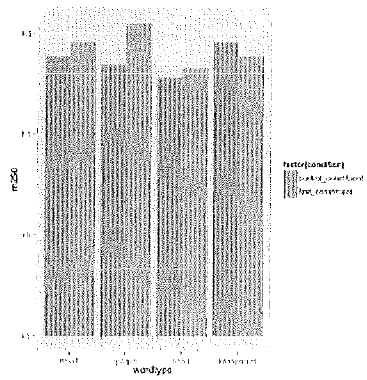



Figure 20: M250 PP Activation per Word Type

### 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.

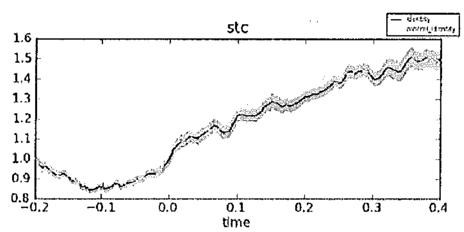



Figure 21: Grand Averages of RP Activation

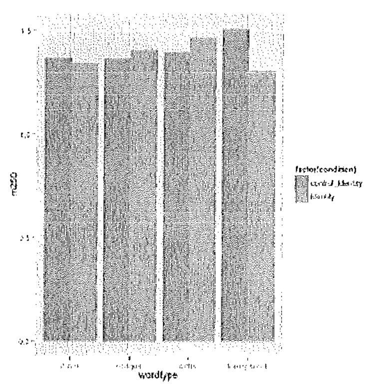



Figure 22: M250 RP Activation per Word Type

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

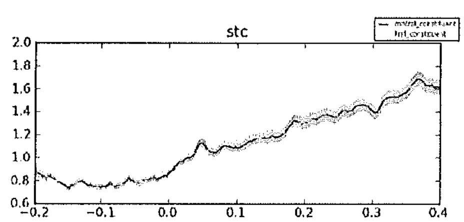



Figure 23: Grand Averages of PP Activation

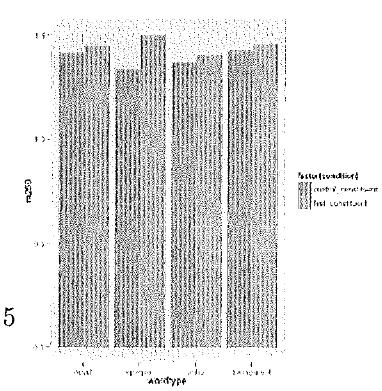
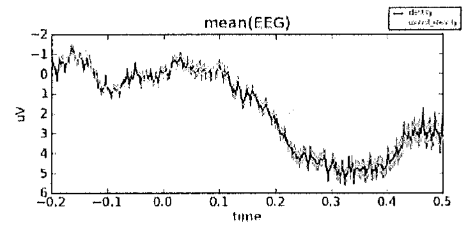


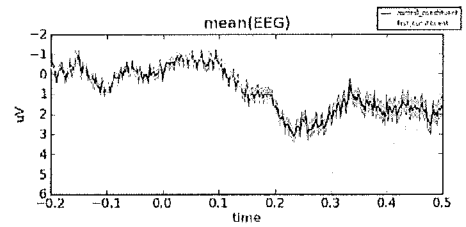

Figure 24: M250 PP Activation per Word Type

### 3.3.1 Outer cluster

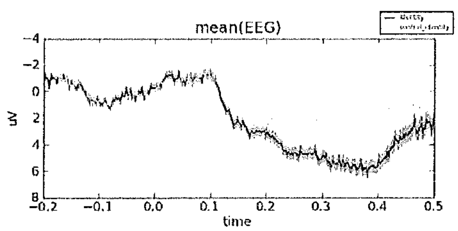
Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 16.20,\ p = .03]$. No other effect was significant.



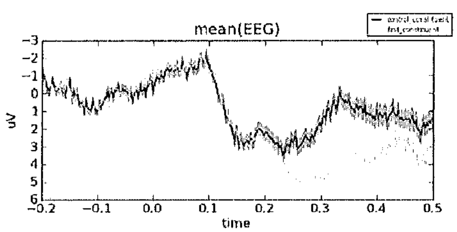

A significant priming was also found for the partial priming condition, $[F_1(1,4) = 122.36,\ p = .00]$. No other effect was significant.




### 3.3.2 Midlateral cluster



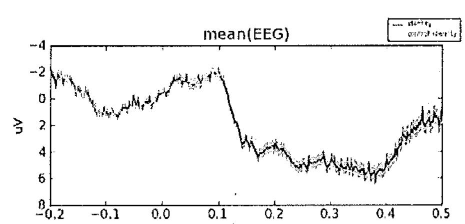

Analyses for repetition priming condition revealed a significant priming effect, $[F_1(1,4) = 14.37,\ p = .03]$.




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, $[F_1(1,4) = 16.72,\ p = .03]$.



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 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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Prof. Michael S. Landy

Teon Brooks
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New York University

October 5, 2012

Dear Teon,

I'm sending you this letter to summarize the results of your advisory committee meeting from earlier this semester and anything else that came up at the faculty meeting at which we reviewed student progress.

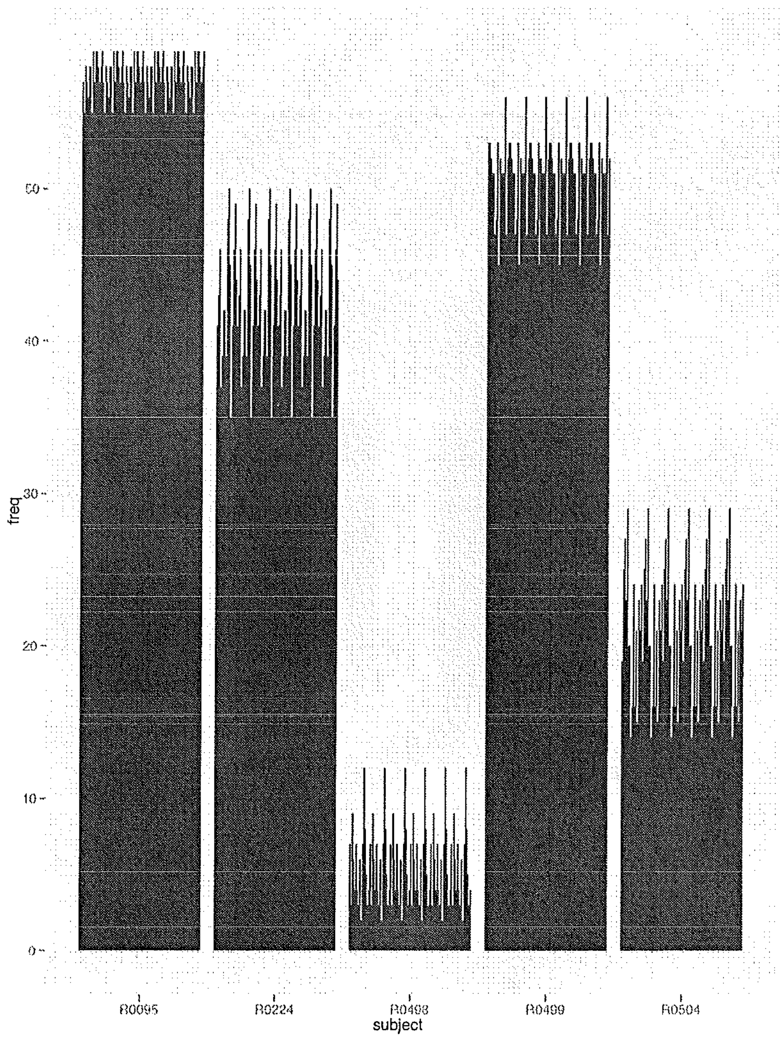
Your progress this last year has been good. Your coursework included difficulty with Math Tools, but has otherwise been okay. It has been suggested that Regression and fMRI Lab will be good choices for your quantitative courses. That looks like that will be all or most of what you need after the current semester in terms of courses. Your research has gone well, and your committee gave your 1st-year paper a "B+." The main concern expressed by your committee was that you treat deadlines more seriously.

There is one point that we wish to emphasize to *all* of our students. There are very few forums in with the C&P Program meets as a whole to learn about each other's areas of research, and likewise for the Department as a whole. Thus, I would like to reiterate that all C&P graduate students are expected to attend all C&P Area seminars, including the Q&A afterward, and any Brown Bags and Departmental Colloquia that occur.

Good luck in your continued studies.

Sincerely,

Michael S. Landy
Coordinator, Program in Cognition & Perception



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