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The Effect of a Go/No-Go Naming Task on fMRI BOLD Activation in the Ventral Visual Processing Stream

by

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Abstract

Background: The go/no-go naming behavioural paradigm has furthered our understanding of basic reading processes, however, its neural representations remain largely unknown. Pilot data using this task (with nonwords) produced fMRI ventral stream activation for regular and exception words. This activation may be due to subjects' strategic reliance on phonology or orthography. Accordingly, using pseudohomophones in a go/no-go naming task served to elucidate behavioural and neural activation associated with the evaluation of orthography. *Method*: Subjects (n=10) were instructed to name aloud letter string stimuli if they *spelt* a real word, during a go/no-go reading task with pseudohomophones. *Results*: Using pseudohomophones as a foil should have forced subjects to rely solely on orthography, resulting in ventral stream activation. Conversely, activation was constrained primarily to the dorsolateral prefrontal cortex. *Discussion*: Manipulation of the experiment's instructions forced participants to rely on higher-level cognitive functions to complete the go/no-go paradigm.

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List of Abbreviations

A and B: A pair of stimulus types

AFNI: Analysis of Functional NeuroImages

BA: Brodmann Area

BOLD: Blood-oxygen-level dependence

C: Stimulus types

DRC: Dual Route Cascaded Model

DLPFC: Dorsolateral prefrontal cortex

EPI: Echo-planar image

Eqn: Equation

EXC: Exception word

fMRI: Functional magnetic resonance imaging

FWHM: Full width at half maximum

IRF: Impulse response function

M_{int}: Intersection map

M_{uni}: Unique map

MRI: Magnetic resonance imaging

mm: Millimetres

ms: Milliseconds

NW: Nonword

p: Voxel coordinate that was created

p: Probability

PDP: Parallel Distributed Processing

PH: Pseudohomophone

REG: Regular word

ROI: Region of interest

s: Seconds

SNR: Signal to noise ratio

SSE_F: Error sum of squares fitting full model

SSE_R: Error sum of squares fitting reduced model

T_E: Echo time

T_R: Repetition time

V: Normalized volume

μL: micro litres

The Effect of a Go/No-Go Naming Task on fMRI BOLD Activation in the Ventral Visual Processing Stream

1. Introduction

The go/no-go naming behavioural paradigm has furthered our understanding of basic reading processes, however, its neural representations remain largely unknown. Accordingly, the current study examined the effects of using pseudohomophones in a go/no-go naming task to elucidate behavioural and neural activation associated with the evaluation of orthography.

Among the various means of evaluating theories of cognition, computational modeling has developed into one of the most prominent. Various computational models of visual word recognition and reading aloud have been hypothesized over the last few decades. Four models assume a distinct process for computing phonology from print, they are: the parallel distributed processing (PDP) model (Plaut, McClelland, Seidenberg, & Patterson, 1996), the connectionist dual process (CDP) model (Zorzi, Houghton, & Butterworth, 1998), the LEX model (Kwantes & Mewhort, 1999), and the dual route cascaded (DRC) model (Colheart, Rastle, Perry, Langdon, & Ziegler, 2001). Each model presents different mechanisms for converting orthography to phonology. The PDP and the CDP models solely represent parallel processing, whereas the LEX model is a purely serial based processing model that does not contain a mechanism for converting orthography to phonology. Conversely, the DRC model is the only model that provides a nonlexical, serial processing route which encompasses specific rules for converting orthography to phonology (Roberts et al., 2003). At present in the literature, the DRC model has also provided the most robust and consistent findings that parallel human behaviour (e.g., the frequency x regularity interaction), than any other computational model (Colheart & Rastle, 1994; Rastle & Colheart, 1998, 1999a, 1999b; Rapcsak, Henry, Teague, Carnahan, & Beeson, 2007; Blazely, Coltheart, & Casey, 2005; Levy, Pernet, Treserras, Boulanouar, Aubry, Demonet, & Celsis, 2009; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and will therefore be considered in the interpretation of the current study.

The dual-route model of reading, in which printed words are processed along two interacting processing streams, has been influential in that it successfully accounts for many of the basic phenomena observed in skilled adult readers, such as: word frequency effects (i.e. where high-frequency words are read faster than low-frequency words), regularity effects (i.e. where regular words are read faster than non-regular words), lexicality effects (i.e. where words are read faster than non-words), and many other well supported basic effects observed in studies of lexical decision and reading aloud (Coltheart, et al., 2001; Roberts, Rastle, Coltheart, & Besner, 2003; Rastle, Harrington, Coltheart, & Palethorpe, 2000; Rastle & Coltheart, 1999a; 1999b; 2000; Coltheart & Rastle, 1994; Coltheart, Curtis, Atkins, & Haller, 1993; Paap & Noel, 1991; Forster & Chambers, 1973). The dual-route model assumes that reading aloud begins with activation of the visual features of a letter string and results in the activation of the letter string at a phonemic level. This occurs through activation and inhibition of units along different levels of the two routes, which work in parallel as readers engage in basic reading. The direct route involves visual recognition of familiar whole-word letter combinations that provides access to whole-word semantic and phonological representations; this route makes use of sight vocabulary. The indirect route actively processes unfamiliar letter combinations by translating the sub-word components into their phonological elements and assembles them into whole-words by sounding them out, also providing access to semantic information; this route uses phonetic decoding.

The dual-route model of reading provides a framework for understanding the cortical representations of language processing. This model parallels the neuroanatomical processing systems of dual route theories for cortical activation which separates activation into two general processing routes: the ventral and dorsal visual processing streams. Currently, much imaging research has supported the existence of brain regions predominantly involved in one of the two routes during word reading tasks (Hickok & Poeppel, 2000, 2004, 2007; Jobard, Crivello, & Tzourio-Mazoyer, 2003; Price, 2010; Borowsky, Cummine, Owen, Friesen, Shih, & Sarty, 2006; Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008; Levy, Pernet, Treserras, Boulanouar, Aubry, De Monet, & Celsis, 2009; Fiebach, Friederici, Muller, & von Cramon, 2002; Richardson, & Price, 2009; Haist, Song, Wild, Faber, Popp, & Morris, 2001).

The ventral stream, which extends ventro-laterally toward the inferior posterior temporal cortex, is involved in mapping sound onto meaning (i.e. lexicosemantic route). This stream is coupled with the direct route of word processing, which allows for an association between familiar visual whole-words (e.g., exception words, *pint*) and their meanings (Hickok & Poeppel, 2004). The dorsal stream, which involves regions of the posterior Sylvian fissure at the parietal-temporal boundary up into the frontal lobe, maps sound from articulatory-based representations (i.e. graphophonological) (Hickok & Poeppel, 2004). This stream is linked to the indirect route of word processing, or sub-word reading system, where unfamiliar visual words (e.g., nonwords, *bint*) are transformed into their auditory counterparts and are sounded out prior to speech, producing neural activation in the dorsal visual processing stream (Jobard et al., 2003).

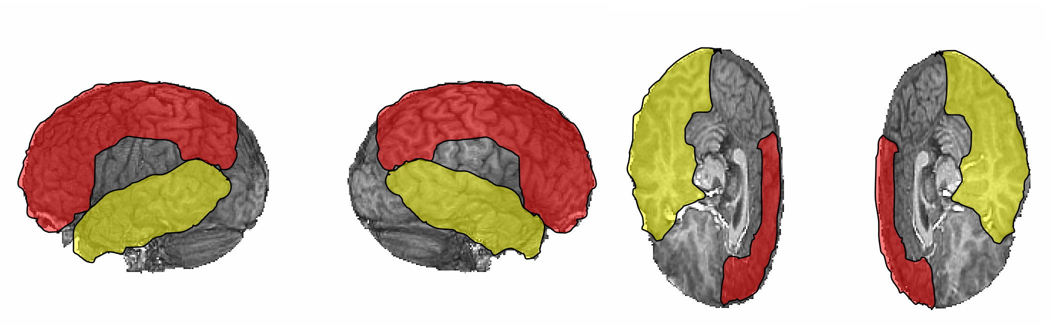

Figure 1. Dorsal (red) and Ventral (yellow) Processing Streams.

Four types of stimuli are valuable in the evaluation of the processing routes. The direct processing route is assessed using exception words (EXC) and the indirect processing route is evaluated using nonwords (NW) and pseudohomophones (PH). The fourth type of stimuli, regular words (REG), can be processed using either route. Exception words are letter strings that have atypical spelling-to-sound mappings (e.g., pint) and can only be named correctly via their whole word representation. Accuracy in naming exception words is taken as a measurement of the direct processing route. Nonwords and pseudohomophones on the other hand are stimuli used as measures of the indirect route. Such stimuli must be sounded out, by mapping graphemes onto phonemes, given that they are completely unfamiliar. Either route can produce a correct response for regular words; while such stimuli have typical letter to sound correspondences, they are often assumed to be read via a direct route when they are high in frequency (Cummine, Sarty, & Borowsky, 2010; Graves, Desai, Humphries, Seidenberg, & Binder, 2010; Jobard, et al., 2003).

Evidence for the dual route model of basic reading has been supported by basic naming tasks (i.e., name aloud the letter string) and lexical decision tasks (i.e., making a word/nonword judgment) (Cummine, et al., 2010; Borowsky, Esopenko, & Cummine, 2007; Cummine, Borowsky,Vakorin, Bird, & Sarty, 2008; Borowsky, et al., 2006; Coltheart et al., 2001; Cohen, et al., 2008; Hino & Lupker, 2000; McClelland, & Rumelhart, 1981). More recently, the go/no-go naming task has been used to further our understanding of the direct and indirect reading routes. The go/no-go naming task requires an overt response only to select stimuli. It is similar to both the basic naming and lexical decision tasks in that it requires overt output which relies on phonological processing, and it forces lexical selection given that participants must first identify if the letters spell a word, respectively. While past studies have shown the benefit of using go/no-go naming tasks to elucidate the roles of the direct and indirect routes behaviourally (Hino & Lupker, 2000), limited work has been conducted to examine the functional involvement of dorsal (e.g., indirect) and ventral (e.g., direct) routes for the same go/no-go task (Frost, Mencl, Sandak, Moore, Rueckl, Katz, Fulbright, & Pugh, 2005). For example, behavioural research using the go/no-go task produces similar reaction time results when compared to a basic naming task (e.g., overtly name aloud all stimuli presented). However, given the requirement of lexical selection prior to overt speech in the go/no-go naming task, it is reasonable to assume that this task would serve to invoke the direct route and produce activation within the ventral processing stream.

In a previous experiment, Cummine, Sarty, and Borowsky (2010) studied fMRI activation in the ventral and dorsal processing streams when high and low frequency exception words and regular words were evaluated during a basic naming task. They found the supplementary motor association area to be an important region involved in the Frequency x Regularity interaction in word naming, in addition to behavioural results consistent with preceding studies (Hino & Lupker, 2000) (i.e., the basic naming task produced a Frequency X Regularity interaction; low frequency EXCs (e.g., sieve) are named significantly slower than low frequency REGs. In contrast, higher frequency EXCs and REGs do not demonstrate the same magnitude of effect.). This study was modified using a go/no-go task, where pilot data was collected and indicated that the go/no-go task (with nonwords) produced activation that was primarily constrained to the ventral stream for regular words (e.g., *hin*t) and exception words (e.g., *pint*). Activation was dispersed along the ventral and dorsal processing streams for both shared and unique maps in the basic naming task. One could not deduce from the preliminary data, however, whether or not this ventral stream activation was due to subjects' strategic reliance on phonology or orthography, because either strategy would aid in selection of correct responses (i.e., the decision to not name aloud nonwords can be based on orthography, given their unfamiliar spelling patterns, or phonology, given their unfamiliar phonological representations). Further to this, the significant Frequency X Regularity interaction that exists in behavioural data involving go/no-go with nonwords suggests that indeed participants are using phonological and orthographic information to make their responses. Thus, in order to refine the effects of go/no-go naming on ventral stream activation, a go/no-go naming task with pseudohomophones (e.g., *pynt)*, which forced participants to rely solely on orthography to successfully complete the task, was proposed. Additionally, determining if participants were effectively relying on orthography could be monitored by attending to their responses. Should participants have allowed phonology to play a role in the lexical decision making process for this task, they would have named aloud the pseudohomophones. These stimuli are nonwords that sound like real words when they are produced, which would not be named aloud should the participants consider only the spelling of the stimuli.

The present study sought to further elucidate the behavioural consequences and the related brain regions involved in basic reading. It was expected that the use of pseudohomophones as a foil in a go/no-go task would force subjects to rely solely on orthography, resulting in localized activation in the ventral processing stream. This hypothesis was based on the extensive behavioural and neuroanatomical support for a dual route model of basic reading. Furthermore, the go/no-go task had been used to support the behavioural dual route model, yet how this task was reflected from a neuroanatomical perspective remained unclear. Therefore, using a go/no-go task with pseudohomophones in parallel behavioural and functional studies served to refine the understanding of underlying direct-ventral and indirect-dorsal routes.

Experiment 1: Behavioural

2.0 Overview of Experiment 1

A behavioural experiment was first run using a go/no-go naming task to investigate the effect of pseudohomophone foils on sub-lexical processing and to evaluate the subsequent Frequency X Regularity interaction. In order to test for the Frequency X Regularity interaction, behavioural reaction time and accuracy during a go/no-go naming reading task with pseudohomophones was collected. Subjects were instructed to name aloud words only if they *spelt* a real word. It was hypothesized that the interaction would be absent, therefore accrediting the go-no/go with pseudohomophones task as being sufficient as a modulator. Using pseudohomophones in the go/no-go naming task would minimize information provided from sub-lexical processing and maximize information provided from the lexical system.

2.1 <u>Experiment 1. Behavioural: Go/No-Go Naming with Pseudohomophones</u>

2.2 *Participants*

A total of 37 undergraduate students from the University of Alberta took part in this study for course credit. Inclusion criteria consisted of normal or corrected normal vision, and English as a first language. The subjects' consent was obtained, and the experiment was performed in compliance with and approval by the University of Alberta Health Research Ethics Board.

2.3 *Stimuli*

A total of 77 stimuli were presented in a mixed sequence (27 regular words, 27 exception words and 23 pseudohomophones). Stimuli were matched for onset phoneme, length, bigram sum, frequency, phonological neighbourhood, and orthographic neighbourhood.

2.4 *Materials*

Stimuli were presented on a computer monitor using EPrime software (Psychology Software Tools, Inc., http://www.pstnet.com). Voice onset was coded via a microphone and the experimenter used a button response to code accuracy on each trial.

2.5 *Procedure*

Participants were tested individually in a normally lit room. Letter strings were presented randomly to the centre of a computer screen. After giving written consent, participants were instructed to read aloud each letter string that *spelt a real word* as quickly and accurately as possible (totaling 54 of the 77 presented stimuli). Participants were given 1800 ms to name each of the stimuli.

2.6 *Results*

A 2 (Regularity) x 2 (Frequency) repeated measures ANOVA was conducted. Only correct responses were included in the subsequent analyses (see Table 1); trials in which reaction times were <250ms, >1800ms or where a voice key error was made were removed, as corresponding to previous literature (Hino & Lupker, 1998; 2000). The mean accuracy rates were as follows: regular words= 96%, exception words = 93%, pseudohomophones = 89%.

By-Subject Analyses. There was a significant Frequency effect, $F(1, 35) = 35.03$, $p<.001$, where high frequency words (Mean = 616.3ms ± 15.8ms) were responded to faster than low frequency words (Mean = 693.6 ms± 22.0ms). There was no significant Regularity effect, $F(1, 35) = 2.33$, $p>.05$, (regular words Mean = 646.6 ms ± 18.616ms and exception words Mean = 663.3 ms ± 19.1ms). There was no significant interaction between Frequency and Regularity, $F(1, 35) =0.04$, $p>.05$ (see Figure 1). The Regularity effect was not significantly greater for low frequency words, with a difference of 15.2 ms between regular words and exception words, in comparison to high frequency words, which showed a difference of 18.2ms. Response times to high frequency regular words (Mean = 607.1 ms ± 16.6ms) were not significantly faster than high frequency exception words (Mean = 625.4 ms ± 16.4ms), $t(35) = 1.904$, $p>.05$, and low frequency regular words (Mean = 686.0 ms ± 23.7ms) were not significantly faster than low frequency exception words (Mean = 701.2 ms ± 23.1ms) $t(35) = .956$, $p>.05$.

By-Item Analyses. The item analyses show the same pattern of results as the by-subject analyses. There was a significant Frequency effect, $F(1, 12) = 17.1$, $p=.001$, no Regularity effect, $F(1, 12) = 2.7$, $p>.05$, and importantly, there was no interaction between Frequency and Regularity, $F(1, 12) = 0.6$, $p>.05$. Response times to high frequency regular words (Mean = 608.0 ms ± 4.8ms) were not significantly faster than high frequency exception words (Mean = 625.6 ms ± 12.7ms), $t(13) = 1.253$, $p>.05$, and low frequency regular words (Mean = 681.1 ms ± 12.8ms) were not significantly faster than low frequency exception words (Mean = 709.1 ms ± 29.8ms), $t(12) = 1.272$, $p>.05$.

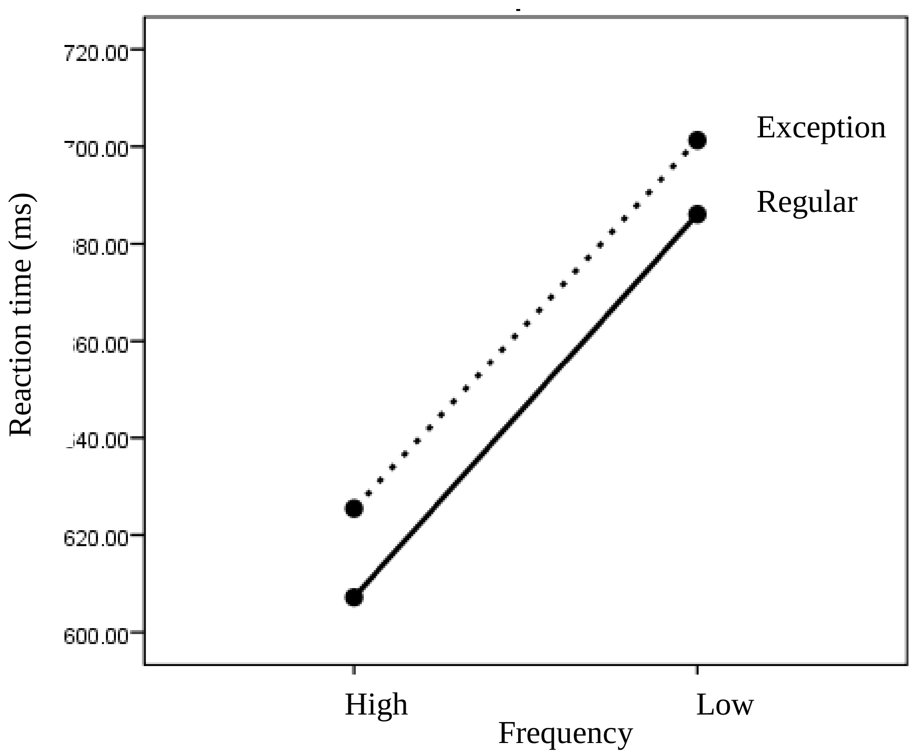

Figure 1. Go/No-Go Naming with Pseudohomophones: Significant Frequency (high vs. low) effect on behavioural reaction time.

Go No-Go with Pseudohomophones

	Exception Words	*Regular Words*
High Frequency	625.45 (16.47)	607.19 (16.68)
Low Frequency	701.28 (23.18)	686.07 (23.75)

Table 1. Mean response times (Std. Error) for stimuli in Experiment 1.

2.7 Summary Experiment 1

The results of this experiment demonstrate that the typical Frequency X Regularity interaction seen in basic naming tasks and the go/no-go with nonwords task is eliminated in a go/no-go task with pseudohomophones foils. In conjunction with a non-significant regularity effect, evidence is provided for the modulation of sub-lexical information using a go/no-go task with pseudohomophones. Specifically, using pseudohomophones in the go/no-go naming task minimized information provided from sub-lexical processing and maximized information provided from the lexical system. For this reason Experiment 2, the functional component of this study, was carried out to test the initial hypothesis (i.e. predominantly ventral stream activation during the go/no-go functional task with pseudohomophones).

Experiment 2: Functional

3.0 Overview of Experiment 2

The current study investigated functional Magnetic Resonance Imaging (fMRI) activation during a go/no-go naming reading task with pseudohomophones. Participants (N=10) were instructed to name aloud words only if they *spelt* a real word in Experiment 2A, and to name aloud words only if they *did not* spell a real word in Experiment 2B. Using AFNI (Cox, 1996), activation for each stimuli type was separated out. It was expected that activation would be localized in the ventral processing stream for Experiment 2A, because the use of pseudohomophones as a foil in the go/no-go task would have forced subjects to rely solely on orthography. Following the results from Experiment 1, which indicated that pseudohomophones could be used in a go/no-go naming task to maximize information provided from the lexical system (direct route), and minimize information from the sub-lexical system (indirect route), lead to the hypothesis of anticipating primarily ventral stream (direct route) activation in a functional go/no-go task with pseudohomophones.

Two fMRI go/no-go naming paradigms were conducted: both event related studies included regular words (REGs), exception words (EXCs) and pseudohomophones (PHs). In Experiment 2A, participants were asked to name aloud all of the REGs and EXCs. In Experiment 2B, they named aloud only the PHs. The Experiment 2B was included as a 'control' task for decision making processing. It allowed for the interpretation of Experiment 2A in the context of naming aloud REGs and EXCs and demonstrated that cortical activation found was not a result of the decision making processing (word/non-word). If the activation was a result of the decision making process, then the activation for REGs and EXCs would be consistent across both Experiment 2A and 2B given that the word/nonword decision had to be made with every stimulus across both studies (only motor cortex would change given that they are only naming REGs and EXCs in the first experiment). Experiment 2 allowed for an evaluation of activation along the ventral and dorsal visual processing streams as a function of the type of stimuli named aloud. Activation maps were created from the imaging data for both unique and shared activation between the REGs and EXCs for each of the naming experiments and stimuli types.

3.1 <u>Experiment 2A. Functional Data: Go/No-Go REG and EXC Word Naming</u>

3.2 *Participants*

A total of 10 female graduate students from the University of Alberta took part in this study. All subjects were right handed and ranged in age from 22 to 26 years old (mean age = 23). Inclusion criteria consisted of normal or corrected normal vision, and English as a first language. The subjects' consent was obtained, and the experiment was performed in compliance with and approval by the University of Alberta Health Research Ethics Board.

3.3 *Stimuli*

A total of 55 different stimuli per naming experiment were presented in a mixed sequence (14 regular words, 14 exception words and 27 pseudohomophones). For the first experiment, participants read aloud the REGs and EXCs, yielding a total of 28 ‘go’ trials. For the second naming experiment, a set of 55 stimuli different from the first experiment were presented and participants were instructed to read aloud the letter strings that *did not spell* real words (i.e. the PHs), yielding 27 ‘go’ trials. All of the stimuli from the two experiments were matched on factors including onset phoneme, length, and word frequency.

3.4 Procedure and Apparatus

After giving written consent, participants were familiarized with the MRI environment and were debriefed on the procedure. For the Experiment 2A, participants were instructed to read aloud each letter string that spelt a real word as quickly and accurately as possible. In the case of Experiment 2A, participants read aloud all REGs and EXCs, 28 of the presented stimuli. In Experiment 2B, subjects were instructed to read aloud all words that did not spell real words, which constituted reading all of the PHs, a total of 27 of the presented stimuli. The experiments and stimuli were counterbalanced to avoid any confounding effects, with half of the participants starting with naming REGs and EXCs and the other half starting with naming PHs. All participants took part in both Experiment 2A and 2B. Participants responded vocally during a regular, periodic gap in the image acquisition that followed the offset of each volume of image acquisition (Borowsky, et al., 2006; Borowsky, Loehr, Friesen, Kraushaar, Kingstone, & Sarty, 2005). That is, a letter string was presented at the offset of an image acquisition, during a gap of 1850 ms, providing a silent window for participants to name aloud the letter string. For each experiment, letter strings were randomly chosen from a list, without repetition, and stimuli were presented one at a time to the bottom-center portion of the projection screen visible to the participant.

All imaging was conducted using a 1.5T Siemens Symphony MRI. For both experiments, 60 data volumes of 30-slice, axial single-shot echo-planar images (EPIs) were obtained. The time required to obtain each image volume was the repetition time T_R= 3700ms, with a 1850 ms gap of no image acquisition in each T_R, gradient echo time was T_E= 55 ms, and a 64 x 64 acquisition matrix was used with a 256 x 256 reconstruction matrix. The EPI slice thickness was 4 mm, with zero separation between slices. The first 5 image volumes were used to achieve a steady state of image contrast and were discarded prior to analysis. A deconvolution of the remaining volumes was used to compute the impulse response function (IRF) for each stimulus type, using 7 measurements of the IRF for each presented stimulus (i.e., a maxlag of 7). The total naming experiment scan time for each experiment was 7:09 minutes.

A computer running EPrime software (Psychology Software Tools, Inc., http://www.pstnet.com) was used to trigger each image acquisition in synchrony with the presentation of visual stimuli. Responses were made during the 1850 ms gaps in image acquisition. The stimuli were presented using a data projector connected to the EPrime computer and a screen that was visible to the participant through a mirror attached to the head coil. In order to capture a full-cortex volume of images for each participant, the inferior-most portion of the cerebellum was dropped. Prior to the naming experiments, T_1-weighted high-resolution anatomical images (T_R = 1800 ms, T_E = 4.38 ms, 256 x 256 acquisition and reconstruction matrix) were acquired in axial and sagittal orientations for the purpose of overlaying the computed activation maps. The position and thickness of the T_1 axial images matched the EPIs to reduce the ambiguity in identifying the anatomical locations of the brain activations.

3.5 Experiment 2B. Functional Data: Go/No-Go PH Naming

3.6 *Participants*

The participants were identical to those who participated in Experiment 2A. Inclusion criteria and ethical approval were identical to Experiment 2A.

3.7 *Stimuli*

A set of 55 stimuli different from Experiment 2A were presented the same mixed sequence (14 regular words, 14 exception words and 27 pseudohomophones). Participants were instructed to read aloud the letter strings that *did not spell* real words (i.e. the PHs), yielding 27 ‘go’ trials. All of the stimuli were matched on factors including onset phoneme, length, and word frequency.

3.8 *Procedure and Apparatus*

The procedure and apparatus were identical to those in Experiment 2A. Participants were given instructions to read aloud each letter string that *did not* spell a real word as quickly and accurately as possible. All of the experiments and stimuli were counterbalanced to avoid any confounding effects.

3.9 *Analyses*

Experiments 2A and 2B were analyzed using an event-related approach. For each participant, two stimulus indicator-time-series of ones, representing the stimulus of interest, and zeros were created that corresponded to the presentation order of the 14 regular words and 14 exception words (Experiment 2A), and the 27 pseudohomophones (Experiment 2B). For example, in the first stimulus indicator-time-series, all exception words were coded as 1 and all other stimuli were coded as 0. The length of the stimulus indicator-time-series corresponded to the number of image volumes collected for each experiment. The impulse response functions (IRFs) for each stimulus type can then be estimated, using 3dDeconvolve, from the measured fMRI signal data by convolving the estimate with the stimulus time series (Ward, 2006) and minimizing the difference between the resulting response and the measured response. 3dDeconvolve produces an estimate of the IRF at several time points for each stimulus type (i.e. maxLag = 7), and a goodness of fit F^*-statistic and its significance value, indicating the fit of the estimated IRF to the original fMRI data for each voxel. The partial *F**-statistic is calculated as follows:

$$F^*\text{-statistic} = [(SSE_R - SSE_F) / (df_R - df_F)]/[SSE_F/df_F]$$

Where SSE_F is the error sum of squares from fitting a full model with all parameters included (all stimuli types) with the degrees of freedom of the reduced and full model included. The SSE_R is the error sum of squares after fitting a reduced model without those parameters corresponding to the stimulus in question using the degrees of freedom of the full model. Only those voxels passing a defined *F*-threshold at 2.18, which corresponds to $p<.05$, are included in the following analyses.

3.10 Unique versus Shared Activation Maps

Unique and shared activation maps were computed as follows. Let C denote one of the stimulus types: regular words or exception words. For each stimulus-type, C, and for each subject, two maps were computed. A threshold map $F_C(p)$ of F-values (θ)and a visibility, or intensity map, $V_C(p)$ (IRF maximum amplitude), where p is a voxel coordinate that was created. The F-value represents the ratio of the data variance to the variance remaining after the IRF model fit. An F-value of 2.18 ($p \leq 0.05$) was used for both experiments to define an active voxel. The corresponding activation map for C was defined as $M_C(p) = K_{C,\theta}(p)$ $V_C(p)$ where $K_{C,\theta}(p) = 1$ if $F_C(p) \geq \theta$ and zero otherwise where $\theta = 2.18$ is the threshold above which a voxel was considered to be activated. Now, let A and B denote a pair of stimulus types (e.g., regular and exception words). Unique maps (M_{uni}) and intersection maps (M_{int}) were defined for paired stimuli A and B for each subject according to:

$$M_{uni}(p) = [K_{A,\theta}(p)\, V_A(p) - K_{B,\theta}(p)\, V_B(p)]\,[1 - K_{A,\theta}(p)\, K_{B,\theta}(p)] \tag{1}$$

$$M_{int}(p) = K_{A,\theta}(p)\, K_{B,\theta}(p)\, (V_A(p) + V_B(p))/2. \tag{2}$$

The unique map represents a difference $(A \cup B)/(A \cap B)$ and shows task subtraction for activations that are not common to conditions A and B. In the representation of Eqn. (1), unique activation to A is represented as a positive intensity and unique activation to B is represented as a negative intensity. The intersection map of Eqn. (2) is a map of average A and B intensities and represents an intersection $A \cap B$ showing activation shared to both conditions A and B. For each Experiment 2A and Experiment 2B, activation maps were calculated for regular words and exception words. The unique and intersection maps, as computed for each participant, were averaged across the participants in each experiment to produce the final unique and intersection maps, as described next.

Using AFNI (Cox, 1996; Version 2006_06_30_1332), unique and intersection map voxels for each participant separated by 1.1 mm distance were clustered and clusters of volume less than 100 µL were clipped out. The data were then spatially blurred using an isotropic Gaussian blur with a full width at half maximum (FWHM) of 3.91 mm. This blurring reduces the anatomical differences between participants and reduces noise in the subsequent averaged maps. The averaging of maps across participants was done after a piecewise affine transformation of individual maps to the Talairach standardized brain atlas (Talairach & Tournoux, 1988). Visual inspection of the individual participant anatomical images did not reveal any structural abnormalities that would compromise the averaging of data in Talairach space. Mean activation maps in Talairach coordinates were determined voxel-wise for each map type along with the corresponding one sample *t* statistic for each voxel mean. The maps that follow show regions of activation containing voxels that surpass both the activation threshold at the individual level ($\theta \geq 2.18$, $p = 0.05$), and a one-tailed *t*-test against zero at the group level. Regions of activation on the resulting maps were deemed significant at $t(9)=1.833$, $p = 0.05$.

4. Results

Standardized anatomical brain maps are used to visualize the location and degree of activation by superimposing those areas that were above the threshold and statistically significant during the naming tasks on each brain. For each Experiment 2A and 2B, two different maps were created; a shared map, showing the areas of activation that were common when each type of stimuli was presented (i.e. REGs and EXCs) and a unique map, which shows the areas of activation that were exclusive to each type of stimuli during presentation (i.e. occurred only during presentation of the REGs and occurred only during presentation of the EXCs). The fMRI maps that follow are depicted with the left hemisphere on the left side of each pair of brain figures. Regions of interest (ROIs) are shown with arrows.

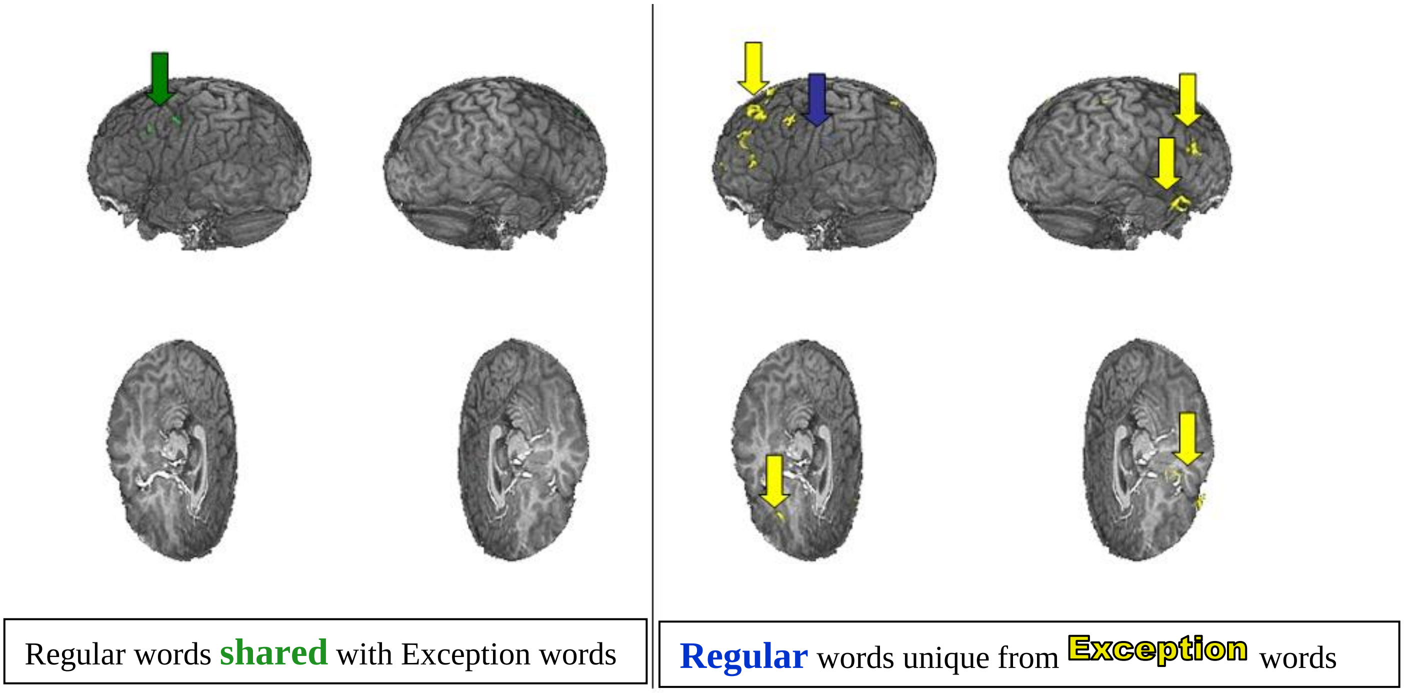

Figure 3A. **Shared** (left) map displaying activation for REG and EXC naming, Experiment 2A.

Figure 3B. Unique (right) map displaying activation for **REG** or **EXC** naming, Experiment 2A. The anatomical maps display right = right.

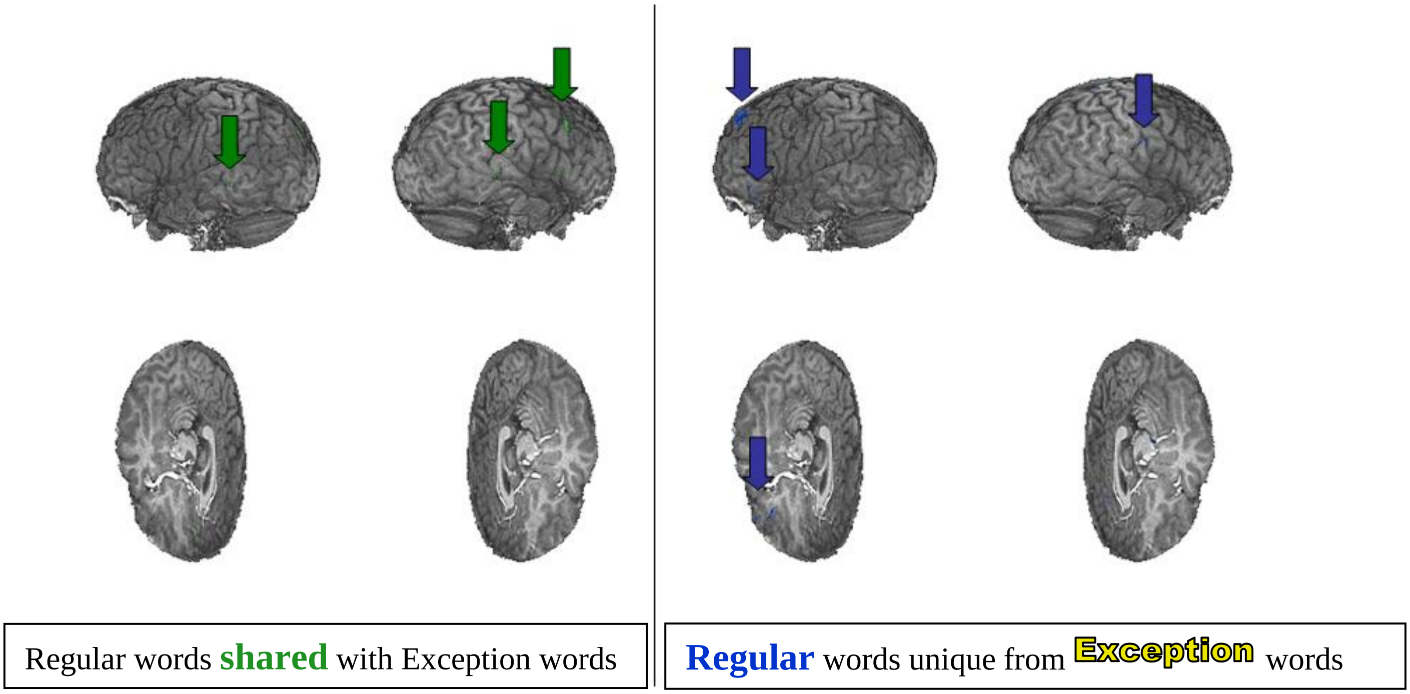

Figure 4A. **Shared** (left) map displaying activation for REG and EXC during PH naming, Experiment 2B.

Figure 4B. Unique (right) map displaying activation for **REG** or **EXC** during PH naming, Experiment 2B. The anatomical maps display right = right.

4.1 Shared Regions of Activation for REG and EXC Reading

As depicted in Figure 3A, the shared regions of activation from reading REGs and EXCs were localized to the motor and premotor cortex, which corresponded to Brodmann's area (BA) 4 and 6 (see Table 2).

4.2 Unique Regions of Activation for REG and EXC Reading

As depicted in Figure 3B, the unique activation from reading REGs primarily included minor activation in the left postcentral gyrus occurring in BA 1, 2, and 3. Unique activation patterns from reading EXCs primarily included the left superior frontal gyri (BA 8, 9, and 10), bilateral middle frontal gyri (BA 6, 9, 10, 46), and the right superior temporal gyrus (BA 22 and 38) (see Table 2).

4.3 Shared Regions of Activation for REG and EXC when Reading PHs

As depictured in Figure 4A, the shared regions of activation for REGs and EXCs during PH reading were localized to the right motor cortex, corresponding to BA 4 and bilateral posterior superior temporal region, most likely corresponding to BA 40, 41, and 42 (see Table 2).

4.4 Unique Regions of Activation for REG and EXC when Reading PHs

As depicted in Figure 4B, the unique activation from reading REGs included activation in the left superior frontal gyrus corresponding to BA 9. There were no significant unique activation patterns for EXCs during PH reading (see Table 2).

		Brodmann's Area	REG & EXC Naming x, y, z		PH Naming x, y, z	
			Left	Right	Left	Right
Shared Activation	Premotor Cortex	6 6	-49, 23, -36 -49, 23, -28	------- -------	------- -------	46, 25, -40 -------
	Posterior Superior Temporal Region	40, 41, 42	-------	-------	-65, -40, -2	66, -33, -9
Regular Words	Motor Cortex	4	-48, 4, -19	-------	-------	56, -11, -34
	Superior Frontal Gyrus	9	-------	-------	-14, 46, -44	-------
	Inferior Frontal Gyrus	47	-------	-------	-51, 33, 3	-------
Exception Words	Premotor Cortex	6	-47, 4, -21	-------	-------	-------
	Dorsolateral Prefrontal Cortex	9 46 46	-32, 27 -49 -47, 35, -18 -49, 34, -2	------- 47, 31, -23 -------	------- ------- -------	------- ------- -------
	Superior Frontal Gyrus	8	-46, 4, -5	-------	-------	-------
	Superior Temporal Gyus	22, 38	------	47, 19, 16	-------	-------

Table 2. Anatomical Area, Brodmann's Area, and Talairach Coordinates for representative regions of activation in ventral and dorsal visual processing streams for each experiment. The centre of the cluster is reported in x, y, z coordinates from Talairach and Tournoux (1988) atlas.

5. Discussion

The purpose of this study was to elucidate the neural activation patterns associated with the evaluation of forced lexical access in go/no-go naming experiments by manipulating the subjects' strategic reliance on orthography. Contrary to the initial hypothesis, unique activation during the reading of exception words was primarily focused to the dorsolateral prefrontal cortex

(DLPFC), with the highest intensity of activation in BA 8, 9, and 46. The dissociation between the initial hypothesis and the effects obtained in this experiment may be a result of one of several cognitive processes which have been linked to DLPFC activation and is supported by previous research. There was an expectation that both regular and exception words would be processed in the ventral processing stream because of the subjects' forced reliance on orthography and the corresponding behavioural findings in Experiment 1 (i.e., no Frequency x Regularity interaction and no Regularity effect). Conversely, it was found that by manipulating the task from the initial unpublished data, via instructing subjects to read aloud only the letter strings that *spelt* words, cognitive processes that were not solely reliant on orthographic information were evoked. This resulted in cortical activation that was localized to the superior and middle frontal gyri—BA 6, 8, 9, and 46. These results indicate that by manipulating the instructions of the experiment, the nature of the task changed and consequently participants relied on higher-level cognitive functions to complete the go/no-go naming task. It is also clear that these results are not solely due to a word/nonword decision making effect, because of the differing areas of activation present in Experiment 2A and Experiment 2B. Should the activation have been caused by a decision making process, both experiments would have presented similar regions of activation for EXC and REG stimuli. This, however, was not found; EXCs and REGs produced activation in bilateral superior temporal gyri when participants were naming PH stimuli. These regions are markedly different than the DLPFC that was active while participants were naming REGs and EXCs, therefore the regions of activation in Experiment 2A are likely due to the cognitive demands necessitated by the task, and not strictly due to a decision making effect.

Although the activation patterns reported in the present study differ from initial predictions, the findings can be understood given previous functional imaging experiments (Chan, Liu, Yip, Fox, Gao, & Tan, 2004), many of which implemented a go/no-go paradigm (Chikazoe, 2010; Garavan, Ross, & Stein, 1999; McNab, Leroux, Strand, Thorell, Bergman, & Klingberg, 2008; Simmonds, Pekar, & Mostofsky, 2008; Jonides, Badre, Curtis, Thompson-Schill, & Smith, 2002; Simmonds, Fotedar, Suskauer, Pekar, Denckla, & Mostofsky, 2007).

Performance of go/no-go tasks necessitates a vast array of cognitive components such as top-down control processes, working memory, stimulus-driven attention, and response inhibition—any of which may have influenced the go/no-go task (Chikazoe, 2010). Similarly, activation in the DLPFC has been implicated in several cognitive processes including: attentional control, memory, and lexico-semantic selection.

5.1 Attentional Control

Top-down control processes contribute to attention and can be regulated through task instructions, goal-directed behaviour, and domain knowledge (Mozer, Shettel, & Vecera, 2006). Functional imaging studies have demonstrated that variations in cognitive task demands influence neural activation. More specifically, functional data has shown that activation in the DLPFC has been associated with attentional control, representing and maintaining attentional demands of a task, as well as decision making, discrimination, computation, and reasoning (Morishima, Okuda, & Sakai, 2010; Talati, & Hirsch, 2005; Jonides, et al., 2002; Smith, & Jonides, 1999; Brass & von Cramon, 2004).

There also is evidence in the literature that shows DLPFC activation during go/no-go tasks requiring increased attention control. For example, Botvinick, Braver, Barch, Carter and Cohen (2001) found that when subjects were required to attend to certain types of stimuli in a go/no-go task but not to others, DLPFC activation (BA9/46) was associated with the stimuli that were attended to because of the increased cognitive control that was required. This same region was involved when participants made a go/no-go response while attending to unpredictive cues in functional paradigms that required cognitive control processes involved in allocating top-down attentional resources (Fassbender, Simoes-Franklin, Murphy, Hester, Meaney, Robertson, et al., 2006; Fassbender, Hester, Murphy, Foxe, Foxe, & Garavan, 2009). Similar results were found in functional studies that varied in task complexity. For example, in studies where complexity of the task was variable, the most complex tasks, those that required working memory and attentional control, involved DLPFC activation (BA9), but in simple tasks, those that did not tax the participants' attentional control, this same pattern of activation was not found (MacDonald, Cohen, Stenger, & Carter, 2000; Garavan, et al., 1999). Very similar frontal regions of activation (BA6/9/46) have also been found in lexical decision tasks where the difficulty of the task has increased as a result of using more complex stimuli, such as pseudohomophone foils (Edwards, Pexman, Goodyear, & Chambers, 2005).

In line with these previous reports, the DLPFC activation in the current work could be a result of increased attentional demands, where subjects required executive functions such as attentional control in order to process the complex task instructions and monitor their ongoing performance for the go/no-go task. This notion is supported from studies showing that the DLPFC is associated with cognitive control and top-down attentional control in go/no-go tasks (Chikazoe, 2010) and may explain the activation that was found in the mid-superior frontal gyri.

5.2 Memory

Activation of the DLPFC has been found to be an important area involved in memory demands (Chikazoe, 2010; Courtney, 2004; Nee, & Jonides, 2009; Curtis, & D'Esposito, 2003; Miller, & Cohen, 2001; Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; McNab, et al., 2008; Tsukiura, Fujii, Takahashi, Xiao, Inase, Iijima, Yamadori, & Okuda, 2001; Cohen, Perlstein, Braver, Nystrom, Noll, Jonides, & Smith, 1997; Feredoes, Tononi, & Postle, 2006). Working memory is a short-term system for storing and manipulating information required for higher cognitive functions. It is often divided into one executive system and two subsystems that store, maintain, or rehearse verbal and visuospatial information. Activation in the DLPFC is consistent with fMRI evidence that shows this area (BA9/46) is recruited during tasks that involve increased working memory load (Simmonds, et al., 2008). For example, DLPFC activation (BA9/46) was found when participants engaged in a go/no-go task which involved counting and keeping numbers in short term memory, but not during a simple go/no-go task where the participants' working memory was not taxed (Mostofsky, Schafer, Abrams, Goldberg, Flower, Boyce, et al., 2003).

Working memory and attention are often thought to be interrelated. It may be that subjects of the current experiment were drawing upon overlapping neural correlates of attention and memory while reading aloud the stimuli in the current experiment (Mayer, Bittner, Bledowski, Goebel, & Linden, 2007; Labar, Gitelman, Parrish, & Mesulam, 1999). For example, when an exception word was presented, the participant had to hold the phonological output code in their working memory, while they made lexical access. Since regular words are processed more readily, they do not tax the participant's working memory, hence the reduced activation in the DLPRC (BA9/46) for these stimuli. There was no increased activation in the ventral stream observed for these stimuli because they we're more effectively and readily being processed along the dorsal stream, along with all the other stimuli—they did not, however, require the memory support processes used by the exception words. Thus, the current activation may be from the interaction between the top-down attentional control of performance monitoring subjects' were utilizing as they made lexical-access and the orthographic information from the stimuli being held, accessed, and manipulated in the subjects' memory.

5.3 Lexico-Semantic Selection

It is widely agreed upon that the left frontal lobes play a key role in supporting the executive components of processing involved in semantic retrieval and search (Chan, et al., 2004; Price, 2010; Graves, et al., 2010; Binder, Desai, Graves, & Conant, 2009; Jeon, Lee, Kim, & Cho, 2009; Hugdahl, Lundervold, Ersland, Smievoll, Sundberg, Barndon, & Roscher, 1999). Cortical activation of the superior/middle frontal gyri (BA6/9/46) is known to be involved in lexical tasks (i.e., associated with the mental lexicon) (Chan, et al., 2004; Jeon, et al., 2009; Whitney, Weis, Krings, Huber, Grossman, & Kircher, 2009; Roskies, Fiez, Balota, Raichle, & Petersen, 2001; Mummery, Patterson, Hodges, & Price, 1998; Fletcher, Shallice, Frith, Frackowiak, & Dolan, 1996). The level of cortical activation observed is dependent upon specific components of semantic demands (Binder et al, 2009). It is difficult to compare activation across semantic retrieval tasks because it cannot always be completely attributable to semantic processing; it may be the result of different task demands (Binder et al., 2009). When the task requires making an orthographic decision and reading aloud stimuli after making a lexical decision, the main difference emphasized in the contrast of the different stimuli is the additional access to meaning of the word condition. The current study's findings are consistent with past imaging results that have found the mid-superior frontal areas (BA9/10/46) to be responsible for guiding goal-related search and selection in the lexicon, where semantically precise words engage a one-to-one mapping process from orthography to meaning and semantically ambiguous words require an increased demand in meaning manipulation and oblige a double check procedure to validate meaning against orthography (Chan et al., 2004). Correspondingly, Scott, Leff, and Wise (2003) found the left mid-superior frontal cortex to be important in lexical semantics decisions. Similar results (BA6/9/10/46) were found by Brunswick, McCrory, Price, Frith, and Frith

(1999), in a task involving processing of words and pseudowords, where implicit and explicit semantic decisions were made by participants. Also, word frequency has been correlated with lexical-semantics (Graves et al., 2010), and therefore semantic information in the frontal cortex was found to be more automatically accessed by high-frequency words (Chee, Hon, Caplan, Lee, & Goh, 2002), such as those presented in the current experiment. It has also been suggested that the left DLPFC may be a mediator between semantic knowledge stores and motor response systems by directing attention to task-relevant information needed for response formulation (Binder, McKiernan, Parsons, Westbury, Possing, Kaufman, & Buchanan, 2003), indicating that there may have been an overlap in subjects' lexical-semantic access and attentional control required in the current experiment.

The activation found in these experiments mirrors that found in the current go/no-go naming experiment. This would implicate that participants from the current study were invoking some sort of lexical check by accessing the semantics of the words and comparing it to the orthography of the word. When EXCs and REGs are closely matched to PHs in terms of orthographic and phonologic familiarity, as they were in the current experiment, subjects will not typically rely on these characteristics when making a lexical selection (Binder, et al., 2003). However, because of the task demands, subjects were forced to use the orthographic form and consequently also engaged in a lexical check by accessing semantics. This explanation is likely given the current data, seeing as EXCs, which are typically processed through whole-word identification in the direct stream, were presented in a demanding task which required participants to process the orthographic form of the words and conduct an extensive search and selection of lexical meanings, consistent with the left mid-superior frontal cortex activation.

5.4 Other Regions of Activation

The shared activation between REGs and EXCs in the left motor cortex (Figure 3A), while they were being read aloud, represents the motor response involved in naming the stimuli. This region is involved in executing and initiating speech movements, and effectively demonstrates the ‘go’ condition, wherein the subjects were vocalizing the correct stimuli as instructed. This is consistent with previous studies that have shown neuronal activation during speech production in the motor and premotor cortex (Price, 2010; Brown, Laird, Pfordresher, Thelen, Turkeltaub, & Liotti, 2009).

The unique activation of the REGs in the dorsal processing stream during naming of the PHs (Figure 4B) is consistent with the dual route model of word processing. Because REGs can be processed in both the dorsal and ventral processing streams, subjects may not have been able to entirely inhibit activation of these stimuli when processing PHs because they occurred in the same indirect sub-word processing path. Regular words provide some ambiguity in this task as participants were using the sub-word route to process the PHs and some of the REGs, which both provide sub-word information leading to increased likelihood of wanting to be read aloud, therefore demonstrating dorsal activation for some regular words. This shared route explains the activation of the regular words in the dorsal stream when subjects were instructed to name aloud the pseudohomophones.

The absence of unique exception word activation during the reading of pseudohomophones (Figure 4B) demonstrates that subjects were effectively using the ‘go’ task to process the pseudohomophones in the dorsal processing stream, and the ‘no-go’ decision to diminish to stop processing of the exception words. Because there was not any activation in the ventral processing stream, it can be concluded that subjects effectively ignored the EXCs, when instructed to read aloud the letter strings that did not spell words (i.e. the pseudohomophones).

In the shared regions of activation during the reading of PHs (Figure 4A), bilateral activation in the posterior superior temporal region was observed. This suggests that individuals were relying on a lexical-direct-ventral strategy to make word/non-word decisions about the REGs and EXCs (Cohen, et al., 2008). It is likely that participants used information from this region to stop processing of words along the ventral stream because if the stimulus appeared in the lexicon, then they would not name it. This notion is further supported by the unique maps which produced no activation for exception words and minimal activation for regular words.

5.5 Summary

In the preceding study, it was hypothesized that the use of pseudohomophones as a foil would result in localized activation in the ventral processing stream, given basic assumptions of direct and indirect processing systems (Hino, & Lupker, 2000; Saur, Kreher, Schnell, Kummerer, Kellmeyer, Vry, et.al, 2008; Edwards, et al., 2005; Hickok, & Poeppel, 2007; Jobard, et al., 2003; Coltheart et al., 2001). Instead, activation of regular words and exception words in the middle and superior frontal gyri (BA 6/9/10/46) was found. This difference can be attributed to the changed nature of the task, which required subjects to recruit higher-level cognitive functions as they completed the go/no-go task.

These results fit nicely with past findings that found dual-route processing is susceptible to changes in task design (Hickok, & Poeppel, 2007), and suggest that the forced lexical access based on orthography increased the complexity of this task, and therefore involved different areas of cortical involvement than were predicted. The results of the current study have helped to clarify the go/no-go naming task and its associated neural representations given increased cognitive demands. Establishing the neural representations of a go/no-go task that forced lexical selection prior to overt naming helped expand our understanding of the dorsal and ventral visual processing stream in basic reading processes by demonstrating that adding another lexical component to the task can recruit higher levels of cognitive processing, such as those associated with the superior and middle frontal gyri and their role in attentional control, memory and lexical semantics.

5.6 Limitations & Future Research

Despite the important information the current study has provided regarding the underpinnings of word processing, it did have some limitations. First, a small sample size was collected – thus, the lack of activation found in the ventral visual processing stream could be a result of power issues (i.e., not enough participants to detect activation in the ventral stream). A second limitation would be the lack of rest conditions sparsed throughout the experiment, which lead to increased noise. Although further investigation into the no-go trials indicated that these stimuli were successfully ignored and served as a ‘rest’ condition, replication of this study is needed to ensure that the results are consistent with a go/no-go task that includes adequate rest periods. Another limitation of this study is the absence of intermittent long rest intervals into the paradigm, which probably would have enhanced the ability to detect changes in regional brain activation associated with the ‘go’ responses.

Assuming that the predicted dual-route model framework is correct, further research must be done to specify the intricacies of the within-stream organization and processes, as was the aim of this current study. Future research must be done to explain how various functional paradigms can be manipulated through task design, cognitive demands and complexity level to expose the effect these play on underlying functional activation in associated processing streams. Moreover, a task that places less cognitive demand on subjects (than the presented study), could be conducted in order to clarify the nature of the ventral visual processing stream in basic reading processes. Such a task that would have a lower probability of activating the dorsolateral prefrontal cortex and its associated higher-level processes may involve a go/no-go task with both pseudohomophones and nonwords (i.e. words that do not have orthographical or phonetic representations in a mental lexicon, e.g. bint). Pseudohomophones, such as those used in the current study, have been demonstrated to provide slower lexical decision responses and are more susceptible to errors than are nonwords

(Borowsky, Owen, & Masson, 2002; Vanhoy & Van Orden, 2001; Simos, Breier, Fletcher, Foorman, Castillo, & Papanicolaou, 2002; Pexman, & Lupker, 1999; Goswami, Ziegler, Dalton, & Schneider, 2001; Seidenberg, MacDonald, & Plaut, 1996). Comparatively, the use of nonwords, especially when presented in a mixed-list format, may reduce the higher level cognitive functions required for the task, because subjects would be less inclined to verify the pseudohomophones' phonological-lexical or semantic representation when presented with nonwords (Borowsky, et al., 2002; Chee, Venkatraman, Westphal, & Siong, 2003). These changes in task design may effectively demonstrate an evaluation of the ventral processing stream.

Additionally, a replication of this study is warranted with the use of an increased number of stimuli. This would provide a broader range of high and low frequency words, which may impact lexical access. Lower frequency words will have less semantic access and therefore a different pattern of activation may be observed with a more diverse and comprehensive set of stimuli. Further research exploring the go/no-go paradigm would provide a more detailed account of the relationship between the ventral and dorsal visual processing streams relative to varying reading tasks. Further research is needed to evaluate the shared and unique brain regions involved in processing whole-word versus sub-word stimuli in order to better understand these processes.

5.7 Clinical Implications

The go/no-go task is a unique paradigm, whose usefulness extends beyond the evaluation of basic reading processes. Specifically, the go/no-go task inherently measures an individual's ability to selectively process certain stimuli, while ignoring others. Manipulating the nature of the foils allows researchers to investigate interference effects and/or strategy choice. The results of this study have important clinical implications regarding the understanding of basic reading processes. The current study gives evidence that functional tasks that are complex may recruit executive functions which may affect word processing. Overall, our findings are important for understanding theories of word recognition and how the dorsal and ventral processing streams are implicated and manifest changes depending on task demands and manipulation of varying stimuli.

6. Conclusion

The results from the presented go/no-go naming experiments provide information about the relationship between behavioural results, task design and functional cortical activation. Accordingly, we must be prudent when linking these complexities to form hypotheses. Researchers interested in understanding the role of specific brain regions during reading and language tasks must consider how manipulation of the tasks' instructions will influence the resulting areas of brain activation. Additionally, hypotheses regarding regions of cortical activation based on behavioural data alone must be verified through functional paradigms, seeing as predictions may fail to include previously unknown outlying influences.

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Figure Captions

Figure 1. Dorsal (red) and Ventral (yellow) Processing Streams.

Figure 2. Go/No-Go Naming with Pseudohomophones: Significant Frequency (high vs. low) effect on behavioural reaction time.

Figure 3A. **Shared** (top) map displaying activation for REG and EXC naming.

Figure 3B. Unique (bottom) map displaying activation for **REG** or **EXC** naming. The anatomical maps display right = right.

Figure 4A. **Shared** (top) map displaying activation for REGs and EXCs during PH naming.

Figure 4B. Unique (bottom) map displaying activation for **REG** or **EXC** during PH naming. The anatomical maps display right = right.

Table Captions

Table 1. Mean response times (Std. Error) for stimuli in experiment 1.

Table 2. Anatomical Area, Brodmann's Area, and Talairach Coordinates for representative regions of activation in ventral and dorsal visual processing streams for each experiment. The centre of the cluster is reported in x, y, z coordinates from Talairach and Tournoux (1988) atlas.

Appendix A: Ethics Approval

ETHICS APPROVAL FORM - DELEGATED REVIEW

Date:	November 10, 2009	
Principal Investigator:	Jacqueline Cummine	
Study ID:	Pro00008951	
Study Title:	A Functional Investigation of Basic Language Processes	
Approval Expiry Date:	September 20, 2010	
Date of Informed Consent:	Approval Date 11/10/2009	Approved Document Informed Consent

Thank you for submitting the above study to the Health Research Ethics Board (Biomedical Panel) and for making the requested changes to your application and to the informed consent document. Although the ICD still contains a number of words that are unlikely to be familiar to the lay public, we assume that you will explain the procedure to the study subjects in terms that they can understand. The debriefing form is unnecessary; relevant information is contained in the information sheet and consent which is approved on behalf of the committee.

The project has been found to be acceptable within the limitations of human experimentation. There are no outstanding ethical issues and your study is approved until September 20, 2010. A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. You will receive electronic reminders at 45, 30, 15 and 1 day(s) prior to the expiry date. If you do not renew on or before that date, you will have to re-submit an ethics application.

For studies where investigators must obtain informed consent, signed copies of the consent form must be retained, as should all study related documents, so as to be available to the HREB on request. They should be kept for the duration of the project and for at least seven years following its completion.

Approval by the Health Research Ethics Board does not encompass authorization to access the patients, staff or resources of Alberta Health Services or other local health care institutions for the purposes of research. Enquiries regarding AHS administrative approval, and operational approval for areas impacted by research, should be directed to the AHS Research Administration office, #1800 College Plaza, phone 407-1372.

Sincerely,

J. Stephen Bamforth, MD
Associate Chair, Health Research Ethics Board (Biomedical Panel)

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix B: Magnetic Resonance Imaging Consent Form

UNIVERSITY OF ALBERTA

Department of Speech Pathology and Audiology

2-70 Corbett Hall
Edmonton, Alberta, Canada T6G 2G4

www.uofaweb.ualberta.ca/rehabmed

Tel: 780.492.5990
Fax: 780.492.9333
Corbett Clinic: 780.492.5314
MSc-SLP Inquiries: 780.492.5088

INFORMATION SHEET

Title of Research Study: A Functional Investigation of Basic Reading Processes

Principal Investigator(s): Dr. Jacqueline Cummine, Phone: (780)-492-3965

Background: There are competing theories regarding the extent to which the translation of print to speech involves single or multiple routes. The present research provides an opportunity to further study the nature of these processes, which may have an impact on the development of language theories, diagnosis of language problems, and language education.

Purpose: You are being asked to participate in a research study to examine the basic processes involved in language function, particularly reading and speech perception.

Procedures: *Participating in this study will involve:*

a) One visit to the NMR Center located in the University of Alberta hospital and approximately one hour of your time.

b) Read and complete an information sheet, consent form and NMR screening checklist

c) Get familiarized with the MRI room, and equipment

d) You will asked to lie in the MRI

e) Begin the study which could involve one or a combination of the following:

a. Name the items (e.g., WHAT is the word, letter, or nonword)
b. Make decisions about items (e.g., HOW would you use it; which items are words or sound like real words; what colour is the object; identify the letter or number; solve a simple arithmetic problem) that will be presented to you on the computer screen.
c. Learn which sounds go with which symbols (e.g., "sh" sound paired with the symbol "¦").
d. Generate words that rhyme with (or are semantically related to) a target item. (e.g., given the target MINT you may come up with lint, hint, dint, etc.).

Your responses, correct or incorrect, as well as your response latency, may be recorded. You will be instructed to respond quickly and accurately, and whether you should adopt any particular strategy when doing the task (e.g., pronounce the letter-strings following the spelling-sound rules of English).

f) You will be removed from the MRI and the researcher(s) will answer any questions you have before you leave.

Possible Benefits: The possible benefits to you for participating in this study are that you may learn about current research in psycholinguistics, cognitive science, and neuroscience and the nature of the basic processes involved in reading and/or speech perception. Your participation also provides us with an opportunity to further study the nature of these processes, which may have an impact on the development of language theories, diagnosis of language problems, and language education.

Possible Risks: You may feel claustrophobic in the MRI scanner. You will have an opportunity to see the MRI setting before participating in the study and if you feel you cannot do the specified tasks in the MRI setting you will be allowed to withdraw from the study. Since the MRI is essentially a large magnet it is important that no metal be worn when near or in the MRI. You will be asked to complete and sign a separate document to ensure that you are able to have this test. When performing the specific study tasks, sometimes people are embarrassed of having made errors, but you should understand that making occasional errors is unavoidable (especially if you are asked to respond quickly). Thus, errors are normal and often expected in this type of research.

Appendix B: Magnetic Resonance Imaging Consent Form

UNIVERSITY OF ALBERTA

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Corbett Clinic: 780.492.5314
MSc-SLP Inquiries: 780.492.5088

Confidentiality: Your confidentiality and anonymity, including your data and any storage medium, will be protected at all times in secured computers (by participant number, not by name), which are behind locked doors when unattended. The researcher will safeguard and store the data, results, and associated material for a minimum of five years.

Voluntary Participation: You are free to withdraw from the research study at any time. If the study is not undertaken or if it is discontinued at any time all information/data collected will be destroyed. If appropriate, the researcher may choose to discontinue a participant's involvement in the study in which case his/her data will be deleted and destroyed (e.g., if there was an equipment failure during the experiment, the participant would be asked to leave

Compensation for Injury: If you become ill or injured as a result of participating in this study, necessary medical treatment will be available at no additional cost to you. By signing this consent form you are not releasing the investigator(s), institution(s) and/or sponsor(s) from their legal and professional responsibilities.

Contact Names and Telephone Numbers:
If you have concerns about your rights as a study participant, you may contact the Research Ethics Office at (780)-492-2615. *This office has no affiliation with the study investigators.*

Please contact the individual identified below if you have any questions or concerns:

Principal Investigator:
Dr. Jacqueline Cummine
Phone: 780-492-3965
Email: jacqueline.cummine@ualberta.ca

Appendix B: Magnetic Resonance Imaging Consent Form

UNIVERSITY OF ALBERTA

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CONSENT FORM

Title of Project: A Functional Investigation of Basic Reading Processes

Principal Investigator(s): Dr. Jacqueline Cummine Phone Number(s): 780-492-3965
____

	Yes	No
Do you understand that you have been asked to be in a research study?	☐	☐
Have you read and received a copy of the attached Information Sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss this study?	☐	☐
Do you understand that you are free to withdraw from the study at any time, without having to give a reason?	☐	☐
Has the issue of confidentiality been explained to you?	☐	☐
Would you like to be contacted about additional studies?	☐	☐

If yes, please provide your preferred contact information (e.g., phone number, email address)

____

Who explained this study to you? ____

I agree to take part in this study: YES ☐ NO ☐

Signature of Research Participant ____

(Printed Name) ____

Date:______________________________

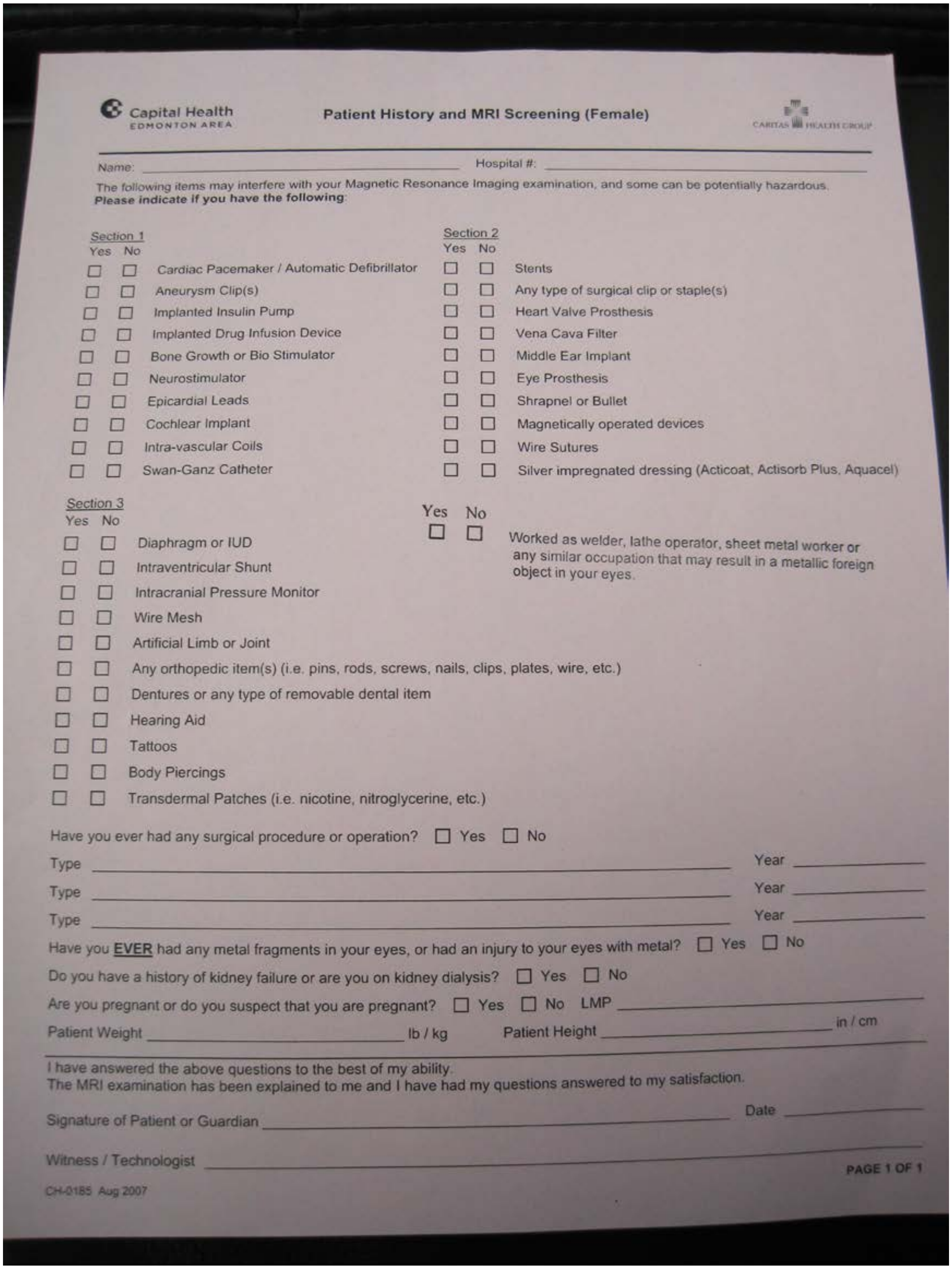
Signature of Witness ____

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

Signature of Investigator or Designee ________________________________ Date __________

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH PARTICIPANT

Appendix C: In Vivo NMR Centre MRI Screening Form



Capital Health
EDMONTON AREA

Patient History and MRI Screening (Female)

CARITAS HEALTH GROUP

Name: ______________________ Hospital #: ______________________

The following items may interfere with your Magnetic Resonance Imaging examination, and some can be potentially hazardous.
Please indicate if you have the following:

Section 1

Yes	No	
☐	☐	Cardiac Pacemaker / Automatic Defibrillator
☐	☐	Aneurysm Clip(s)
☐	☐	Implanted Insulin Pump
☐	☐	Implanted Drug Infusion Device
☐	☐	Bone Growth or Bio Stimulator
☐	☐	Neurostimulator
☐	☐	Epicardial Leads
☐	☐	Cochlear Implant
☐	☐	Intra-vascular Coils
☐	☐	Swan-Ganz Catheter

Section 2

Yes	No	
☐	☐	Stents
☐	☐	Any type of surgical clip or staple(s)
☐	☐	Heart Valve Prosthesis
☐	☐	Vena Cava Filter
☐	☐	Middle Ear Implant
☐	☐	Eye Prosthesis
☐	☐	Shrapnel or Bullet
☐	☐	Magnetically operated devices
☐	☐	Wire Sutures
☐	☐	Silver impregnated dressing (Acticoat, Actisorb Plus, Aquacel)

Section 3

Yes	No	
☐	☐	Diaphragm or IUD
☐	☐	Intraventricular Shunt
☐	☐	Intracranial Pressure Monitor
☐	☐	Wire Mesh
☐	☐	Artificial Limb or Joint
☐	☐	Any orthopedic item(s) (i.e. pins, rods, screws, nails, clips, plates, wire, etc.)
☐	☐	Dentures or any type of removable dental item
☐	☐	Hearing Aid
☐	☐	Tattoos
☐	☐	Body Piercings
☐	☐	Transdermal Patches (i.e. nicotine, nitroglycerine, etc.)

Yes	No	
☐	☐	Worked as welder, lathe operator, sheet metal worker or any similar occupation that may result in a metallic foreign object in your eyes.

Have you ever had any surgical procedure or operation? ☐ Yes ☐ No

Type ______________________ Year __________

Type ______________________ Year __________

Type ______________________ Year __________

Have you **EVER** had any metal fragments in your eyes, or had an injury to your eyes with metal? ☐ Yes ☐ No

Do you have a history of kidney failure or are you on kidney dialysis? ☐ Yes ☐ No

Are you pregnant or do you suspect that you are pregnant? ☐ Yes ☐ No LMP __________

Patient Weight __________ lb / kg Patient Height __________ in / cm

I have answered the above questions to the best of my ability.
The MRI examination has been explained to me and I have had my questions answered to my satisfaction.

Signature of Patient or Guardian ______________________ Date __________

Witness / Technologist ______________________

CH-0185 Aug 2007

PAGE 1 OF 1

Appendix D: Stimuli used in Experiment 1

Regular Words High Frequency
dark
food
free
girl
goes
had
heat
home
leave
much
too
twice
win

Exception Words High Frequency
does
door
front
full
give
gone
most
once
one
own
says
touch
two
whom

Regular Words Low Frequency
brain
bunch
coil
ditch
flame
proud
sag
snatch
stack
sweep
thrust
torn
truce

Regular Words Low Frequency
bought
breath
broad
dough
earn
learn
sieve
spread
steak
sweat
thread
tour
tread

Pseudohomophones
boarn
braiv
coalt
dawt
flore
foart
fyne
gawlf
gyde
hawt
helled
hoap
mynd
pryd
stait
stroal
swhis
terhn
theem
toon
truhmp
tule
wyz

Appendix E: Stimuli used in Experiments 2A and 2B

Regular Words	**Exception Words**	**Pseudohomophones**	
board	both	boarn	
feel	full	phlash	nyse
while	where	whyt	wyfe
much	most	mohr	wehn
days	does	dryv	fyne
girl	give	gaim	dawt
food	front	feeld	leest
wore	wood	woak	theem
brain	bread	braiv	boarn
ease	earn	ehj	pryd
swell	swear	swhis	stroal
ditch	dread	drore	soke
coil	comb	doun	stait
hoarse	hearth	hoest	bern
had	have	toon	truhmp
nine	none	spawt	wyz
home	whom	swoar	mynd
well	once	flore	gawlf
free	four	hoap	foart
dark	door	cleen	coalt
leave	learn	breaz	terhn
truce	tread	hoald	helled
bound	bought	bote	tule
proud	prove	seaks	gyde
stack	steak	mawths	hedj
sag	sew	layt	mylz
snatch	sieve	owt	klass
bunch	bush	hawt	