CORTICAL RESPONSES TO FAMILIAR AND NOVEL ORTHOGRAPHIC SYSTEMS

BY

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ABSTRACT

The Visual Word Form Area is a portion of the occipitotemporal cortex which has been shown to respond specifically to visually presented words, leading to it being implicated as a significant region in the process of reading. The VWFA seems to display a great deal of plasticity, as the ability to read has been proposed to be based on a functional reorganization of this area during the process of learning to read and becoming attenuated to language specific word-formation regularities. The effect of familiarity with an orthographic system and the way in which it modulates the N170 ERP response originating in the Visual Word-Form Area is still largely uncertain. Previous research by Maurer et al. (2008) has demonstrated a left-lateralization for familiar orthographies which is absent in novel orthographies which tend to demonstrate either a lack of lateralization in this response, or a slight right-lateralization.

Based on Maurer et al. (2008), we have conducted a study which built upon their approach but adjusted their methodology and stimuli in several ways. Firstly, a single experiment was designed, including all 3 language conditions of interest: English, Japanese Hiragana, and a non-linguistic symbol set. The experiment was further randomized across all three conditions rather than presented in block format. This allowed for the direct comparison of language conditions for participants within the same experiment, allowing comparisons across conditions tested within the same experimental context with the same participants. In addition, our study included tighter controls for word length, bigram frequency, character size and spacing to further ensure the veracity of our data.

Our results confirm the left-lateralization observed for familiar language conditions, but also demonstrate an amplitude modulation of the N170 response for familiarity, in which novel

orthographies create a more negative response than familiar orthographies in the N170 time window. This pattern was later reversed in subsequent time windows as lexical processes were engaged, prompting a much more negative response for familiar orthographic conditions over novel ones. This indicates that the amplitude of the N170 response is directly affected by experience with orthographic systems.

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Introduction

While language has been a facet of human culture for an extraordinarily long time, and underlying neural architecture seems to be specifically disposed toward speaking/signing and understanding, one facet of our modern use of language is, on an evolutionary timeline, extremely recent: the ability to read and write. Writing has only been a function of human culture for the last 5,000 years. Each individual society's definition of literacy, and its spread throughout the populace has been a dynamic factor throughout the course of human history, but widespread literacy among a majority of the populace was not possible until the mid-19th century with the advent of the moving-type press and the ability to quickly reproduce written documents. It seems anyone not impaired by a neurological disorder which would prevent them from doing so is capable of learning to read. This obviously demonstrates the fact that reading is clearly not a skill developed by evolution, because processes of natural selection work on much longer timelines and illiteracy has not been selected out of the human population, but rather systematically eliminated through education. This suggests that, from a cortical standpoint, the ability to read is a modular adaptation of some previously existing neural circuitry.

This of course begs a question of how reading is possible, what neurological circuitry is at work to connect an image with a word or sound in the human mind, and whether specialized neurological architecture is at work behind this process. As we will examine throughout this section, the same localizations of the human cortex seem to be consistently implicated in the task of reading. If these regions are specifically tuned to this task yet occur outside the process of human evolution, another mechanism must be at work to allow these processes to occur.

Dehaene & Cohen (2007) posit that this is possible through their theory of 'Neuronal Recycling', wherein cultural tasks such as reading or arithmetic, through learning, functionally adapt a specific part of the human cortex to their task. In order for this to occur, the specialized task must be functionally similar to the original purpose of this cortical area, and the cortical area in question must inherently have enough plasticity to be capable of adapting to this task. Reading, by this reasoning, specifically adapts a portion of the cortex responsible for medium range visual detection in the center field of vision, in order to discern specific 'word forms' and encode them such that language related processing in the brain may occur.

Identifying the degree to which this plasticity remains in adulthood and may be useable in learning a novel orthographic system is the ultimate goal of this line of research. As a first step toward examining experience-dependent changes in orthographic processing at the brain level, we will measure responses to cross-linguistic stimuli: those that are familiar, and those that are unfamiliar to participants in the current study. In the following sections, we will first discuss candidate electrophysiological responses associated with reading to determine which will be relevant for this study, as well as regional localizations associated with these responses. Then, background literature regarding familiar versus novel orthography will be examined and discussed at length, noting, where applicable, problems related to this field of research which require further addressing. Finally, we will present our current study in brief overview before examining the specific methodology of our study, its results, and the interpretation of these results.

Brain Responses Associated with Orthographic Processing

Magnetoencephalography (MEG) and electroencephalography (EEG) data are excellent in terms of temporal resolution in detecting the time course of neural responses but generally poor in terms of spatial localization for detecting the source of these responses. These techniques measure magnetic waves and electrical signals respectively, originating largely from the cortical surface of the brain. While these techniques are capable of millisecond by millisecond tracking of said neural responses, localizing the signals based on signals received from sensors outside the brain is still at best an estimate based on source modeling. The opposite can be said for imaging techniques such as functional magnetic resonance imaging (fMRI), wherein spatial localization is very high, but determining the time course of neural responses is generally poor. This is because fMRI tracks the magnetic resonance of red blood cells as they supply oxygen to neurons in the human brain, also referred to as the Blood-Oxygen-Level Dependence (BOLD) signal, which change their response to an externally applied magnetic field as a consequence of the loss of oxygen in supplying neurons. The use of the BOLD response as a dependent measure for comparing brain activation across conditions provides excellent spatial resolution, on the order of millimeters, and is thus very precise in terms of determining the location of an effect, but because this signal takes several seconds to reach full strength, it is very poor in terms of determining the time course of the processes underlying this effect.

In an fMRI study, Cohen et al. (2002) investigated the process of word recognition, using stimuli consisting of words, consonant strings, and checkerboards. This study confirmed greater activation in the left fusiform gyrus (also referred to as the occipitotemporal gyrus, BA 37) for words over either consonant strings or checkerboards, and greater activation for consonant strings over checkerboards. Stimuli were presented in either the left or right visual fields, and subjects were instructed to indicate by button-press which field the stimulus occurred in. The increase in activation for words and consonant strings over checkerboards was interpreted to indicate a specialization for language related processing over general visual complexity. The increased activation for words over consonant strings was interpreted to represent a language-specific process at work, but they caution that this response may not be a lexical process at work so much as a response to well-formed words. Based on the observed sensitivity of this region to words, this region of the left occipitotemporal cortex has been referred to as the Visual Word-Form Area (VWFA)

Dehaene et al. (2002) further investigated this region, by comparing French words and well-formed pseudowords in a combined auditory/visual same-different task. Participants were presented with a stimulus pair either auditorily or visually and asked to indicate via button press whether these stimuli were the same or different while neural responses were monitored via fMRI. The results of this study suggested that these cortical regions demonstrate no difference in activation between words and well-formed pseudowords. This would seem to indicate that processing in the left-fusiform gyrus is a pre-lexical process, occurring after general visual feature and letter recognition but before lexical processes become active.

Recent work by Dehaene et al. (2010) demonstrates encouraging possibilities in relation to the plasticity of the occipitotemporal cortex. In a series of several auditory and visual tasks, involving lexical decision for auditory tasks and finding a target star symbol for visual tasks, groups of Brazilian and Portuguese illiterate, adult-literate and childhood-literate subjects were examined via fMRI, seeking both localizations of activation for reading, and BOLD signal response strength. There was a demonstrated increase in activation in the VWFA for words in both literate subject groups compared to the illiterate subject group, and this increase extended into the V1 primary visual cortex. Further, in regressions which removed factors such as reading ability and socioeconomic status, these increased activations in the VWFA for words were statistically similar for both the early and late literates compared to illiterate subjects. This indicates that there exists a potential for literacy to selectively reorganize cortical structures regardless of when the skill is acquired.

Early MEG responses to written words were investigated by Tarkiainen and colleagues in a series of experiments (1999, 2002), the first of which tested 1 letter and 2 letter strings, as well as 4 letter strings which formed words, all of which were presented with 4 different levels of noise caused by Gaussian diffusion. The study also included 3 string lengths of geometric symbols and 4 character letter-like symbols (Latin capitals rotated 90, 180 or 270 degrees), all of which were presented without noise. Subjects were instructed to focus on the stimuli and occasionally (1.5% probability) a question mark would appear onscreen directing the subject to repeat the most recent stimulus. The second study incorporated the same stimuli as the first, adding line drawings of faces with four degrees of noise, as well as line drawings of common household objects and scrambled faces presented with no noise. Photographs of faces and common household objects were also included. The task was likewise the same, with the exception that participants were now asked to name either the previous stimulus (for letters), or the facial expression (for line drawings of faces). These studies found two specific patterns of activity. The first of these was a response peaking approximately 100ms post stimulus onset, occurring predominantly in the primary visual cortex, which displayed no distinct preferences for words or faces, and with an even hemispheric distribution of both.

The second response peaked at 180ms post stimulus onset, responding most strongly to words, but also responded strongly to letter-like symbols (capital letters rotated to various novel orientations). This response was strongly left-lateralized, in contrast to the recognition of faces which demonstrated a right-lateralized response. Using dipole localization, these responses were traced to specific regions of the inferior occipitotemporal cortex. This is the same localization as the VWFA, identifying this electrophysiological response as a candidate for tracking language-specific orthographic processing.

The M170 is a response specific to MEG. Using EEG, specifically for the study of Event-Related Potentials (ERPs), an analogous response originating from the same underlying cortical activity exists referred to as the N170. Other research by Dehaene and colleagues (2004), which tracked ERP responses to a letter detection task using words created with similar or dissimilar capital/lowercase letter forms, demonstrated case and location invariance for the N170. These findings essentially mean that these responses do not discriminate between upper and lowercase letters, including both relatively transparent case pairs (such as ‘O’ and ‘o’) and relatively opaque case pairs (such as ‘G’ and ‘g’) where the two cases share very few common features. Further, the location of the word’s presentation in the subject’s visual field makes no difference in the course of processing, as processing always occurs in the left occipitotemporal cortex. This demonstrates that the N170 response is capable of recognizing words regardless of superficial differences in letter case, and is independent of simple visual recognition processes (such as the ~100ms peaking response reported by Tarkiainen et al. (2002)) wherein the visual field the stimulus was presented in directly affected the region in which it was processed, indicating that the VWFA, which produces this response, is specialized for the task of word recognition.

An earlier study by Dehaene et al. (2001), which included an ERP measure, studied imageable nouns with and without a masked prime, while subjects were instructed to categorize the nouns as either being natural or man-made. This study demonstrated an effect for priming, wherein a word, when repeated even at such a rate to be only subliminally visible to the subject, created a decreased activation in the N170 response with subsequent repetition. This indicates that the N170 response occurs autonomically, without conscious choice, or in this case even the awareness of the reader.

Pylkkänen and Okano (2010) further demonstrated a priming effect between the two syllabary orthographies of Japanese, Katakana and Hiragana (details concerning these orthographic systems and their relation to a third Japanese orthography, Kanji, to follow in a later section), finding that a word still produced a priming effect even if it was presented first in a syllabary in which it did not typically occur. This study comprised 3 experiments, a masked priming behavioral task, an unmasked priming behavioral study, and an MEG study utilizing unmasked priming. All three experiments involved a lexical decision task. This, they argue, demonstrates a connection between an orthographic stimulus and its phonological correspondent.

Studies on Novel versus Familiar Language Conditions

In contrast to studies which have determined the N170 to be a pre-lexical component, Maurer et al. (2005) conducted an ERP study comparing words, pseudowords and symbol strings and found an increased activation for words over pseudowords. This would seem to indicate a lexical process at work which preferentially discriminates for real words. However, as the experimenters include no information with regards to controls on the well-formed nature of their pseudo-word stimuli, this may instead simply be the same response to well-formed letter strings (see Cohen et al. (2002) & Dehaene et al. (2002), above) which has been mentioned previously.

The majority of research on the topic of visual word recognition indicates that lexical access occurs subsequent to the N170 component. For instance, research by Bentin et al. (1999) demonstrated two ERP responses active during lexical decision and semantic tasks in single-word reading studies (lexical decision tasks were odd-ball tasks asking participants to make decisions to words interspersed between illegal nonwords, words interspersed between legal pseudowords, and pseudowords interspersed between words, while semantic tasks required participants to count abstract words interspersed between concrete words, pseudowords and illegal nonwords). The N350 response, active in lexical decision tasks and peaking in the mid-temporal electrode areas, but this response was found to be larger for both words and pseudowords compared to illegal nonwords. This was taken to indicate a level of phonological processing at work which was not strictly a lexical process. In contrast, the N450, an ERP component starting approximately at 350ms and peaking at 450ms and more anterior and superior than the N350, demonstrated greater activation for pseudowords over real words during the semantic processing task. This data would therefore indicate that while well-formedness can be determined by a number of different processes earlier in the processing stream, responses reflecting lexical access do not emerge before approximately 350ms.

Other studies have implicated additional components; all subsequent to the N170, such as the N400, which has been shown to be sensitive to lexical effects such as word frequency, priming, and semantic category membership (see Kutas & Federmeier, 2000 and Lau et al., 2008 for a review of these findings). Further research by Proverbio et al. (2004) in a single-word reading study (using a unique paradigm wherein participants were presented with an auditory phone and asked to determine by button-press whether the phone was present in a visually presented word) demonstrated an earlier ERP component showing lexical sensitivity. Termed the N3, this component lasted between 250-350ms occurring in frontal and temporal regions and demonstrated greater negativity for nonwords (including both pseudowords and illegal nonwords) than words. The greater response for nonwords, including pseudowords, over real words would therefore indicate that lexical access may occur starting as early as 250ms, as simple phonological probability would not create differences between valid pseudowords and real words. Taken together, these studies suggest that lexical effects typically emerge after the N170, consistent with the view of the N170 as a prelexical response.

A later study by Maurer et al. (2008) greatly informs the present study. As this study forms the basis for our present study, and our present study is created to expand upon their findings, it is extremely valuable to discuss this study in detail. In a series of 3 experiments, two separate sets of orthographic stimuli were compared in a blocked one-back task design. The one-back task is a simple task which is aptly suited to the study of unfamiliar orthographic processing, as a subject is only directed to push a response button when detecting an immediate repetition of a stimulus. This alleviates a need for the subject to have previous experience with an orthographic system as simple visual recognition is sufficient for the task. While the repeated stimuli appear infrequently and in a randomized order, participants must evaluate each stimulus to determine whether it was a repetition of the previous stimulus, although overt button-press responses are only made to stimuli they decide have been repeated. The orthographic systems used in this series of experiments include 3 separate Japanese orthographies, the English Latin alphabet, and a geometric symbol set.

Kanji, Hiragana and Katakana are the three orthographic systems used in written Japanese. Kanji are logographic characters borrowed directly from Chinese, such that the information encoded by them is semantic rather than phonological. Due to successive waves of borrowing from the Chinese language, many Kanji are in fact subject to multiple readings, depending on the time period during which the borrowing occurred, yielding semantically synonymous but phonologically distinct oral representations for a single character. Hiragana and Katakana, in contrast, are syllabaries derived from the same logographic Chinese symbols and largely simplified from them. In contrast to Kanji, each character in Hiragana or Katakana corresponds to a specific phonological value; either a single vowel, a CV combined unit, or a nasal sonorant coda. As such, Hiragana and Katakana provide a transparent phonological representation in contrast to Kanji's highly opaque phonological representation. Each of these orthographies also has a distinct function within the system of written Japanese as a whole, with Hiragana being used primarily for the dual purposes of adding inflection to logographic Kanji and representing words of Japanese origin which lack a Kanji representation in the lexicon, while Katakana is used primarily to represent foreign loanwords of approximately the last century as well as onomatopia and scientific terminology.

Maurer et al. (2008)'s first experiment compared 2 character Kanji stimuli to 2-3 character Hiragana stimuli in a blocked one-back design, using 40 stimuli of a particular condition, each repeated once, in separate blocks. 12% of these stimuli were presented twice in succession, constituting a stimulus repetition which the participants were expected to detect. Participants included 18 native speakers of Japanese who could also read English, and 17 native speakers of English who were inexperienced with the Japanese language. There was found to be a significant left-lateralization of the N170 response for Japanese speakers for both conditions, while English speakers demonstrated a bilateral response. Further, a greater response for Hiragana characters was demonstrated than for Kanji amongst Japanese speakers. This was speculatively interpreted to be a difference caused by the variable length amongst stimulus types, with Hiragana strings being longer in some cases than Kanji strings. The effect of length on N170 responses remains unclear, but one study which did control for length as a specific factor in the response of the N170, Hauk & Pulvermüller (2004) found the opposite effect as would be predicted by Maurer et al. (2008), namely that shorter stimuli produced a greater amplitude response than longer stimuli. This mismatch complicates the analysis of results from Maurer et al. (2008), and seems to suggest an effect unrelated to length at play in this data.

Maurer et al. (2008)'s second experiment compared two Katakana stimulus types, words that are typically rendered in Katakana, and words typically rendered in Kanji that had been transcribed into Katakana. Other than stimuli, procedures for this experiment were the same as experiment one. Much like experiment one, a left-lateralized response was noted for Japanese speakers while a bilateral response was noted for English speakers. No significant differences were noted between the two types of Katakana for Japanese speakers.

In experiment three, English strings were compared to a geometric symbol set, consisting of 8 characters, a circle, triangle, square and diamond, and these 4 symbols with a descender line attached. With only 8 symbols in their non-linguistic condition, it naturally follows that this symbol set was both not matched to any one language set, nor did it attain the depth or variability of a full orthographic system used by a natural language. This experiment resulted in a left-lateralized response for both speaker groups for the English language stimuli, and a bilateral response for symbol strings. The N170 response for English words was significantly increased for native Japanese speakers compared to their native English speaking counterparts. This was tentatively attributed to an effect of "novice vs. expert learning". The increased N170 response was absent for English non-words however.

Taken together these three experiments suggest a lateralization effect for familiar versus novel orthographic stimuli, wherein familiar stimuli are processed in the left-hemisphere while unfamiliar stimuli are processed bilaterally. It should be noted that while all language conditions were present in the study across the three experiments, the experiments themselves only allowed paired comparisons between their two specific orthographic stimuli types.

Another study which examined the effect of experience was Baker et al. (2007), an fMRI study comparing English words, English consonant strings, Hebrew words, Chinese words, line drawings, and number strings, among groups of English readers and native speakers of English who were also native readers of Hebrew. While English-only readers demonstrated a larger response for English words and consonant strings, Hebrew readers showed the same pattern, with an additionally even stronger response for Hebrew characters. This indicates, based on the language & orthographic backgrounds of the participants, a very strong role of experience in modulating responses.

The experimenters proposed two potential hypotheses to account for this processing difference. The first was that this processing is dependent on language-specific experience. While this explanation does account for the difference in processing between English-only readers and readers of Hebrew, it does not account for the greatly increased response for Hebrew strings over English strings. Their second hypothesis was that the increased activation for Hebrew strings over English strings in Hebrew readers was the result of increased attention to the Hebrew stimuli over the course of testing. However, this hypothesis was problematic for the researchers to adopt as increased attention alone would have created the same effect for non-Hebrew readers as well in the blocked one-back trials, where their novelty to inexperienced readers would have resulted greater difficulty processing them. We will return to these alternative hypotheses regarding the findings of Baker et al. (2007), and how they relate to the findings of the current study, in the Discussion section.

A behavioral study by Wong et al. (2011), comparing Latin, Chinese and pseudo-letters during a rapid serial visual presentation task found an additional effect of orthographic familiarity. Participants were presented with two characters before each trial sequence of 20 images, and asked to identify which of the two characters was presented during the sequence afterward. The presentation rate was modulated by a staircase design, wherein threshold speed of the presentation rate was modulated by the participants' responses, such that correct responses increased the presentation speed of subsequent trial sequences. Each condition (e.g. Latin letters with Chinese character distracters and pseudo-letters with Latin distracters as reported below) comprised a block of 30 trial sequences. During the presentation of Latin letters to English speakers and Chinese-English bilinguals, distracter Chinese characters created a slow-down response for bilingual speakers, limiting the threshold presentation rate of images per second they viewed based on their number of correct responses, but this effect was absent for monolingual English speakers. This indicates both an effect for familiarity and the recruitment of the same underlying neurological architecture for both orthographies. However, the same was not seen for a similar pseudo-letter seeking task with Latin letter distracters, which the researchers claim indicates this difference is not based strictly on familiarity, as Latin letter distracters should have had a similar effect for both groups as Chinese characters did for bilinguals. However, as this study was behavioral in nature, there exists no direct neurological data to compare with other related findings in the field.

Current Study

The first step in this research, and the basis of the current paper, was to replicate and extend Maurer et al. (2008)'s findings with an English-only control group who have no prior experience with Japanese orthography. We have elected to adapt the methodology of Maurer et al. (2008), testing Hiragana, English and an enhanced non-linguistic symbol set, along with pseudo-word controls for each language condition, all of which were presented in the same experiment and used a randomized presentation order such that no two subjects saw the same order of stimuli. Additional controls on stimuli were utilized in order to further understand the effect of familiarity on the N170 response. As length speculatively affected the amplitude of the N170 in Maurer et al. (2008)'s first experiment, we investigated potential length effects among 3 and 4-character stimuli. Likewise, to continue testing the pre-lexical status of the N170 brain response, words and non-words were directly comparable, matched tightly for bigram frequency to ensure that non-words followed realistic letter combination patterning, for which research has indicated the N170 response may be sensitive.

Methods

Participants

16 native speakers of English with no background in Japanese were recruited for the purposes of this study from the university community. Participants had a mean age of 29.3 years and a female to male ratio of 13:3. Participants provided full and informed consent and were paid for their participation in the study. Prior to the experiment, participants completed the Edinburg Handedness Inventory. Participants who used corrective lenses for any form of visual

impairment were instructed to bring their lenses and wear them during the course of the experiment. Participants also completed a short survey asking them to self-rate their knowledge of English and Japanese, to confirm that the participants were native speakers of English with no prior background in Japanese.

Materials

English				Non-Linguistic				Hiragana			
3 Character		4 Character		3 Character		4 Character		3 Character		4 Character	
Word	Non	Word	Non	Word	Non	Word	Non	Word	Non	Word	Non
fit	ane	main	herg	⧗⧗∇	⧗⊘⧗	⊘⧗⧗⊘	⧗⧗Δ⧗	こまつ	わしい	うれしい	みくろう
bus	ong	from	gath	○∇Δ	Δ⊘⧗	⧗ΔΔ⊘	⧗⧗∇⧗	こみち	げない	こたえる	くれるい
gun	ont	more	lind	⧗∇⊘	Δ⊘∇	⊘ΔΔ⧗	○⧗⊘∇	さます	ぎるい	たくさん	うこもね
his	ent	west	vean	⧗⧗Δ	⧗⊘∇	∇⧗Δ∇	∇⧗⧗⊘	さゆり	いんせ	それから	あがりて
but	fon	will	sten	○∇∇	⧗Δ⊘	∇⧗○○	Δ∇⧗⊘	ぢんげ	うとり	おいしい	どこなで

Table 1. Example stimuli. See Appendix I for full list of stimuli.

Each language set had 150 3 character strings and 150 4 character strings to control for possible length-specific effects in processing. Controlling length in this manner prevents any differences between orthographic stimuli types due to possible length related effects. Further, such a fine-grained difference in length allows for the testing of the effect of subtle length manipulations in the amplitude of the N170 as speculated by Maurer et al. (2008).

Further, each language included 150 real words and 150 pseudowords specifically designed for the purposes of this experiment, in order to ensure that this process is occurring prelexically. This allows us to directly compare the effects of real words versus a well-formed non-word, testing the contentious findings of lexical sensitivity within the N170 response.

The 300 non-linguistic stimuli were likewise split between 3 and 4 character strings. Thus they are as evenly matched to our real orthographic stimuli conditions as possible in terms of quantity and length.

Within each orthographic condition of 300 stimuli, the stimuli were evenly divided among 4 groups, between 3 and 4 word conditions and word and non-word conditions, such that each orthography included a set of 75 stimuli (5 of which are visible in Table 1, above) for each of the following conditions: 3 character words, 3 character non-words, 4 character words, and 4 character non-words. 10 stimuli from each group of 75 target stimuli were used as triggers for the one-back behavioral measure, yielding 120 total triggers balanced equally across all groups. The total triggers comprised 13.3% of the token stimuli set, which is nearly the same 13% ratio of triggers to total targets as seen in Maurer et al. (2008)'s study. To avoid potential priming effects in the analysis of our data, the second repetition of these stimuli were excluded from analysis, as priming has been shown to affect the amplitude of the N170 response. As such, including these repetitions in the analysis data would only confound results with task-related artifacts.

Hiragana real word strings were culled from Nakama 1: Japanese Communication, Culture, Context (Makino, Hatasa & Hatasa '98), a textbook for introductory level Japanese language. The purpose of using an introductory level textbook was to locate frequently occurring words which would be familiar to a learner of Japanese as a second language, which allowed for the extension of this study to L2 learners of Japanese in the future. This yielded 139 3 character strings and 118 4 character strings. Words using glides or geminates, both of which utilize a smaller subscript Hiragana character, were excluded in order to keep all character sizes equal. The lists for each string list were further narrowed based on lexical frequency statistics from the NTT corpus (Amano & Kondo, 2003) to 75 of each. Each of the final strings was predominantly occurring in Hiragana (as opposed to Katakana or Kanji) and/or was heavily represented across all orthographic systems (> 10,000 occurrences), such that none of them were occurring in an orthographically unfamiliar form.

Bigram frequencies for each string were calculated based on the co-occurrence of characters within the NTT corpus, providing an additional control on stimuli absent in Maurer et al. (2008)'s study. This was accomplished using a Perl script which converted the original text encoding to the most recent version of Unicode (UTF-8) making it readable within the Perl programming language. Next, tabulations of the co-occurrence of characters within the corpus could be computed. This allowed us to automatically and systematically extract bigram frequencies for all of the Japanese stimuli, making it possible to match the Japanese words and nonwords on this property. Using these calculations, nonword strings were generated as foils to their real word counterparts (75 each of 3 and 4 character strings). A one-way ANOVA was performed to ensure that the bigram frequencies of real and nonwords of both lengths were all statistically similar ($F=1.377$, $p=0.25$).

English real word strings were likewise culled from Insights for Today (Smith & Mare, 2004), an English as a Second Language textbook. This was to ensure that English word strings would be frequently occurring and familiar to learners of English as a second language, as this study would as previously mentioned be extended to other subject populations, including native speakers of Japanese who had learned English as a second language. This yielded 129 3-letter and 193 4-letter words. These lists were further narrowed to the 75 most frequently occurring in each list based on lexical frequency calculations in the CELEX corpus (Baayen et al. 1993).

75 nonword foils for each string length were generated from the ARC Nonword Database (Rastle, Harrington & Coltheart, 2002). Bigram frequencies of these nonwords were compared against the English real words using the MCWord Orthographic Wordform Database (Medler & Binder, 2005) to ensure they were not significantly different from each other. Another one-way ANOVA was performed on English stimuli as with the Hiragana stimuli previously to ensure bigram frequency was not significantly different between stimuli types ($F=0.768$ $p=0.513$).

A non-linguistic symbol set was created in the laboratory utilizing FontCreator 4.0 software by HighLogic, Inc. and provided to the researchers consisting of 26 letter-like symbols intended to match the complexity of a natural orthographic system, enhancing this Non-Linguistic control from the 8 geometric figures utilized by Maurer et al. (2008). English word and non-word strings of both lengths were copied and rendered in this symbol set to ensure that the use of non-linguistic symbols would follow a naturalistic bigram patterning. This allows our Non-Linguistic stimuli set to additionally follow natural usage patterns of an orthography for a natural language, such that some characters are naturally more commonly used than others, just as the individual letters in the English conditions do.

English strings were rendered in Courier New font. Japanese Hiragana strings were rendered in Malgun Gothic. Both fonts are normally monospaced and highly legible, which in turn simplified further controls between orthographies. HighLogic's FontCreator 4.0 software was utilized to correct differences between the size and width of characters between the three orthographic sets, to ensure no one symbol string would be significantly different in size, orientation or line thickness from its cross-condition pairs.

As the stimuli in the Maurer et al. (2008) study were subtended at 1.8 degrees of visual angle (that is, the amount of the visual field occupied by the stimulus, taking into account not only size on the computer screen, but also distance between the stimulus presentation computer and the subject's eye) for English and Non-linguistic strings, and a visual angle of 1.9 for Hiragana strings, the researchers of this study elected to normalize across all three conditions to a standard 1.8 degrees of visual angle for all of them as this was the value of two of three conditions and reasonably close in value to the measure for Hiragana stimuli.

It was also found that rendering black text on a grey background was too straining for pilot participants and created an excessive number of blink artifacts; thus, turquoise text on a black background was selected for use in the current study.

Procedure

Participants were seated in a comfortable chair approximately 75cm from a cathode-ray tube display monitor with a 100 kHz refresh rate. After placing the electrode cap and keeping scalp impedances below 5 kOhms, participants were given a practice session for the one-back response paradigm which lasted approximately 3 minutes, during which time the participants were asked to press a button on the response device (a Microsoft SideWinder Plug & Play Game Pad) when a stimulus was repeated immediately, as in the main task of the experiment. Brain responses were recorded using a 64-channel cap (details to follow in subsequent section).

The main task consisted of the 900 target stimuli, which included non-repeated stimuli and first-occurrence of one-back trigger stimuli. The 120 second-occurrence trigger stimuli (those to which the subject was instructed to respond via button-press) were also included, each of which directly followed their matched counterpart in the target stimuli set. Each stimulus was displayed as in the Maurer et al. (2008) study for 250ms, followed by a randomized inter-stimulus interval of between 1500 and 2500ms, again following the procedure of the Maurer et al. (2008) study. All stimuli were presented using Paradigm software created by Perception Research Systems, Inc. Participants were given 5 breaks spaced evenly among the target stimuli in order to help them remain focused on the task. Breaks lasted until the participant directed the program to continue by means of a button press response. Not counting breaks, the total length of the experiment was approximately 40 minutes.

Data Recording and Analysis

ERP data was recorded on a Neuroscan SynAmps2 system, using an Ag/AgCl cap made by Electro-Cap International Inc. The cap included 59 active scalp sites, arranged based on an extension of the international 10-20 system. Electrodes were placed at frontal (FZ, FPZ, FP1, FP1, F1, F2, F3, F4, F5, F6, F7, F8, F3A, F4A), central (CZ, C1, C2, C3, C4, C5, C6, C1A, C2A, C1P, C2P), temporal (T3, T4, T5, T6), parietal (PZ, P1, P2, P3, P4, P5, P6, P1P, P2P, P3P, P4P) and occipital (OZ, O1, O2) regions, as well as Fonto-central (FCZ, FC3, FC4) Centro-parietal (CPZ, CP3, CP4), Fronto-temporal (FT7, FT8), Tempero-central parietal (TCP1, TCP2), Tempero-parietal (TP7, TP8) and cerebellum (CB1, CB2) additional sites. Impedances were kept below 5 kOhms. Data was recorded referenced to the left mastoid channel, and separately re-referenced to both mastoid channels later during analysis. Bipolar electrode montages were also placed vertically above and below each eye, as well as a horizontal montage placed just outside the lateral canthi. Recordings were sampled at 1000 Hz, with an online band pass filter of 0.15 Hz to 200 Hz.

ERP data was analyzed across target types. ERP data from the second repetitions, which directly followed their matched target stimuli, were excluded from analysis as the ERP data from these second repetitions would necessarily be corrupted by priming effects. Additionally, the ERP data was also marked such that repeated stimuli which were missed by the participants and target stimuli which were falsely identified as repeated by the participants would be recognizable as an incorrect response during analysis. Data was baseline corrected, averaged across target type, low-pass filtered to 30kHz and mean amplitude values were extracted for the following time windows: 90-160ms and 250-375ms. The 90-160ms time window was identified as the primary focus of inquiry for the purposes of this study based on existing literature and cursory examination of the data, but later time window of 250-375ms was also of interest during the analysis of lexical properties.

Electrodes were grouped for regional analysis in terms of right and left anterior and posterior electrode groups, with right and left occipitotemporal regions created from a subset of the posterior electrode groups. The left anterior region consisted of electrodes F1, F3, F3A, F5, F7, C1, C1A, C3, C5, FC3, FT7, and T3. The left posterior region consisted of electrodes T5, TCP1, TP7, C1P, CP3, P1, P1P, P3, P3P, P5, O1, and CB1. From this region, electrodes P3P, O1, and CB1 were selected to form the left occipitotemporal region. Right regions consisted of the even-numbered analogues to the electrodes of the left regions of analysis. Finally, for late lexical effects, the electrodes F7, FT7, and T3 were selected for a Left Anterior analysis group.

Predictions

If the pattern of lateralization for familiar vs. unfamiliar orthography observed in Maurer et al. (2008) extends to the current design, we expect to find a lateralization difference among familiar and novel stimuli, namely that familiar orthographic stimuli will elicit a left-lateralized response, while novel will elicit a bilateral response. Should the amplitude difference recorded in the first experiment of Maurer et al. (2008) which was taken to reflect length differences between Kanji and Hiragana stimuli, we would expect the longer 4-character strings to elicit a greater amplitude response than the 3-character strings. However, we could also predict, based on the findings of Hauk and Pulvermüller (2004), a smaller amplitude response to 4-character strings over 3-character strings. Finally, based on the findings of Maurer et al. (2005), lexical differences may be detectable in the N170 response. Results of other studies, such as Bentin et al. (1999) and Proverbio et al. (2004), would indicate processing differences between words and nonwords would only occur subsequent to the N170.

Results

Data was analyzed in terms of four principal areas of inquiry: Cross-language amplitude effects, lateralization, length and lexicality effects. In the following, we present the results for each property, focusing on earlier (90-160 ms) and a later (250-375 ms) time windows of interest.

Cross-Language Effects

Amplitude differences across languages demonstrated a clear distinction in terms of the effect of familiarity across languages, as seen in Figure 1, below. When comparing across languages in the 90-160ms time window, the left-occipitotemporal region showed significantly less activation for the familiar English stimuli when compared to either novel Japanese or Non-linguistic stimuli types ($t(15) = 2.473$, $p = 0.026$ and $t(15) = 5.298$, $p < 0.001$, respectively), while Japanese and Non-linguistic stimuli were not significantly different from each other ($t(15) = -1.723$, $p = 0.105$)

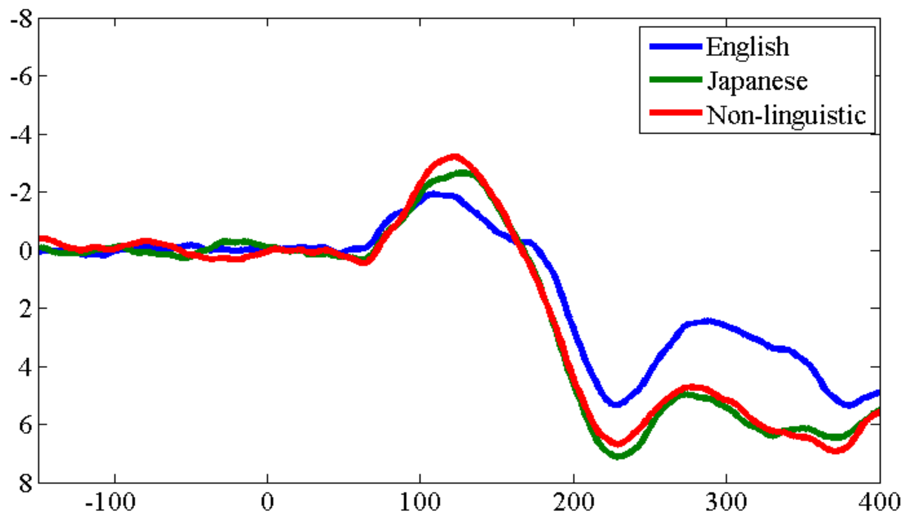

Figure 1. ERP waveforms for English, Non-Linguistic, and Japanese from averages of the electrodes in the Left-Occipitotemporal Region group.

In the later 250-375ms time window a reversal in this trend is recorded, with English stimuli showing significantly greater activation than either Japanese or non-linguistic stimuli within the same region (English vs. Japanese: $t(15) = -5.226$, $p < 0.001$, English vs. Non-

Linguistic: $t(15) = -4.297$, $p = 0.001$) while no significant differences were recorded between Japanese and non-linguistic stimuli ($t(15) = -0.412$, $p = 0.686$). These differences between familiar and novel orthographic systems will be discussed at length in a later section. Differences between the three language conditions are further demonstrated with topoplots, graphical representations of voltages over all of the scalp electrodes during a specific time window, using subtraction waveforms (subtracting the value of one condition from the value of a second condition, thus displaying the difference between two conditions over time) as illustrated in Figure 2, which shows greater posterior negativities (depicted in blue) for the Japanese than English (leftmost column) and the Non-Linguistic than English conditions (middle column); no similar difference is observable for the Japanese vs. Non-Linguistic comparison (rightmost column).

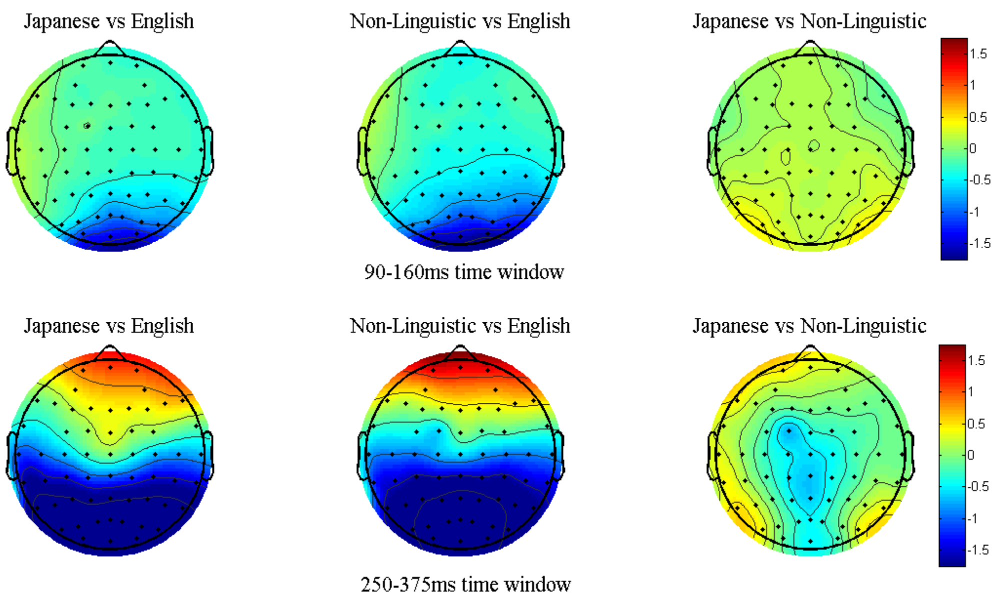

Figure 2. Topoplots demonstrating subtractions of two stimuli in two separate time windows: 90-160ms (top row) and 250-375ms (bottom row)

Lateralization

Analysis was expected to yield lateralization differences across languages as presented in Maurer et al. (2008), and these findings were largely consistent with that study. Within the 90-160ms time window, collapsing across all within-language stimuli types, English was found to be significantly left lateralized in the occipitotemporal region analysis ($t(15) = 2.329$, $p = 0.034$), as seen in Figure 3 (leftmost waveform), below.

Japanese and non-linguistic stimuli both showed no significant lateralization effects within the occipitotemporal region (Japanese, $t(15) = 1.156$, $p = 0.266$, non-linguistic, $t(15) = 1.294$, $p = 0.215$, see Figure 3 (center and rightmost waveforms, respectively),) The lateralization effect can be seen in Figure 4, topoplots of the various language conditions in the 90-160ms time window which demonstrate these differences. As these findings run largely congruent to those of Maurer et al. (2008), brief mention of them will be made in the subsequent discussion section.

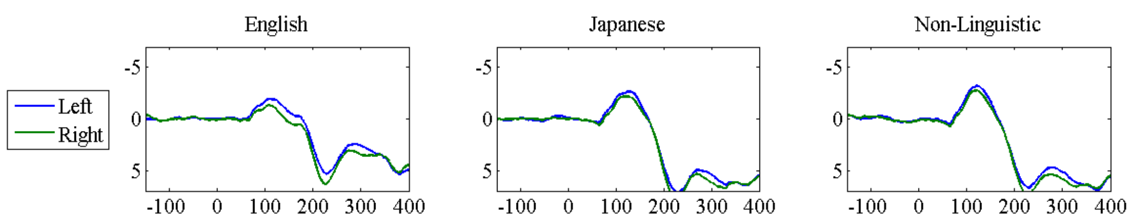

Figure 3. ERP waveforms comparing responses to English, Japanese and Non-Linguistic stimuli taken from averages of electrodes in the Left Occipitotemporal Region group to Right Occipitotemporal group

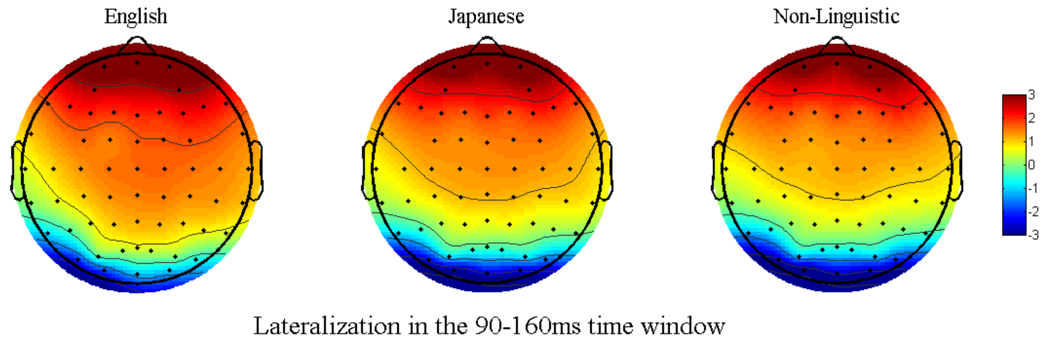

Figure 4. Topoplots for all 3 Language conditions in the 90-160ms time window, demonstrating the greater degree of left-hemisphere negativity in the occipitotemporal region for English, and a broadly distributed negativity in the occipitotemporal regions for Japanese and non-linguistic conditions.

Length

No significant differences for length were recorded in any within language pair-wise comparison were recorded for either word or non-word conditions, or when collapsed across lexical conditions as shown in the figure below. The lack of length differences will be addressed in the discussion section. Figure 5 shows length comparisons for English, Japanese and Non-linguistic stimuli respectively.

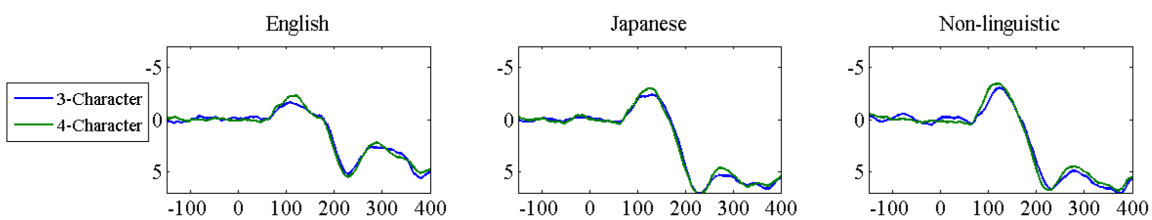

Figure 5. ERP waveforms taken from averages of electrodes in the Left Occipitotemporal region, comparing 3-character words and nonwords to 4-character words and nonwords for English, Japanese and Non-Linguistic stimuli.

Lexicality

Lexicality effects would only be expected to emerge in this study for English, as participants only had knowledge of English, and therefore lacked lexical representations for any stimuli from the Japanese language group. However, whether these effects would be expected to emerge at the N170, or subsequent to the N170, is a matter of debate. Recall that a majority of the literature on this topic indicates that the N170 response is prelexical, suggesting that lexical effects should not be evident for the N170 time window, even for the English stimuli . However, some findings in the literature which do suggest potential lexical effects emerging at N170 (e.g., Maurer et al. 2005) make this an area of inquiry worth examining.

In the 90-160ms time window, no lexical effects for either the familiar English stimuli or the novel Japanese Hiragana stimuli were found to be significant. (English: $t(15) = 0.027$ $p = 0.979$, Japanese: $t(15) = 0.249$ $p = 0.806$) See Figure 6 for lexical comparisons in the occipitotemporal region group (leftmost column).

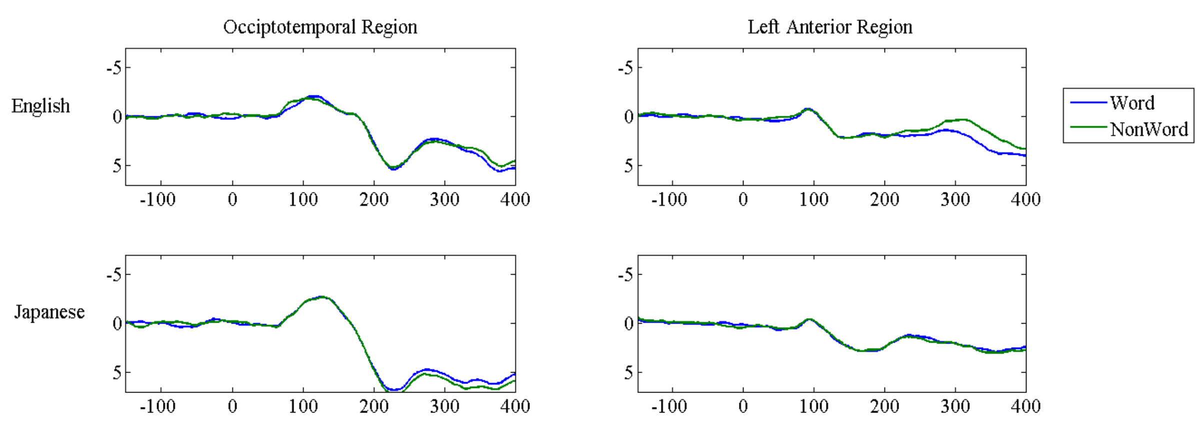

Figure 6. ERP waveforms taken from averages of electrodes from the Left Occipitotemporal and Left Anterior region groups, comparing words and nonwords for English and Japanese stimuli.

However, in the 250-375ms time window, a significant effect for lexicality was noted in the familiar English conditions for the Left Anterior group ($t(15) = 3.886$ $p = 0.002$), as shown in Figure 6 (upper right waveform). As predicted for novel orthographic stimuli this difference caused by lexical status was absent for the Japanese conditions ($t(15) = -0.442$ $p = 0.665$), demonstrated in Figure 6, (lower right waveform). This activation in left anterior areas during this time window appears roughly analogous to the N3 component reported in Proverbio et al. (2004), showing increased amplitude responses for pseudowords over words in the same time window.

Behavioral Data

Although the behavioral task was not designed to reveal differences in processing across conditions, but rather serves to keep the participants' attention focused on the stimuli, we provide a description of participants' performance here, in order to demonstrate that the participants were indeed attending to the stimuli and performing with high accuracy. Of the 120 second-repetition trigger stimuli for the one-back task, subjects missed on average 6.1 targets, or 5.1%. In the remaining 900 first-iteration stimuli, subjects falsely identified 9.9, or 1.1% as repetitions, leaving 93.8% correct responses across all stimuli.

Broken down across languages, subjects performed better in the familiar English condition than they did in the unfamiliar Japanese or non-linguistic conditions. In English conditions, subjects averaged 0.2 missed second-repetitions (0.5%) and 1.2 falsely identified first-iterations (0.4%). Japanese stimuli in contrast displayed an average of 2.5 missed second-repetitions (6.3%) and falsely identified 4.2 (or 1.4%) of first-iterations. In the non-linguistic stimuli condition, subjects missed an average of 3.4 (or 8.6%) second-repetition targets and falsely identified 4.6 (or 1.5%) of first-iterations as repetitions.

Discussion

Our results have demonstrated a clear N170 response congruent with studies conducted in the reading and visual processing fields. Further, these results have demonstrated a strong effect of familiarity in relation to the amplitude of this response, in an experiment wherein these stimuli were randomized across stimulus type, and tightly controlled for length, lexical properties, and bigram combinatorics. The finding of this amplitude distinction occurring in addition to the lateralization effect for familiarity noted by Maurer et al. (2008) provides an intriguing new dimension to our knowledge of the role of experience in orthographic processing. Likewise, the fact that the lateralization effect noted by Maurer et al. (2008) was replicated in the present study even with numerous controls for length, lexicality, bigram frequency, as well as being randomized across stimuli, demonstrates the robustness and reliability of this pattern of effects.

In terms of cross-language effects, for which there is an emerging literature in terms of its effects on the N170 response, our findings are fairly consistent with other literature on the subject. Maurer et al. (2008) reported a lateralization effect for familiar versus novel stimuli wherein familiar stimuli demonstrated a left-lateralized response while novel stimuli were elicited a bilateral or right-lateralized response. This expected pattern was evident in this data as hypothesized. This pattern of lateralization is fairly straightforward to understand in terms of neurological processing. The VWFA is localized to the left occipitotemporal cortex, and has been 'tuned' to recognize familiar orthographic stimuli as meaningful units of information.

Therefore processing of a familiar orthography would occur predominantly in this specialized region. In contrast, the VWFA would not be tuned to process novel orthographic stimuli as meaningful and specialized processing would not be available. Instead, we would expect a much more generalized response, employing wider cortical regions which could be brought to bear on the task of recognition.

In contrast to Maurer et al. (2008), the present study found a greater amplitude N170 response for novel stimuli than for familiar stimuli as well. It is possible that the difference demonstrated between our data and that of Maurer et al. (2008) represents an effect of attention created by task related differences. Maurer et al. (2008) utilized a blocked design, wherein stimuli were not mixed between types. This would have allowed participants to quickly realize whether or not stimuli in an entire block would be linguistically meaningful very rapidly, allowing them the ability to adopt an alternate recognition strategy which would not rely as heavily on language-specific processing. As our stimuli were randomized across stimuli types, participants had no way of predicting whether a given stimulus would be linguistically relevant before it was presented, and thus had less opportunity to adopt alternate recognition strategies. As has already been mentioned, the one-back response paradigm requires constant evaluation on the part of participants to detect repetitions. As such, more attention may have been required of the participants because of the potential for linguistically meaningful information in any potential stimulus, despite the fact that the one-back paradigm is designed not to require familiarity with the orthographic conditions being tested.

Explanations for this amplitude difference demonstrated by our study are difficult to explain fully, mainly due to the limited literature to date on the effect on familiarity on lexical processing. A similar response was found in Baker et al. (2007) an fMRI study utilizing both blocked design one-back paradigm and an event-related paradigm comprised of groups of 5 stimuli of the same type mixed randomly. The study compared two known orthographies (English and Hebrew) among speakers who were effectively bilingual readers of both. As the Hebrew stimuli elicited a much greater response than English stimuli for bilingual Hebrew readers but not for English only speakers, one hypothesis for the response difference was that this response difference was based on prior experience. While there is certainly a role being played by prior experience, Baker et al. (2007) presents data which demonstrates an effect moving in the opposite direction as that shown in our findings, wherein, for English-only readers, the novel Hebrew characters showed no greater activation than number strings. Our findings, in contrast, demonstrate novel orthographic conditions causing a greater amplitude response when compared to familiar orthographic conditions. What Baker et al. (2007) initially consider in order to explain why Hebrew characters yielded a larger response than English letters, in Hebrew/English bilinguals, provides a concrete explanation as to why the Japanese and non-linguistic stimuli in our study yielded a greater amplitude response, namely that the increased response is the result of increased attention to Hebrew stimuli over English stimuli during the task. This attentional argument is in fact a poor fit for their data, in that a novel language stimulus of Chinese characters was also included, and this created a much lower response than either the English and Hebrew words, or the Latin letter strings. Further, this greater response was only present for Hebrew words in Hebrew readers, but absent in English-only readers. One would expect greater responses for Chinese characters in both groups and an equally large response for Hebrew in the English-only group comparable to the observed response for Hebrew in Hebrew readers, while Hebrew readers would likely have a response to Hebrew strings similar to the English word stimuli. While this attentional hypothesis is a poor fit for the data presented in Baker et al. (2007), our data does show a greater amplitude response for novel stimuli over familiar stimuli as would be predicted by this hypothesis, strongly indicating that these increased amplitudes reflect an effect of increased attention to novel stimuli in the current study.

Returning to one of the results of experiment three in Maurer et al. (2008), native Japanese speakers, who were also experienced speakers of English, were found to have an increased amplitude N170 response to English words compared to native English speakers. This increase in response was posited to be due to “novice vs. expert learning”, however as participants had begun studying English at an average 9.9 years of age and had been living in an English-speaking country for an average of 9.4 years at the time of testing, the participants were likely more experienced than the term ‘novice’ would typically imply. As in the Baker et al. (2007) study, applying the attentional hypothesis to this data is problematic as the previous two experiments which tested Japanese orthographic conditions showed no increase in the N170 for native English speakers while viewing Japanese orthographic conditions which were completely novel to them. However, our previously stated hypothesis that the blocked design of the experiments in Maurer et al. (2008) could have reduced the attention of participants by allowing them to quickly predict whether all stimuli of an entire block were linguistically meaningful or not after the presentation of a limited number of stimuli would explain the lack of an increased N170 response for native English speakers to Japanese orthographic stimuli. If the increased amplitude response of the N170 for native Japanese speakers to English words is in fact an effect of attention, this would seem to indicate that non-native orthographies retain a degree of the novel quality which modulates this amplitude difference even with a large amount of experience.

Our study tested responses to familiar and novel orthographic stimuli in adult readers, however controls on our study also allowed for us to test for effects of lexicality and length effects of stimuli on the N170 response. In terms of lexical effects, our findings were largely in line with the majority of the established literature wherein the N170 response is demonstrably a pre-lexical process. While Maurer et al. (2005) found a greater effect for words over pseudowords in their study, no such effects were found in the 90-160ms time window isolated for our analysis. As Maurer et al. (2005) report no controls for bigram frequency between words and pseudowords or other such controls which might inform a pre-lexical process on the well-formed quality of the presented stimulus, it is entirely possible that their lexical effects were in fact an effect of the response discriminating between well-formed words and poorly formed pseudowords.

With regards to lexicality, our data seems most analogous to the data presented in Proverbio et al. (2004), in that the lexical effects presented by our data, occurring in the left anterior portions of the cortex between 250 and 375ms, most closely match with the N3 component presented in their study. This demonstrates that the N170 response is, as the majority of existing literature states, a prelexical process, with lexical access occurring during later processing.

Unlike the previously mentioned Hauk & Pulvermüller (2004) study, no effects for stimulus length were apparent in our results. While their length difference compared words averaging 4.1 letters in length in the short condition to words of 6.2-6.3 average letters in length in the long conditions, our stimuli were simply a comparison of 3 and 4 letter words. Overall the difference in length in the Hauk & Pulvermüller (2004) study was greater than ours and occurred in greater string lengths in general, whereas our ‘long’ string length condition is 0.1 letters shorter than the Hauk & Pulvermüller (2004) 'short' condition. Taken together, the lack of length effect in the present study is not particularly surprising. The purpose of including such a minor length effect was not to test the effect of string length on the N170 response in general, but specifically to examine Maurer et al.'s (2008) hypothesis that the greater negativity observed in their Experiment 1 for Hiragana strings over Kanji was due to a length difference, where Kanji were always 2 characters long and Hiragana strings were 2-3 characters in length. Considering the lack of a length response in the present study for a similarly small difference, and Hauk and Pulvermüller (2004)'s observations that shorter strings elicited a greater N170 response than longer strings, this evidence indicates that it is unlikely that the observed significant difference between the two conditions in the Maurer et al. (2008) study was caused by such a minor difference in string length. It is worth noting that as length effects are still largely understudied in the N170 response literature, which would prevent this explanation from being ruled out completely. Rather, this should be considered along with other possible explanations for the anomalous processing difference noted in the Maurer et al. (2008) study.

Conclusions

Our study has demonstrated the existence of an amplitude based modulation in the N170 response to the familiarity of orthographic stimuli in a reading task. This amplitude based modulation was found in addition to the reports of effects of familiarity on lateralization. The present study differed from Maurer et al. (2008), in that stimuli were randomized between conditions, the notion that this increase in amplitude for unfamiliar language stimuli is a result of increased attention during the task is perhaps the most obvious explanation for this amplitude related difference.

The most obvious next step in this line of research is of course to continue this experiment with the second participant group present in Maurer et al. (2008), namely the Japanese speakers with English language experience. Based on these findings, we would expect speakers with experience in Japanese and English to show the increased amplitude only for non-linguistic stimuli, if indeed the attentional effect on the N170 amplitude is strictly one of novel vs. familiar orthographic systems. However, if the increased amplitude of the N170 for native speakers of Japanese for English words does in fact reflect a persistent novel characteristic which is retained despite considerable experience with a non-native orthography, we would expect to see an effect similar to the native English speakers of the present study, albeit with an increased amplitude to the completely novel non-linguistic symbol set and the non-native English words compared to the native Japanese Hiragana conditions.

A third experimental group, English speaking learners of Japanese, would allow us to examine both the canonical lateralization and amplitude based effects for familiarity by studying participants in the process of acquiring a novel orthography. These learners could be expected to show either a reduced amplitude N170 for Japanese stimuli compared to that of the English only group, or an 170 amplitude analogous to the N170 for English demonstrated by English-only speakers, depending on their level of experience with Japanese and the rate at which familiarity modulates this response. Additionally, as Maurer et al. (2008) reported left-lateralization for both native and non-native orthographies, this participant group would allow us to study the effect of learning on this lateralization and at what rate this lateralization occurs.

Along with the left-lateralization presented by Maurer et al. (2008) for familiar orthographic conditions, we are now presented with two potential vectors for studying the effects of familiarity in modulating the N170 response in ERP. The degree of connection between the left-lateralization for familiarity as demonstrated by Maurer et al. (2008) and the familiarity-based amplitude differences demonstrated by the present study are also potentially of interest. Namely, are the two familiarity effects linked, based on the same adaptation of the VWFA to expertise with a new orthography, or do these two familiarity effects demonstrate different rates of modulation, with one occurring faster than the other? Extending the current study to both of the participant groups suggested would allow for a strong initial examination of the possible connection between these two effects by examining data from participants with varying degrees of familiarity with novel orthographic systems and thus allowing for examination of the way these effects change as a result of L2 learning involving novel orthographic systems.

Further evaluation could be taken by broadening the stimuli types to a number of familiar and unfamiliar language conditions, as was done in the Baker et al. (2007) study, but using equipment which allows for high degrees of temporal resolution, namely EEG or MEG, allowing for stimuli to be completely randomized across conditions as we have done with the Maurer et al. (2008) study, rather than in small groups of stimuli as was done in the event-related portion of Baker et al. (2007)'s study, and measuring the results of event-related potentials rather than the BOLD signal (the measurement of brain activity provided by fMRI, which while precise in terms of localization, provides very poor temporal resolution). Findings analogous to those of this present study would strongly support a task-specific attention-based modulation of the N170 response.

The fact that this study failed to find lexical differences in the N170 response is not particularly surprising as a lack of lexical differences during this response has been noted numerous times. When comparing studies wherein lexical effects emerged during the N170, such as Maurer et al. (2005), to those studies wherein no lexical effects were observed, such as

Dehaene et al. (2002), the absence of controls for sublexical combinatorics such as bigram frequency in Maurer et al. (2005) suggests that these may be an effect of sublexical differences, which would maintain the status of the N170 response as a pre-lexical process. The findings of the current study thus converge with previous reports identifying lexical effects emerging subsequent to the N170 (e.g. Bentin et al., 1999, Proverbio et al., 2004)

Likewise, our lack of length effects in the N170 response was not surprising, due to the small differences in length. The paucity of research directly comparing length modulations of the N170 response is a strong justification that future studies incorporate more stringent length controls as demonstrated in this study, in order to understand the potential contributions of length to the response itself.

Taken together, these results demonstrate both lateralization and amplitude effects of the familiarity of an orthographic system, reflected in the N170 ERP component. Further, the direct comparison of English words to nonwords, in which the two stimulus types were tightly matched for sublexical properties such as length and bigram frequency, yielded lexical effects only subsequent to the N170, consistent with the view of the N170 as a prelexical response. Moreover, this experiment presents a design applicable for tracking the acquisition of an unfamiliar orthography in adulthood, including both lexicalized and novel stimuli in both the first and second language, as well as a rich, complex non-linguistic stimulus set, which are tested within the context of the same experiment. Further research using this paradigm has the potential to increase our understanding of the process of acquisition of a novel orthography as an adult in the process during the course of second language learning.

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Appendix I - Stimuli

English				Non-Linguistic				Hiragana			
3 Character		4 Character		3 Character		4 Character		3 Character		4 Character	
Word	Non	Word	Non	Word	Non	Word	Non	Word	Non	Word	Non
fit	ane	main	herg	[illegible]	[illegible]	[illegible]	[illegible]	こまつ	わしい	うれしい	みくろう
bus	ong	from	gath	[illegible]	[illegible]	[illegible]	[illegible]	こみち	げない	こたえる	くれるい
gun	ont	more	lind	[illegible]	[illegible]	[illegible]	[illegible]	さます	ぎるい	たくさん	うこもね
his	ent	west	vean	[illegible]	[illegible]	[illegible]	[illegible]	さゆり	いんせ	それから	あがりて
but	fon	will	sten	[illegible]	[illegible]	[illegible]	[illegible]	ぢんげ	うとり	おいしい	どこなで
not	ede	like	linz	[illegible]	[illegible]	[illegible]	[illegible]	しきり	じんそ	やさしい	ふじしん
she	wha	some	stis	[illegible]	[illegible]	[illegible]	[illegible]	しぐれ	べんか	ずいぶん	しばりま
her	ces	time	veat	[illegible]	[illegible]	[illegible]	[illegible]	するり	まいせ	はじめて	がんがら
one	hof	only	tous	[illegible]	[illegible]	[illegible]	[illegible]	せいゆ	うかり	いちばん	やばりつ
out	ked	very	toof	[illegible]	[illegible]	[illegible]	[illegible]	あなた	ねがり	かわいい	しぎかつ
him	nof	over	tofe	[illegible]	[illegible]	[illegible]	[illegible]	どちら	うちん	たいてい	いちんつ
who	esh	well	stev	[illegible]	[illegible]	[illegible]	[illegible]	こちら	けたり	さんざん	せがりい
can	wis	even	trep	[illegible]	[illegible]	[illegible]	[illegible]	とたり	やわり	たいへん	いいちん
now	hab	down	mesc	[illegible]	[illegible]	[illegible]	[illegible]	すごい	ゆかく	ときどき	ないしさ
two	yat	back	whap	[illegible]	[illegible]	[illegible]	[illegible]	かない	らかま	ですから	めきがり
any	tem	most	woul	[illegible]	[illegible]	[illegible]	[illegible]	ひどい	やまり	さびしい	でるちま
our	mof	many	rass	[illegible]	[illegible]	[illegible]	[illegible]	はがき	そのり	ことわざ	せごこう
way	yed	good	loof	[illegible]	[illegible]	[illegible]	[illegible]	ことし	やます	ただいま	よぼりで
how	nis	such	chif	[illegible]	[illegible]	[illegible]	[illegible]	わたし	あわる	おはよう	がりてぼ
new	hir	also	mofe	[illegible]	[illegible]	[illegible]	[illegible]	いくら	でもと	かなしい	びんごし
man	gis	work	neld	[illegible]	[illegible]	[illegible]	[illegible]	くろい	さまね	もうろう	せんぱみ
May	esk	long	porm	[illegible]	[illegible]	[illegible]	[illegible]	ないか	くみち	ぜんせん	ばだりぬ
off	tef	life	vebe	[illegible]	[illegible]	[illegible]	[illegible]	いくつ	かさし	たのしい	むせいご
day	jis	same	wras	[illegible]	[illegible]	[illegible]	[illegible]	どうも	いやり	きたない	せなまり
old	arf	last	ceag	[illegible]	[illegible]	[illegible]	[illegible]	みどり	つばり	たいそう	けるたい
why	bem	each	ghax	[illegible]	[illegible]	[illegible]	[illegible]	おなか	でかれ	おととし	ぱすもし
few	sef	look	sove	[illegible]	[illegible]	[illegible]	[illegible]	どうぞ	だりき	もたもた	いありね
far	lep	fact	dorg	[illegible]	[illegible]	[illegible]	[illegible]	とおり	うもし	しんせき	だんたく
end	alc	year	nime	[illegible]	[illegible]	[illegible]	[illegible]	たぶん	にもり	ともだち	ものうす
use	seg	part	teig	[illegible]	[illegible]	[illegible]	[illegible]	きれい	でまつ	にんじん	ともにく
saw	vez	home	blec	[illegible]	[illegible]	[illegible]	[illegible]	あそこ	すんご	いけばな	ぱまれん
set	rov	room	tiew	[illegible]	[illegible]	[illegible]	[illegible]	きのう	ぬもり	しいさい	もなさい
per	bef	need	borf	[illegible]	[illegible]	[illegible]	[illegible]	あいだ	でばり	すきやき	ちわりも
war	gom	less	yedd	[illegible]	[illegible]	[illegible]	[illegible]	きらい	いもね	むらさき	はねぎつ
lot	mab	hand	farl	[illegible]	[illegible]	[illegible]	[illegible]	うどん	きそり	たべもの	みせどう
big	fra	head	palk	[illegible]	[illegible]	[illegible]	[illegible]	いとこ	たらう	しんぶん	ぬこもう
car	pow	kind	barl	[illegible]	[illegible]	[illegible]	[illegible]	おとな	こちば	おおきい	うにもん
god	wev	face	psem	[illegible]	[illegible]	[illegible]	[illegible]	かばん	みそで	あかるい	いぴまれ
air	hoy	case	salc	[illegible]	[illegible]	[illegible]	[illegible]	やすい	まちそ	くちびる	のこもど
age	cak	help	kois	[illegible]	[illegible]	[illegible]	[illegible]	はしか	くみろ	せんたく	かれども

bed	div	high	meff	○⧗▽	▽⧗▽	⧗⧗⧗⧗	⊘⧗⧗⧗	ろうか	すまに	ふうせん	ねばりし
job	gur	love	snom	○△○	⧗▽△	○△▽⧗	△⊘△⊘	かゆい	しもに	いくすう	はりしい
bit	fac	best	gwad	○⧗▽	⧗⧗△	○⧗△▽	⧗▽⧗▽	あした	ぱりど	おもいで	そんまぎ
top	wep	half	weef	▽△△	▽⧗△	⧗⧗○⧗	▽⧗⧗⧗	さとう	あだれ	やそしま	ちごりす
run	ceb	four	zarp	△▽⊘	△⧗○	⧗△▽△	▷⧗△△	すこし	ゆふん	いずれも	しいんつ
ten	cla	real	spom	▽⧗⊘	△○⧗	△⧗⧗○	△△△⊘	しまい	うぽひ	みじかい	ちいばす
boy	gac	sure	oope	○△◁	⧗⧗△	△▽△⧗	△△△⧗	うしろ	えしぽ	いもうと	のそもり
six	cid	open	hizz	△⧗▽	△⧗▽	△△⧗⊘	⧗⧗▷▷	たんす	ぬじき	おとうと	いそうき
bad	yur	body	spad	○⧗▽	◁▽△	○△▽◁	△△⧗▽	いいえ	ふそり	すずしい	よみせい
pay	pab	five	fows	△⧗◁	△⧗○	⧗⧗▽⧗	⧗△▽△	さかな	るにか	たてもの	ものつれ
red	wut	soon	smic	△⧗▽	▽▽▽	△△△⊘	△⊘⧗△	ふるい	ふびし	うんどう	すものか
act	yec	play	pems	⧗△▽	◁⧗△	△○⧗◁	△⧗⊘△	ぶどう	ばれみ	たまねぎ	わごしい
cut	caz	girl	womn	△▽▽	△⧗▷	⧗⧗△○	▽△⊘⊘	めぐみ	そだり	ぶんがく	しいだい
sir	nam	book	deug	△⧗△	⊘⧗⊘	○△△○	▽⧗▽⧗	りんご	らちば	さかなや	ひちんそ
law	gid	past	sosc	○⧗▽	⧗⧗▽	△⧗△▽	△△△△	おんな	ろばね	だいがく	ほまかり
art	foz	idea	spoo	⧗△▽	⧗△▷	⧗▽⧗⧗	△△△△	いたい	まねし	くつした	まねもり
sea	aib	week	foab	△⧗⧗	⧗⧗○	▽⧗⧗○	⧗△⧗○	たたみ	えがと	おんがく	うちせご
son	ows	form	dwot	△△⊘	△▽△	⧗△△⊘	▽▽△▽	みかん	びさて	すいえい	うどうき
low	osp	hard	cuic	○△▽	△△△	⧗⧗△▽	△▽⧗△	ようじ	ぐそめ	おかえし	ろつしい
hot	gwi	name	milv	⧗△▽	⧗▽⧗	⊘⧗⊘⧗	⊘⧗○▽	そうじ	すぼち	がくせい	しいまそ
eye	woc	true	nilv	⧗◁⧗	▽△△	▽△▽⧗	⊘⧗○▽	いちご	れまに	せんげつ	だりもり
oil	dav	food	solp	△⧗○	▽⧗▽	⧗△△▽	△△○△	たまご	えはれ	みざいろ	にぎがい
tax	wob	land	maph	▽⧗▽	▽△○	○⧗⊘▽	⊘⧗△⧗	ながい	せぎま	とりにく	うんごち
arm	yog	call	cavs	⧗△⊘	◁△⧗	△⧗○○	△⧗▽△	しずか	せちも	べんごし	こもわせ
due	plu	live	aigs	▽▽⧗	△○▽	○⧗▽⧗	⧗⧗⧗△	あおい	けるま	ばんごう	がらびし
hit	jid	show	twif	⧗⧗▽	○⧗▽	△⧗△▽	▽▽⧗⧗	せかい	れるま	すうがく	うどうし
dry	psa	poor	keer	▽△◁	△△⧗	△△△△	○⧗⧗△	たかい	うしさ	きいろい	まいだれ
tea	oab	view	sheg	▽⧗⧗	△⧗○	▽⧗⧗▽	△⧗⧗⧗	ちかく	りだす	さまざま	ねしまり
fat	yoz	word	rond	⧗⧗▽	◁△▷	▽△△▽	△△⊘▽	しごと	けるい	いくばく	ないかれ
lie	zos	line	onde	○⧗⧗	▷△△	○⧗⊘⧗	△⊘▽⧗	かずく	しんせ	しがらみ	よばりき
box	ith	city	lerg	○△▽	⧗▽⧗	△⧗▽◁	○⧗△⧗	おもい	とのな	しきたり	せのまい
sky	thu	road	derd	△○◁	▽⧗▽	△△⧗▽	▽⧗△▽	えいご	にまり	このごろ	ねしよい
dog	ine	wife	hesc	▽△⧗	⧗⊘⧗	▽⧗⧗⧗	⧗⧗△△	ほんぶ	いしさ	このとき	せごしべ
key	rin	late	iche	○⧗◁	△⧗⊘	○⧗▽⧗	⧗△⧗⧗	れきし	さいち	このまま	かいつれ
gas	ain	area	uche	⧗⧗△	⧗⧗⊘	⧗△⧗⧗	▽△⧗⧗	おとこ	がりか	さようだ	しかりて