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Ihász Petra: Word Superiority Effect in Bilingual Lexical Decision
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Word Superiority Effect in Bilingual Lexical Decision

The present study is a part of a larger-scale research, in which the temporal characteristics of written word recognition of bilinguals are studied. The research goal of this lexical decision test is to gain information about the temporal characteristics of recognition at the orthographic, phonological and semantic levels of processing. The research questions concern the temporal characteristics as well as the ERP components of bilingual written word recognition. 23 Hungarian-English bilingual participants were tested in the Electroencephalogram laboratory of the University of Pannonia. All of them have C1 level English proficiency and use English at work and in their everyday lives on a daily basis. The results show different patterns for real word and non-word processing in the parietal-occipital area in the early (150-200 ms) and late (200-250 ms) phases of N170 ERP component, which is the perceptual phase of recognition. It means that word recognition starts at as early as 200-250 ms from the onset of the stimulus by the orthographic-phonological processing. However, at this level participants can only identify whether the word is real or not, but not whether it is Hungarian or English.

Keywords: EEG, ERP, bilingual visual word recognition, lexical decision, word superiority effect

1. Introduction

The study of individual bilingualism has a relatively short history that goes back to the onset of infant bilingual development research in the 1990s, following the study of the bilingual mental lexicon with different psycholinguistic tests, and finally, mapping up the structure and function of the bilingual brain with a neurolinguistic approach using neuroimaging procedures. Each and every individual experiences a particular language acquisition pattern, and they use their two languages in their everyday lives on a daily basis, with different people in different situations, in different topics (Grosjean, 1982). The diversity of perspectives and different linguistic settings contribute to the increase in bilingualism research.

1.1. Lexicon(s) in the brain: the bilingual mental lexicon

To know a word means two things: (i) the word is stored in the mental lexicon, and whenever it is needed, it can be retrieved; (ii) it can be recognized and understood while listening or reading, and we can produce it in the oral and written forms. In language perception and production, the declarative memory plays a crucial role as it contains the mental lexicon, which stores the lexical items.

The mental lexicon of an individual is unique and is a specific selection of the total lexicon of a language. There are no two identical mental lexicons, as the words we store are selected based on our culture, knowledge of the world, interest, etc. Lexicons of different languages build up as databases. The concept of the mental lexicon itself was first used by Treisman (1961), who compared the mental lexicon to a kind of storehouse in her dissertation. Since then, psycholinguistic research has been emerged, and psycholinguists found that words exist in the mind, and are not organized as lists of words in an alphabetical order (Aitchison, 1987) but rather as topic related concepts. The bilingual mental lexicon is assumed to contain elements of both languages in a unitary or separated ways (Navracsics, 2007). The bilingual individual, according to Grosjean's functionalist and wholistic view (1989), is not the sum of two monolinguals, and it is very exceptional to find someone who is balanced in both languages and speaks both languages equally fluently. One of the languages will always be dominant, as the Complementarity Principle (Grosjean, 2010; Grosjean & Li, 2013) confirms, as bilinguals acquire and use their languages for different purposes, in different domains of their lives.

The investigation of the bilingual mental lexicon is the key to understand the nature how languages are organized in the brain. The mental lexicon contains all the information (phonological, morphological, semantic and syntactic) that speakers have about individual words and morphemes (Murthy, 1989). The semantic memory – reflected in the lexicon – is not only of linguistic character because it contains the mental representation of one's knowledge of the world. When we study the semantic representation of bilinguals, we have to take the structure of the mental lexicon, the links of the languages as well as culture(s) into consideration (Navracsics, 2007). In bilinguals, the relationship between an L1 and an L2 word varies from individual to individual, since the acquisition pattern and the frequency of use of the words vary (Singleton, 1999).

1.2. Bilingual written language processing

In bilingual visual language processing, we study the brain activations and the mental lexicon when processing two languages at a time, normally in a bilingual mode. Visual word recognition can be studied at the word, sentence and text levels. This study focuses on bilingual word recognition, which refers to the moment when there is a match between the printed word and one of the orthographic forms stored in the mental lexicon, i.e. lexical access is successful. In its broader sense, word recognition includes all mental activity from the perception of the word until the knowledge with its lexical representation is available (De Groot, 2011). By studying written word recognition, researchers intend to find out whether a written word leads to the activation of both linguistic subsystems or whether the activation is restricted to the contextually relevant subsystem of the bilingual memory. Co-activation of information in the other subsystem is referred to as language-nonselective lexical access, while the activation of information in the relevant subsystem is known as language-selective lexical access (De Groot, 2011). De Groot also suggests that the presentation of a word to a bilingual often results in parallel activation in both linguistic subsystems.

1.3. Visual word recognition models

The main focus of bilingual visual word recognition is the neurocognition of multiple languages. In the last few years, there has been a huge increase in understanding the neurocognitive mechanisms of language representation and processing. The central topics concerning the neurocognititon of multiple languages were the following: (i) how bilinguals select between their languages, (ii) whether the conceptual meanings are associated with individual words shared across translation equivalents or each language has a separate conceptual storage space, etc. These questions have been examined using cognitive and behavioral paradigms, and neurocognitive methods. This chapter provides an insight into the bilingual cognitive models and their neural evidence.

The presupposition that both languages of a bilingual individual are active most of the time led to the question of how bilinguals are capable of selecting the correct language that is supposed to be used in a certain context. Several studies claim that there is no constant co-activation of both languages (Schwartz & Kroll, 2006; Titone et al., 2011), and relying on Green's Inhibitory Control Model (1998), according to which bilinguals solve the conflict between languages by suppressing the representations of the non-target language while they activate the representations of the target language, a great number of studies suggest that the bilingual individual needs to apply a high level of cognitive control during language processing (Grant et al., 2019).

1.3.1. The Bilingual Interactive Activation (BIA) model

Based on the interactive activation (IA) model for monolingual visual word recognition (McClelland & Rumelhart, 1981), Dijkstra & Van Heuven (1998) developed the Bilingual Interactive Activation (BIA) model. In the monolingual interactive activation model, there are three levels of nodes representing features, letters, and words. Between these three levels there are two types of relationship: (i) inhibitory connections between nodes that are responsible for activation within a level, and (ii) across-level connections that cause activity of inhibition depending on whether features or letters are active in the recognition process (Grant et al., 2019). The BIA model is very similar concerning the levels of representation units, which represent visual letter features, letters, orthographic word forms and language information, but it is more complex since the interaction occurs not just in one, but in two languages. According to this model, visual letter features and letters are stored in a common system, whereas words are stored in different linguistic subsystems. During the reading process, feature nodes activate relevant letters, letter nodes activate words in the relevant language, and words from both languages might interact in the bilingual word recognition processes (Grant, et. al., 2019).

1.3.2 The semantic, orthographic, and phonological interactive activation (SOPHIA) model

Since the BIA model did not represent semantics, Van Heuven and Dijkstra (2001) developed the Semantic, Orthographic and Phonological Interactive Activation (SOPHIA) model. This model describes the levels of visual and auditory word recognition. The first level of the model is sublexical orthography and sublexical phonology, which are in continuous interaction with each other. The second level represents orthographic words and phonological words, which are also in interaction with each other and with the first level, similarly to the BIA model. The sublexical features (orthography and phonology) activate the word of the appropriate language, and inhibit the activation of the non-target language. The target language gets activated, and the semantic level is also significant at this point, since it is responsible for deciding whether the word has a meaning or not.

1.3.3. The Bilingual Interactive Activation+ (BIA+) model

The original BIA model was extended by semantic and phonological representations, and a non-linguistic task/decision subsystem was added to the word identification subsystem. In the word identification subsystem (similarly to the SOPHIA model), the sublexical orthography and the sublexical phonology are in continuous interaction with each other, and the lexical orthography and lexical phonology are in connection, as well. In this subsystem, the input is processed on the level of sublexical orthography and phonology and then on the level of lexical orthography and phonology. When the target language is chosen, the semantics of the word is checked. The task/decision subsystem receives the input from the identification subsystem, where the correct language is identified and gets activated (Dijkstra & Van Heuven, 2002).

1.4. Neurolinguistic and psycholinguistic studies of the bilingual mental lexicon: lexical organization in the bilingual mind

The neurolinguistic approach to bilingualism focuses on demonstrating the manner in which the two languages are stored in the brain and how differentially (or similarly) they are processed. The early studies focused on (i) how words of the two languages are stored in the mind; (ii) whether there are two separate lexicons or there is one common lexicon that contains all the information; (iii) whether the conceptual representation is common or separate, and (iv) how the lexicons are connected to each other and to the conceptual representation. Early research on the bilingual mental lexicon suggests that words are stored and retrieved in a network of associations (Nattinger, 1988). More recent brain mapping evidence shows that concepts are distributed all across the brain, in both hemispheres. Different parts of the brain get activated depending on the meaning of the word. Although every bilingual's brain is different, there are certain topics that are located in the same areas, regardless of languages (Huth et al., 2016). So the question is how the mind manages two linguistic systems: do bilinguals store information in a unified system and have identical access to both languages, or is the information storage linked to separate languages, meaning two separate mental lexicons (Appel & Muysken, 1987; De Groot, 2011)? One of the most salient questions regarding the bilingual mental lexicon is whether bilinguals' languages are integrated and whether lexical access is selective or non-selective. According to the widely accepted consensus, the bilingual lexical access is characterized by non-selectivity (De Groot et al., 2000; Dijkstra & Van Heuven 1998, 2002). This non-selectivity is true for orthographic (De Groot & Nas, 1991) and phonological codes (Duyck, 2005, Jared & Kroll, 2001). Most researchers share the assumption that there is a parallel activation of the two languages in lexical access regarding language production and perception (Hoversten et al., 2017). A great number of studies have proven that the bilinguals' two languages are constantly activated, and the languages that are not used in certain contexts are never fully deactivated (Dijkstra, 2005; Dijkstra & Van Heuven, 2002, Schmid, 2010; Peeters et al., 2018). Researchers also agree that there is a continuous co-activation at all linguistic levels, such as phonology, syntax and semantics (Miwa & Baayen 2021). For example, at the phonological level, homophones activate the non-target language, too (Marian & Spivey, 2003).

1.4.1. Word superiority effect

Word superiority effect is a well-known phenomenon in neurolinguistic and psycholinguistic research that describes a superior processing and better recognition of words in comparison to pseudo-words and non-words (Sand et al., 2016). According to Starrfelt et al. (2013), single words are simply processed faster than single letters; however, when multiple stimuli are presented simultaneously, letters are recognized more easily than words both in terms of perceptual processing speed and visual short term memory capacity.

MEG studies, which produce spatial and temporal information about brain activities, revealed that orthographical and phonological information of the words takes places in the intero-temporal area (often referred to as visual word form area). This area responds to the visually presented words and pseudo-words. Thereafter the information is forwarded to the inferior-frontal gyrus, where the linguistic processing takes place (Peeters et al., 2018).

ERP studies show that skilled readers have access to multi-layer phonological representations during word recognition, and they also identify information about consonants and vowels, syllables, sub-phonemic information (voicing), segmental and suprasegmental features easily and quite quickly (Halderman et al., 2012).

Simos et al. (2002) examining brain mechanisms for reading words and pseudo-words found that reading words having a meaning results in activations in the left posterior middle temporal gyrus and in the mesial temporal lobe areas, while reading pseudo-words ended up in higher activations in the posterior superior temporal gyrus, and in the interior parietal and basal temporal areas, furthermore, they found that pseudo-words cause activations in different parts of the brain. Pseudo-words require high level of phonological awareness. On the other hand, for an experienced reader, reading a word carrying a meaning that has a high frequency does not require much phonology, and the recognition does not depend on lexical retrieval, the process is rather automatized (Perea et al., 2005).

1.6. The present study

The present study seeks to find out whether written language processing of bilingual people is the same in L1 and L2, where the different activations occur in the brain and what the temporal differences between the recognition of English and Hungarian words are. Furthermore, the experiment investigates which parts of the brain and in what order get activated in the recognition process, what the activation process is like. The study was approved by the Ethics Committee.

For this study, the following research questions were formulated: (i) What are the neurolinguistic characteristics of bilingual visual word recognition?; (ii) Do the two languages have the same activation patterns?; (iii) If not, where are the differences?; (iv) What causes the differences?

My hypotheses are as follows: (i) Word recognition activates different parts of the brain from the moment of the stimulus onset until the identification of the word; (ii) the activation occurs at different places through time; (iii) the recognition of the two languages has the same activation patterns; (iv) word frequency has a decisive role in word recognition.

2. Methods

2.1. Participants

23 Hungarian–English bilingual volunteers (10 males, mean age: 24.57 yrs, 19 right-handed) were tested in the EEG laboratory of the Information Technology Faculty at the University of Pannonia. All of them were native speakers of Hungarian with C1 level English proficiency, and they all use English at work and in their everyday lives. They spend at least half an hour a day reading English books and articles. The majority actively uses English for several hours a day on average. None of the participants have lived in an English-speaking country for longer than 3 months. They come from Hungarian monolingual families and use Hungarian at home. All of them are late bilinguals; they acquired English in an instructed way at primary or secondary school (mean age of acquisition is 9.97 years). They all had normal or corrected-to-normal (glasses or contact lenses) vision, they did not have any hearing impairment, language disability, learning disability, and no one reported any history of neurological illness.

2.2. Test materials

2.2.1. Language decision test

The language decision test included 180 monosyllabic words: 60 Hungarian (e.g. *bál, cím, lyuk*), 60 English (e.g. *age, cat, hair*) and 60 interlexical homographs (words with identical spelling but different meanings in the two languages) (e.g. *comb, hold, mind*) and cognates (words with identical spelling and same meaning in the two languages) (e.g. *blog, film, lift*). To control for word frequency, I used the Hungarian National Corpus (HNC) for Hungarian, and the Corpus of Contemporary American English (COCA) for English. The Hungarian National Corpus currently contains up to 187 million words. The corpus is divided into five subcorpora by regional language variants, and into five subcorpora by text genres, as well (http://www.nytud.hu/). COCA has more than one billion words from eight genres, and it has more than 25 million extra words each year. Due to these features, both HNC and COCA are suitable databases to study word frequency. I checked the frequencies of homographs in the test: the mean frequency of the words with Hungarian meanings is 23773, and the mean frequency of words with English meanings is 711622. The results of the frequency check also shows that the rank based on frequency is 44538 for the Hungarian non-homographic words. Since all participants were Hungarian, they were familiar with all Hungarian words. As for the English words, their mean frequency is 3381. According to the Oxford dictionary (www.oxforddictionaries.com), all English words belong to A1-B1 levels. Participants were asked to make decisions whether the word on the screen is Hungarian or English and click on the left (English word) or right (Hungarian word) button of the computer mouse. With this experiment, I checked language activation.

2.2.2. Lexical decision test 1

The lexical decision test contained 30 Hungarian (e.g. *ajánló, ebédlő, hegedű*), 30 English 6-letter words (e.g. *abroad, casual, option*) and 60 non-words (e.g. *eekkff, ggggss, paaars*). Non-words were created by randomly putting letters together in a way that they could not structurally resemble any meaningful words in either language. The participants' task was to decide whether the letter string they see on the screen is a word or not. With this test, I checked the word superiority principle.

2.2.3. Lexical decision 2

This modified version of lexical decision test included 60 Hungarian (e.g. *amagyi, erédes, marisó*) and 60 English 6-letter pseudo-words (e.g. *bliney, foreet, rapoon*)., and their structures matched with either the Hungarian or the English phonotactic rules. The participants' task was to decide by clicking on the left (English) or right (Hungarian) buttons of the computer mouse, which of the presented letter strings would suit the Hungarian and which the English language. With this test, I checked the phonological awareness in the two languages.

2.3. Measuring neural activity

Participants were tested in the Electroencephalography (EEG) laboratory of the Faculty of Information Technology at the University of Pannonia, Veszprém, Hungary. A 128-channel amplifiers EEG was used to collect the data. All participants were included in the analysis. EEG is a non-invasive method to measure the electrical activity of the brain. The main advantage of EEG over other brain imaging methods (e.g. fMRI, PET) is its superior temporal resolution.

2.4. Procedure

Before the measurement, a consent form along with the instructions was handed to each participant, and they had to read and sign it. The basic instructions were included in the consent form. Participants were informed that the experiment takes approximately one hour, it is non-invasive, which means that it does not cause physical pain or inconvenience, and they can interrupt the experiment at any time without any consequences. None of the participants interrupted the measurement.

As a second step, participants filled in a non-standardized language background questionnaire related to their Hungarian and English language use. They also completed a standardized questionnaire (Language Experience and Proficiency Questionnaire – LEAP-Q), in which they had to (i) list all the languages they know in order of dominance and (ii) in order of acquisition, (iii) provide the percentage of the time they are currently and on average exposed to each language, and (iv) indicate if they have lived abroad for a longer period of time, etc. (Marian et. al., 2007).

Participants were asked to minimize eye-movements, eye-blinks, and every other type of muscular movement, such as swallows, coughs, gnashing of teeth, nodding, etc., during the test in order to diminish the noisiness of the data. After a 6-stimulus trial for each participant, the real experiment started. Every participant received a different randomization of stimuli. Stimulus words were presented twice in order to get the necessary quantity of data so that I could draw more clear-cut conclusions after the analyses. After each test they could relax (rest their eyes, drink some water) as much as they wanted and they continued with the next task when they felt ready.

2.4.1. Custom-made program

A previously designed custom-made program (MATLAB, MatLab Inc.) running on a PC was used for the experiments (Navracsics & Sáry, 2013). Stimuli were presented on a white background, using black characters (Arial, font size 14) in the middle of the screen. The viewing distance was set to be the appropriate normal viewing distance of a computer screen (~ 50 cm). Trials started with the onset of a fixation spot in the middle of the screen, which was followed by a stimulus chosen from the pool. The inter-trial interval was set for 1 s, the stimulus stayed on the screen for 2 s (exposure time). During this time participants were required to hit the right or left button according to the task instructions. If no response key was selected during the exposure time, the program did not record anything and the next trial started (fixation onset for 1 s, etc.). The task was machine paced to ensure a constant level of attention of the participants.

Participants were shown 6 stimuli initially to become familiar with the procedure (training phase). After a short break, the tests were presented in a semi-random fashion (test phase). The program recorded correct/incorrect hits and response latency times.

2.4.2 EEG measurement

EEG data were recorded using a 128-channel Biosemi ActiveTwo measurement device with Ag/AgCl active electrodes placed and arranged in the Biosemi equiradial ABC layout cap. Measurement was performed at fs = 2048 Hz sampling frequency. Word stimulus and response keypress events were transformed into Biosemi EEG trigger signals using a special-purpose trigger unit (Issa et al., 2017). The unit includes a display-mounted light sensor for stimulus and user controlled micro-switches for response detection, and transforms the generated trigger impulses to TTL-level input for subsequent sampling by the Biosemi USB Receiver unit. The digitised EEG data is stored in raw reference-free Biosemi format in BDF data files.

2.5. Data analyzing methods

The measured data was first pre-processed to remove DC offset, then re-referenced to average reference and band-pass filtered with a 0.5-45 Hz linear phase FIR filter. Next, stimulus-locked epochs were extracted with a 500 ms pre-stimulus and 2000 ms post-stimulus interval. Each stimulus-response trigger signal pair was used to determine the subject reaction time (RT) for each word. Epochs including extreme signal amplitudes, blinks or extensive muscle noise, or having extreme reaction time values ($RT < 100$ ms, $RT > 1500$ ms) were rejected manually. Next, each epoch was baseline-corrected by computing the signal average for the -300 to 0 ms interval, and removing the average from the entire signal. Finally, the extracted epochs for each of the 128 electrodes were averaged.

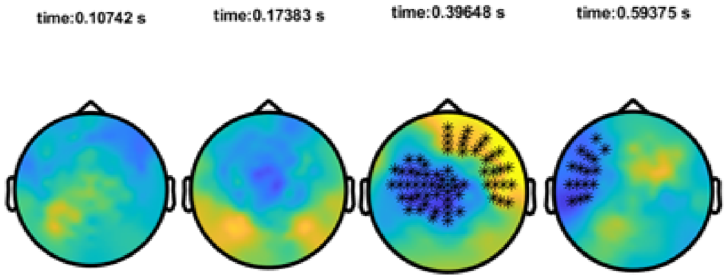
Each participant was analyzed individually, and a group statistical analysis was carried out, with the Statistica software (StatSoft, Inc.) using nonparametric statistical methods (Sign test) and Chi-square test. Tests were classified as significant if the corresponding type error was smaller than 0.05.

3. Results

3.1. Brain activation in the process of word recognition

Word recognition activates different parts of the brain from the moment of the stimulus onset until the identification of the word. The process of word recognition is illustrated by the four topoplots in Fig. 1., which show the activated areas in yellow; the significant differences are represented with dots, as in all the illustrations below in this subchapter.

Figure 1. Topoplots representing brain activation in the process of word recognition



At the onset of the stimulus the visual cortex gets activated. P100 is the first component in a series of components that responds to visual stimuli. It is the first positive-going component and its peak is normally observed in around 100 ms. As for the neurolinguistic background, this is where the identification of letter strings takes place.

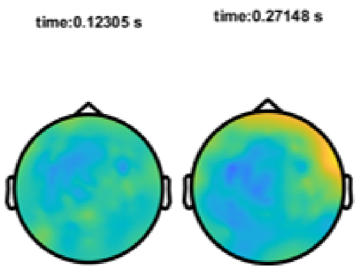
N170 is a component of the event-related potentials (ERP) that reflects the neural processing of words. This is where the identification of lexical entries takes place.

N400 is a negative-going deflection that peaks around 400 ms post-stimulus onset, although it can extend from 250-500 ms. N400 is generally maximal over centro-parietal electrode sites. The N400 is a normal brain response to words and other meaningful stimuli, such as visual words. Furthermore, N400 is associated with lexico-semantic processing that activates word processing.

3.2. Hungarian and English words

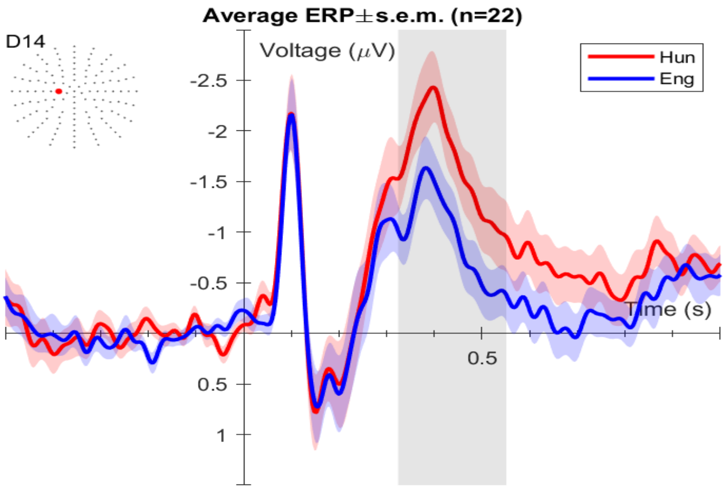
It is observable that between 100 and 300 ms (orthographic-phonological level) there is no significant difference between the recognition of Hungarian and English words (Fig. 2.). However, the most relevant channels that are involved in visual word recognition show significant differences (Channel 14 in Fig. 3.) as can be seen in the ERP curves.

Figure 2. Topoplots representing the recognition of Hungarian and English words between ~100 and 300 ms



The grey line represents the significant difference (Hungarian words are presented by the red line and English words by the blue one). From the ERP curves it is visible that cognitive regions start to take part in the processing, since there is a significant difference (see grey path in Fig. 3.) in the activation patterns in the central region.

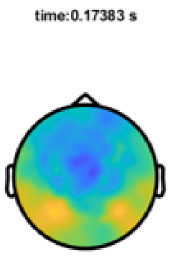
Figure 3. Channel D14 representing significant difference between the recognition of Hungarian and English words



3.3. Words and non-words

At 170 ms, there is an activation in the visual cortex, and as time goes on, occipital, occipito-parietal, frontal lobes and the central parts of the brain show activations, as well (Fig. 4.).

Figure 4. Topoplot representing the recognition of words and non-words at ~170 ms



As opposed to the recognition of Hungarian and English words, significant difference occurs between the recognition of words and non-words at the early phase of word recognition (200-350 ms) in the temporal lobe. Channel D24 (temporal lobe, Fig. 5.) shows higher brain activity in case of words (between 230 and 380 ms), which means that the recognition of real words requires greater cognitive activity; furthermore, semantics has a role in recognition (around 500 and 600 ms).

Channel D14 (central part of the brain) also represents significant difference between the two categories at 350-500 ms, which indicates the semantic processing of words.

Figure 5. Channel D24 representing significant difference between the recognition of words and non-words

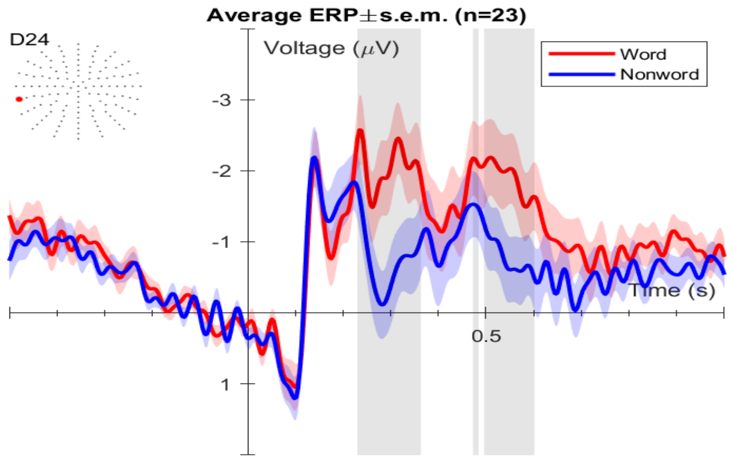


Figure 6. Channel D14 representing significant difference between the recognition of words and non-words

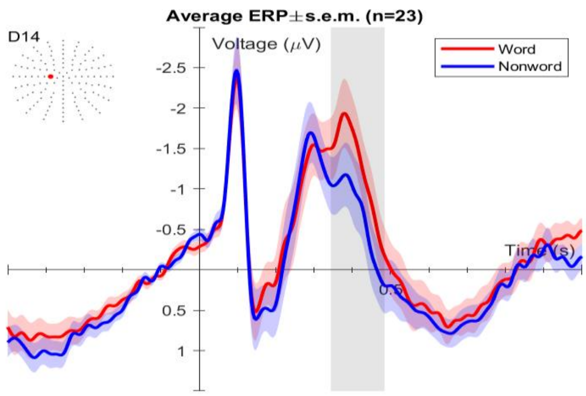
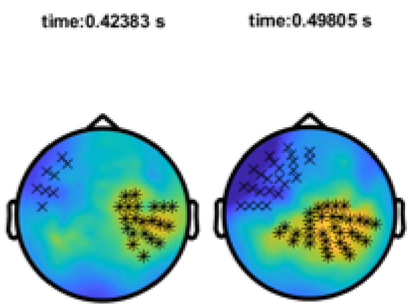
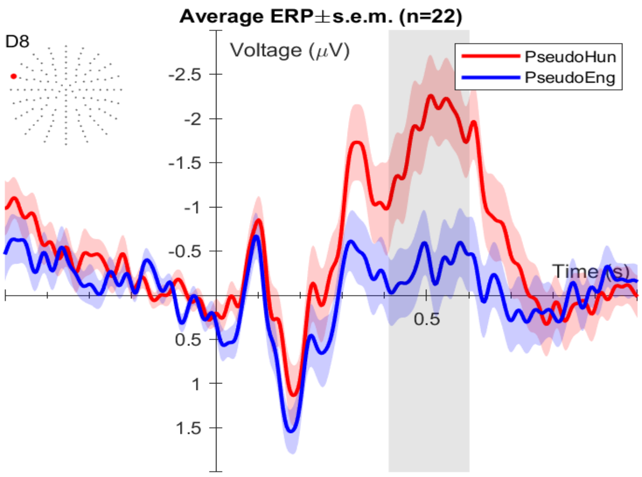


Figure 7. Topoplots representing the recognition of pseudo-words



Channel D8 (temporal and frontal lobes) show high brain activity (Fig. 8.), which means that it is quite a huge cognitive burden to decide which language the pseudo-words belong to.

Figure 8. Channel D8 (temporal lobe) representing significant difference between the recognition of Hungarian and English pseudo-words



3.5. Homographs

At the beginning of word recognition (between 100 and 300 ms, which is the orthographic-phonological level of word processing), no significant difference between the two categories is observable. Significant difference occurs only at 490 ms and after (Fig. 9.).

ERP curves show that in motor processing there is no significant difference, which means that homographs are processed equally, regardless the language. Channel D8 (representing temporal-frontal lobe) shows that Hungarian and English curves separate from each other between 400 and 600 ms (Fig. 10.), but the difference is not significant. At this time participants decide whether they recognize the homographs as an English or a Hungarian word, but there is no difference between the way they decide.

Figure 9. Topoplots representing the recognition of homographs

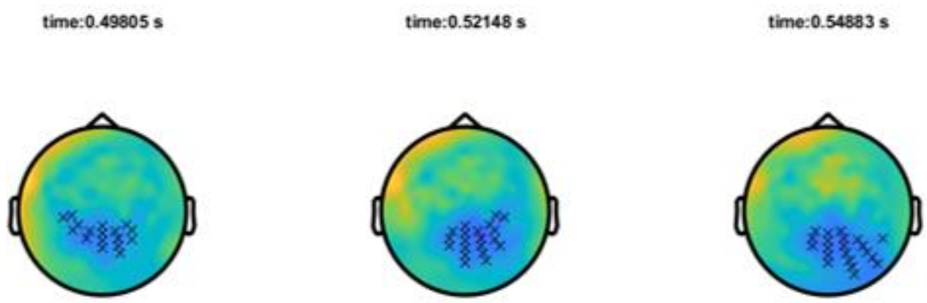
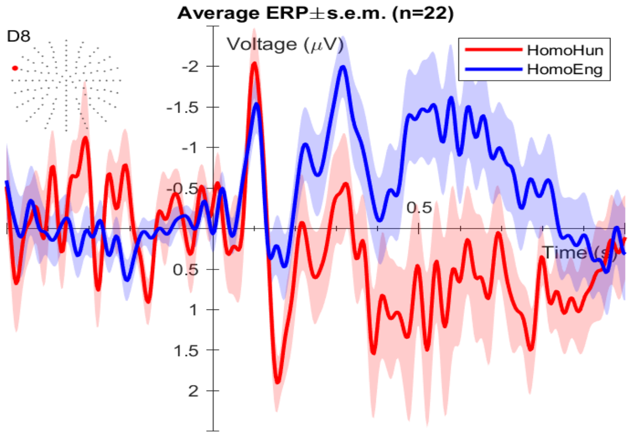


Figure 10. Channel D8 (temporal lobe) representing the recognition of homographs



3.6. Psychophysical results

I compared my results with the results of the psychophysical tests of the same measurements to see whether the results are the same. Psychophysics is the scientific study of the relation between stimulus and perception. In psychophysical tests, reaction time and accuracy are measured.

As Fig. 11. and 12. suggest, the psychophysical results do not always coincide with the results of the experiments that were carried out with imaging techniques. The psychophysical analysis shows that there is no significant difference either in reaction time or in accuracy between the two categories in each test.

With the help of the psychophysical analysis of the same data we are able to compare how much more defined and accurate the results that we receive from an EEG study are.

Figure 11. Psychophysical analysis of reaction time

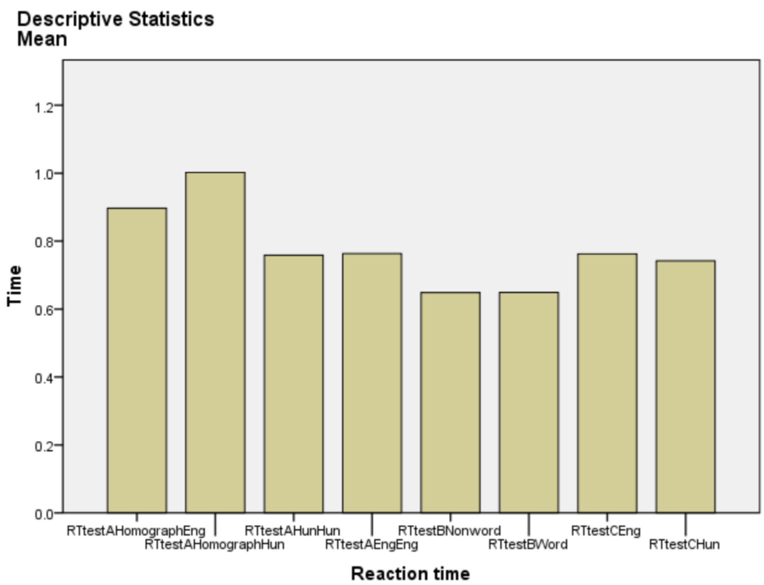
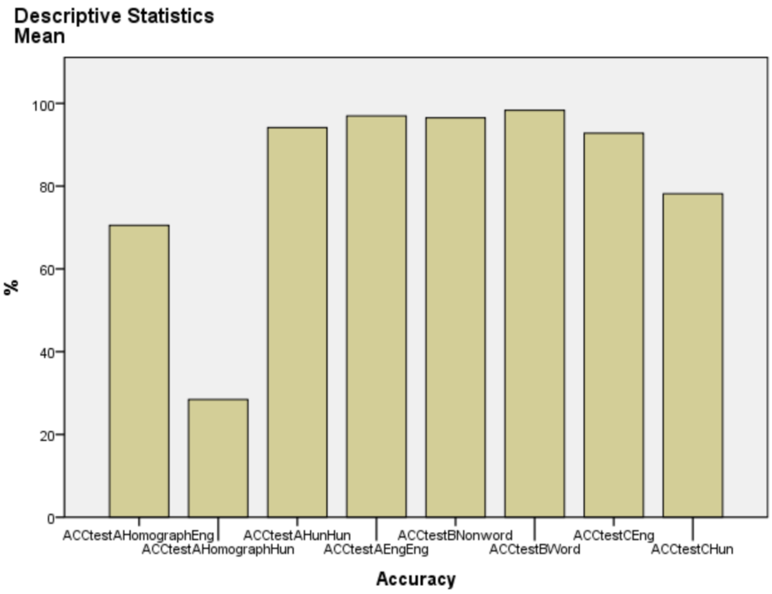


Figure 12. Psychophysical analysis of accuracy



4. Discussion

The aim of the present study is to find out the neurolinguistic and temporal characteristics of bilingual visual word recognition, and to investigate which parts of the brain and in what order get activated in the recognition of Hungarian and English words, homographs, non-words and pseudo-words. The study also seeks to discover the role of word superiority effect, and whether word frequency and linguistic typology are influencing factors in bilingual word recognition.

During visual word recognition, different parts of the brain get activated from the onset of the stimulus. At 100 ms, the visual cortex gets activated, and the visual system responds to the letter strings. Although there is high-level linguistic information processing at this level, the visual system responds only to the frequency of letter strings, and the lexical-phonological and lexical-semantic processing is involved much later (Carreiras et al., 2013) as it was seen in our measurement, as well. N170 reflects the neural processing of words. This is where the identification of lexical entries takes place and it is the proof of the word superiority effect. N170 is a response that makes a difference between words and non-words or pseudo-words (Maurer et al., 2005). N400 is associated with lexical-semantic processing that activates word processing (Laszlo & Armstrong, 2013).

My results suggest that word recognition activates different parts of the brain from the moment of the stimulus onset until the identification of the word, and confirm the hypotheses related to the neurolinguistic and temporal characteristics of bilingual visual word recognition (Navracsics & Sáry, 2013; Carreiras et al., 2013; De Groot, 2011). In the recognition of Hungarian and English words, there is no significant difference between the two categories on the orthographic-phonological level. It means that the participants did not need any special effort to identify the words, which implies that word familiarity plays a crucial role in visual word recognition as it is claimed in Assadollahi and Pulvermuller (2003), Dambacher et al. (2006), and Yum and Law (2021). During visual recognition of words, pseudo-words and non-words, word frequency, familiarity, and grapheme-phoneme consistency are all influencing factors (Navracsics & Sáry, 2017; Davis, 2012).

In case of the recognition of words versus non-words, there is activation in the visual cortex at 170 ms, and occipital, occipito-parietal, frontal lobes, and the central regions of the brain also get involved. Significant difference between words and non-words occurs at 200-350 ms in the temporal lobe with higher brain activity in case of words. The recognition of real words requires greater cognitive activity, and semantics has a role in recognition. The results suggest higher brain activity in case of real words, which proves the hypothesis of word superiority principle. According to the word superiority principle, non-words are recognized more easily than real words both in terms of perceptual processing speed and visual short-term memory capacity (Starrfelt et al., 2013). This is the reason why participants recognized non-words faster than that of words (Navracsics & Sáry, 2013). In case of pseudo-words significant difference between the two categories occurs only at 420 ms, when the lexical-semantic processing takes place. Temporal and frontal lobes show high electrical brain activity, so the participants need quite a huge cognitive burden to decide which language the pseudo-words belong to, however phonological awareness help them to decide. It supports the previous findings of phonological awareness having an influence on bilingual visual word recognition (Halderman et al., 2012; Perea et al., 2005; Simos et al., 2002). In case of the recognition of homographs, at the beginning of word recognition (on the orthographic-phonological level), there is no significant difference between the two categories. Neither do ERP curves represent significant difference, which means that homographs are equally processed regardless the language. Although there is a difference between the brain activations in the temporal and frontal lobes, this difference is not significant. At this point participants are able to decide whether they recognize the homographs as a Hungarian or an English word, but there is no difference between the way they make the decision. These data coincide with the former findings related to the homograph effect, which explains that participants are exposed to a greater cognitive burden (Navracsics & Sáry, 2013), and the reaction time is longer due to the fact that both lexicons are active (Grosjean, 2001; Elston-Guttler et al., 2005).

While Hungarian has a shallow writing system and is built on a consistent mapping of graphemes to phonemes, English has a deep one and there is no grapheme-phoneme correspondence rule in it. Hungarian and English are typologically non-related languages. In case of bilinguals, who speak two typologically unrelated languages, the language specific letter string immediately activates the appropriate language, since the other language lacks that combination of letters (Singleton, 1999). In my test, in case of highly proficient bilinguals the recognition of the two languages has the same activation patterns. These results correspond with other researchers' results gained from investigations on typologically related languages, such as Spanish-English (Macizo et al., 2010; Schwartz et al., 2007), or Dutch-English (Lemhöfer & Dijkstra, 2004; Van Assche et al., 2009), which suggests that typology does not influence word recognition.

5. Conclusion

Bilingual visual word recognition starts at as early as 200-250 ms from the onset of the stimulus by the orthographic-phonological processing. Different patterns can be identified for word and non-word processing in the parietal-occipital area in the early (150-200 ms) and late (200-250 ms) phases of N170 ERP component, which is the perceptual phase of recognition. The recognition of pseudo-words is prolonged and requires phonological awareness. Different patterns for pseudo-word processing are observable in the occipital, occipito-parietal, frontal lobes, and in the central regions of the brain. The recognition of English and Hungarian words shows identical patterns of activation with the successful discrimination of languages at N400-600 components, where the semantic processing of words occurs. However, the recognition of homographs requires longer time. The recognition of real words requires great cognitive activity, and semantics has a great role in visual word recognition.

As a consequence, the results support the idea that the visual word recognition of alphabetical languages activates different parts of the brain from the onset of the stimulus to the recognition, and during this process, activation occurs at different places through time. Furthermore, regardless the typology, there is no difference between the recognition of L1 and L2 words in case of highly proficient bilinguals.

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