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Event-Related Potentials in the Study of Hungarian-English Bilingual Visual Word Recognition

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Thesis for obtaining a PhD degree in the Multilingual Doctoral School of the University of Pannonia

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PhD Dissertation

Abstract

Ihász Petra

Event-Related Potentials in the Study of Hungarian-English Bilingual Visual Word Recognition

Word recognition includes all mental activity from the perception of the word to the identification of its lexical representation that is available in the mental lexicon. Studies in bilingual written word recognition 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 (De Groot, 2011). Lexical decision test results cover a wide range of information about visual word processing. With an electrophysiological (EEG) study the 'what', 'when', 'where', and 'how' can be revealed in visual word recognition (Carreiras et al., 2013). In lexical decision tasks, letter strings are presented and participants decide whether the letter strings are words or not while response latencies and accuracy are measured.

The research goal of this paper 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 the isolated bilingual word recognition process. Based on previous psychophysical results (Navracsics & Sáry, 2013), my hypotheses are as follows: (i) in highly proficient bilinguals, the latency of L1 word recognition is similar to that of L2 recognition; (ii) the recognition of real words is faster than that of pseudo-words; (iii) orthographic and phonological awareness helps word recognition, (iv) the recognition of homographs is longer than non-homographs; (v) the influencing factors of visual word recognition are frequency, word classes, the length of the words, familiarity and language dominance.

23 Hungarian–English bilingual individuals (10 males, mean age: 24.57 yrs) volunteered to take part in the EEG study. All of them were Hungarian L1 speakers with C1 level English proficiency, and use English at work and in their everyday lives on a daily basis. The language decision test included 180 monosyllabic words: 60 Hungarian, 60 English words, and 60 interlexical homographs and cognates. The participants' task was to decide whether the word appearing on the screen was English or Hungarian. With this experiment, I checked language activation. The lexical decision test contained 30 Hungarian and 30 English words and 60 non-words, each consisting of 6 letters. 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. The modified version of the lexical decision test contained 60 Hungarian and 60 English six-letter pseudo-words, and their structures matched with either the Hungarian or the English phonotactic rules. The participants' task was to decide whether the words on the screen fit into the Hungarian or the English language. With this test, I investigated phonological awareness.

A custom-made program (MATLAB, MatLab Inc.) running on a PC was used for the experiment. EEG data were recorded with a 128-channel Biosemi ActiveTwo measurement instrument. The program recorded all the hits, and the latencies were registered. The EEG data were filtered and the ERP curves were analyzed in relation to both English and Hungarian words.

In the recognition of Hungarian and English words and homographs, the mean response language per participant indicated high accuracy for both Hungarian and English conditions (96% and 98%, respectively), whereas the homographs indicate a bias towards English responses (27% Hungarian response). No significant difference was found in the mean response times of Hungarian and English words, whereas the interlexical homographs produced around 150 ms longer responses. In the processing of Hungarian and English words, there was no difference between the two categories in the early phases of recognition, corresponding with the orthographic-phonological level. However, the neural representation of the two languages differed later reflecting the differences in semantic or decision-related processes. In the case of the Hungarian-English interlexical homographs, the ERP waveforms did not show significant differences between the items perceived as English or Hungarian. The recognition of homographs did not trigger different processing patterns; however, various cognitive efforts could be observed. These data coincide with the former findings related to the homograph effect (Navracsics & Sáry, 2013), which explains that participants are exposed to a greater cognitive burden in the recognition, and the reaction time is longer due to the fact that both lexicons are active. The results show significant difference between the recognition of words and non-words at the early phase of word recognition (200-350 ms) in the temporal lobe. The higher brain activity in the case of words shows that the recognition of real words requires greater cognitive activity. In the case of pseudo-words, a significant difference occurs at 420 ms between the recognition of pseudo-words designed with the phonological rules of the English and Hungarian languages.

Keywords: *EEG, ERP, bilingualism, written word recognition, bilingual visual word recognition, language decision, lexical decision, homograph effect, homographs, interlexical homographs, cognates, non-words, pseudo-words, language activation, word superiority effect, phonological awareness, reaction time, psychophysics, neurolinguistics, psycholinguistics*

Doktori értekezés

Kivonat

Ihász Petra

Eseményhez kötött potenciálok a magyar-angol kétnyelvű vizuális szófelismerésben

A szófelismerés folyamata magában foglalja az összes agyi tevékenységet, ami az észleléstől a szóazonosításig tart. A kétnyelvű írott nyelvi feldolgozás témakörében folytatott kísérletek azt kutatják, hogy az írott szó mindkét nyelvi alrendszert aktiválja-e, avagy az aktiváció a kétnyelvű memóriának csak a kontextuálisan releváns alrendszerét érinti (De Groot, 2011). Az, hogy az agyban lévő aktiváció mikor, hol és hogyan történik, elektrofiziológiai tesztekkel (EEG) kiválóan vizsgálható (Carreiras és társai, 2013).

Az EEG teszt célja, hogy információt gyűjtsünk a szófelismerés ortográfiai, fonológiai és szemantikai szintjeiről. Korábbi pszichofizikai kutatások (Navracsics & Sáry, 2013) eredményein alapulva az alábbi hipotéziseket fogalmaztam meg: (i) A szófelismerés időbeli aspektusai a két nyelvben megegyeznek a második nyelvüket magas szinten beszélő kétnyelvűek esetén; (ii) a valódi szavak felismerése gyorsabb, mint az álszavaké; (iii) az ortográfiai és fonológiai tudatosság segíti a szófelismerést; (iv) a homográfok felismerése több időbe telik, mint a nem homográfoké (homográf-hatás); (v) a szógyakoriság és a nyelvspecifikus karakterek befolyásolják a vizális szófelismerést.

23 magyar anyanyelvű fiatal felnőtt vett részt a kutatásban (10 férfi; átlagéletkor: 24,57 év). Mindannyian C1-es szinten beszélik az angolt, és napi szinten használják munkájukban vagy az iskolában. A nyelvi döntés teszt 180 egyszótagú szót tartalmazott: 60 magyar, 60 angol szót és 60 interlexikális homográfot és kognátuszt. A résztvevők feladata az volt, hogy eldöntsék a képernyőn megjelenő szóról, hogy angol-e vagy magyar. Ezzel a teszttel a nyelvi aktivációt vizsgáltam. A lexikai döntés teszt 30 magyar, 30 angol szót, illetve 60 értelmetlen betűsort tartalmazott, melynek mindegyike 6 betűből állt. Az értelmetlen betűsorok random betűkombinációkat alkottak olyan módon, hogy fonológiai struktúrájukban egyik nyelvre se hasonlítsanak. A résztvevők feladata az volt, hogy eldöntsék a képernyőn lévő szavakról, hogy szavak-e, vagy nem. Ezzel a teszttel a szószerűségi elvet vizsgáltam. A lexikai döntés teszt második változata 60 magar és 60 angol hatbetűs álszót tartalmazott, amelyek struktúrájukban a magyar vagy az angol fonológiai szabályokra támaszkodnak. A résztvevők feladata az volt, hogy a képernyőn lévő szavakról eldöntsék, hogy a magyar, vagy az angol nyelve illenének-e bee. Ezzel a teszttel a fonológiai tudatosságot vizsgáltam.

Saját készítésű programot (Matlab, MatLab Inc.) használtam a kísérlet elvégzéséhez. Az EEG adatokat 128 csatornás Biosemi ActiveTwo mérőeszközzel vettem fel. A program összegyűjtötte az adatokat, majd az ERP komponenseket kielemeztük mind a magyar, mind az angol nyelv vonatkozásában.

A magyar, angol szavak és homográfok felismerése esetén a magyar és angol szavak felismerése nagy pontosságot mutatott (96% és 98%), míg a homográfok felismerése az angol válaszok irányába hajlott (27% magyar válasz). Az elemzés megerősítette, hogy a magyar és angol szavak felismerésének reakcióidejében nincs különbség, azonban az interlexikális homográfok körülbelül 150 ms-mal hosszabb válaszokat produkáltak. A magyar és angol szavak feldolgozásában a felismerés korai szakaszában (ortográfiai-fonológiai szakasz) nem volt különbség a két kategória között. A nyelvek neurális reprezentációja azonban később különbözött, a szemantikai és döntési folyamatok szintjein. A magyar-angol interlexikális homográfok esetében az EKP hullámok nem mutattak szignifikáns különbséget. Habár kognitív erőfeszítés figyelhető meg a homográfok esetében, azok nem váltanak ki eltérő feldolgozási mintákat. Ezek az adatok egybeesnek a homográf-effektussal kapcsolatos korábbi megállapításokkal (Navracsics & Sáry, 2013), ami azt magyarázza, hogy a résztvevők nagyobb kognitív terhelésnek vannak kitéve a felismerés során, és a reakcióidő hosszabb, mivel mindkét lexikon aktív.

Az eredmények szignifikáns különbséget mutatnak a szavak és a nem szavak felismerése között a szófelismerés korai szakaszában (200-350 ms) a temporális elektródáknál. A szavaknál tapasztalt magasabb agyi aktivitást azt mutatja, hogy a valódi szavak felismerése nagyobb kognitív aktivitást igényel. Az angol és magyar álszavak esetében 420 ms-nál jelentős eltérés mutatkozik. A temporális és homlokelektródáknál magas elektromos agyi aktivitás érzékelhető, ami azt mutatja, hogy milyen hatalmas kognitív megterhelés az álszavak nyelv szerinti megkülönböztetése.

Kulcsszavak: *EEG, ERP, kétnyelvűség, írott nyelvi szófelismers, kétnyelvű szófelismerés, nyelvi döntés, lexikai döntés, homográf-hatás, homográfok, interlexikális homográfok, kognátuszok, nemszavak, álszavak, nyelvi aktiváció, szószerűségi elv, fonológiai tudatosság, reakcióidő, pszichofizika, neurolingvisztika, pszicholingvisztika*

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Végül, de nem utolsósorban szeretném kifejezni legmélyebb hálámat családomnak, vőlegényemnek és barátaimnak. Nem lehetek elég hálás drága szüleim feltétel nélküli szeretetéért, folyamatos bátorításukért és belém vetett hitükért. Köszönöm, hogy mindig a legjobbat adták nekem, és mindig ott voltak, amikor szükségem volt rájuk.

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non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.

Figure 25. Distributions of correct response time means across participants in the first experiment. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.

Figure 26. (Top) Topoplots representing the ERP difference between words and non-words at denoted times. Channels with significant contrast are denoted by asterisks ($p < 0.01$). (Bottom) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels. The shading represents times of significant difference ($p < 0.05$).

Figure 27. Distributions of correct response time means across participants in the second experiment. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.

Figure 28. (Top) Topoplots representing the ERP difference between Hungarian-like and English-like pseudo-words at denoted times. Channels with significant contrast are denoted by crosses ($p < 0.05$) and asterisks ($p < 0.01$). (Middle) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels. (Bottom) ERP waveforms at the left temporal D8 (left panel) and the right central B21 (right panel) channels. The shading represents times of significant difference ($p < 0.05$).

Figure 29. The distribution of Hungarian and English pseudo-words

Figure 30. The distribution of items per experiment. ExperimentA refers to the language decision task, including homographs, Hungarian and English words, experimentB refers to the first lexical decision task, including words and non-words, experimentC refers to the second lexical decision task, including Hungarian pseudo-words and English pseudo-words

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List of Abbreviations

AOA – age of acquisition

BIA – The Bilingual Interactive Activation model

BIA + – The Bilingual Interactive Activation + model

BIA-d – The developmental Bilingual Interactive Activation-d model

EEG – electroencephalography

ERP – event-related potential

L1 – first language

L2 – second language

LEAP-Q – Language Experience and Proficiency Questionnaire

MROM – The Multiple Read-Out Model

RT – reaction time

SOPHIA – The Semantic, Orthographic, and Phonological Interactive Activation model

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1 INTRODUCTION

1.1 Bilingualism research and its necessity

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 bilingual 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, and on different topics (Grosjean, 1982). The diversity of perspectives and different linguistic settings contributed to the increase in bilingual research.

There are several reasons that lead to bilingualism. Contributing factors can be the linguistic composition of a country, immigration, education, and culture. Myers-Scotton (2002) enumerates six circumstances that promote the conditions of bilingualism. They are as follows:

- military invasion and sequent colonization, especially if the conquest was followed by a long period of stability;
- living in a border area or an ethnolinguistic enclave, since border residents become bilingual, they learn each other's languages;
- ethnic awareness;
- migration for social, economic, and recently climatic reasons;
- education as the ability to speak specific languages has always been seen as the hallmark of the educated person.

Although the need for bilingual studies has not long been in the spotlight, the rise in the number of bilinguals has increased their significance. Due to the growing number of bilingual students attending monolingual schools, studies on visual word recognition of bilinguals are crucial. Research on bilingualism helps teachers become more aware of the process of bilingual word recognition, which also aids bilinguals' literary growth. On lower levels (orthographic and phonological), word recognition patterns of orthographically related languages (for instance, English and Dutch) are assumed to be similar (Van Assche et al, 2009), but at higher cognitive levels, in semantics, recognition is substantially language-specific (Lemhöfer & Dijkstra, 2004). Language-specific characters help the recognition process in the case of orthographically unrelated languages (e.g. Hungarian and Chinese).

The present paper draws attention to the significance of how bilinguals might differ from monolinguals, and how their (language) learning strategies and word recognition patterns differ from each other. In opaque (deep) orthographies, writing systems do not have a one-to-one correspondence, which indicates that the reader must acquire the peculiar or arbitrary pronunciations of words. With transparent (or shallow) orthographies, the spelling-sound correlation is clear: one can pronounce a word correctly by following the rules of pronunciation. It means that words are spelled consistently and have a one-to-one relationship between their graphemes and phonemes. Readers who first learned to read opaque morphosyllabic orthography use less sublexical phonology while reading in the second language than do other second language learners, which helps the learning processes (Borleffs et al., 2017). Meanwhile, readers who learn transparent orthography for the first time rely more on the features of sublexical phonology, which makes learners less susceptible to teaching (Bhide, 2015). Depending on the word type, the surrounding context, and the individual's literacy experiences, reading strategies, reading speed and accuracy might vary. There is an understanding that literacy experiences, including which language a person learns to read in first and how they are taught to read, can have significant effects on the further reading processes. People who learn to read a more transparent orthography tend to depend less on morphological and orthographic information and more on sublexical phonology (Bhide, 2015).

The literacy development of bilinguals is a worldwide issue, since the number of bilinguals (and multilinguals) is emerging. Studies on bilingual processing at the word level are important, as teachers could get a better understanding of how bilingual word recognition takes place and what reading and processing difficulties bilingual students may have.

1.1.1 Assessing bilingualism

Bilingualism is the knowledge and use of at least two languages by individuals in their everyday lives. The assessment of bilingualism raises methodological questions as it is important to understand the many forms of bilinguals and bilingualism, as well as their key characteristics, in order to be able to distinguish them and use the appropriate and accurate methodology in bilingualism research. It is crucial to know every detail about the participants so that the results provide an adequate and reliable overview of their performance.

According to the age of second language acquisition, people can be categorized as early or late bilinguals. Early bilinguals acquire both languages at a very young age, and the acquisition of the two languages can be simultaneous or consecutive (or successive) (De Houwer, 1995). Simultaneous bilingualism refers to a child who acquires two languages simultaneously from birth. This usually generates strong bilingualism, which is frequently referred to as additive bilingualism. Simultaneous bilingualism may develop in children who are regularly exposed to two languages from before age two and who continue to be exposed to these languages up until the final stages of language development (De Houwer, 1995). In this case, both languages are acquired as first languages. Successive early bilingualism refers to a child who learns a second language early in life after having partially mastered their first language. For instance, when a child relocates to a setting where the language in use is not their native language.

Recent literature on early, and, especially infant bilingualism (Meisel, 1989; De Houwer, 1990; 2009) suggests using the terms 'bilingual first language acquisition' (BFLA) and 'early second language acquisition' (ESLA). In the case of BFLA, both Language A and Language Alpha are exposed to children at home. It means that BFLA children do not have their first and second languages in their chronological sense. Meanwhile, ESLA is the process that young children go through when they are first raised speaking only one language (L1) and later begin hearing a second language (L2) on a regular basis. ESLA children typically hear just one language at home and come into contact with the second language in a group setting away from the family, like a childcare facility or preschool (De Houwer, 2009).

Bilingualism that develops after age 6 or 7, particularly throughout adolescence or maturity, is referred to as late bilingualism (Beardsmore, 1986). Following the learning of the first language, late bilingualism is a form of sequential bilingualism. Late bilinguals use their experience to learn the second language after having previously mastered the first (Beardsmore, 1986; Pelham & Abrams, 2014).

According to the strength and dominance of languages, there is a distinction between (i) additive, (ii) subtractive, and (iii) passive bilingualism. Additive bilingualism describes a situation in which a person acquires two languages in a balanced way, and strong bilingualism emerges. When a person learns a second language at the expense of their first language, particularly when that first language is a minority language, the condition is referred to as subtractive bilingualism. In this situation, first language proficiency declines while second language proficiency – typically the dominant language – increases. Understanding a second language without being able to speak it is referred to as passive bilingualism (Valian, 2015).

Bilinguals' language performance can be characterized by a number of features. Bilinguals are influenced by the Complementarity principle (Grosjean, 1997) which means that they acquire and use their languages for different purposes, in different domains of life, with different people. As a consequence, they are rarely fluent and balanced in all language skills in both their languages; rather, they are dominant bilinguals. Bilinguals' proficiency depends on the use of a language. Furthermore, the language repertoire of bilinguals may alter over time due to changes in the surroundings and the habitat. Grosjean (2008) enumerates the main defining linguistic characteristics of the bilingual individual, which are the followings: (i) language history and language relationship (focusing on which languages were acquired, when, and how, and what the linguistic relationship is between the languages), (ii) language stability (whether there are any languages that are still being acquired), (iii) function of languages (which languages are used currently and for what purpose, and to what extent), (iv) language proficiency (what is the bilingual's proficiency in the four linguistic skills, (v) language mode (how often and for how long the bilingual is in a monolingual vs bilingual mode, and how much they code-switch), (vi) biographical data (including age, sex, socioeconomic status, etc.).

Measuring instruments that assess bilingualism intend to determine bilingual proficiency based on the list above. In bilingual neurolinguistics studies, language proficiency is measured subjectively, through self-evaluation questions, such as 'On a scale from zero to ten what is your proficiency in understanding spoken language?'.

Although these tests are standardized, they give a biased analysis of the individual's bilingual proficiency. One of the widely known instruments is the LHQ (Language History Questionnaire) and its interned-based version (LHQ 2.0) (Li et al., 2014). It puts an emphasis on language proficiency and language use and contact. BLP (Bilingual Language Profile) (Birdsong et al., 2012) is another instrument for evaluating language dominance through self-declaration. Its purpose is to determine a general bilingual profile based on different linguistic variables. Another instrument to assess bilingualism is the one by Berns et al. (2007), which collects information about language use in different approaches and different media. It also focuses on the extent of various aspects that contribute to language proficiency. One of the most widely recognized instruments is that of Marian et al. (2007), which is called LEAP-Q (Language Experience and Proficiency Questionnaire). Their aim is to elaborate a trustworthy and accurate questionnaire for assessing bilinguals' linguistic profiles. LEAP-Q is a validated, reliable and efficient questionnaire for discovering the increasingly diverse populations linguistically and their language profiles. It is available in more than 20 languages, and can be used by researchers across several disciplines (psychology, neuroscience, linguistics, education, etc.) to give an extensive description of bilingual participants (Kaushanskaya & Blumenfeld, 2019).

1.2 The brain and the language

The focus of this dissertation is on bilingual visual word recognition. In order to understand the written language processing of bilingual individuals, to find out how different activations occur in the brain, and to study which parts of the brain get activated and in what order, it is essential to understand how the human brain builds up.

The human brain is responsible for all functions of the body; it interprets information from the outside world. It controls intelligence, creativity, emotion, and memory. Various senses (sight, smell, touch, taste, and hearing) send messages to the brain, which hereby is the center of our thoughts, memories, speech, movement, etc.

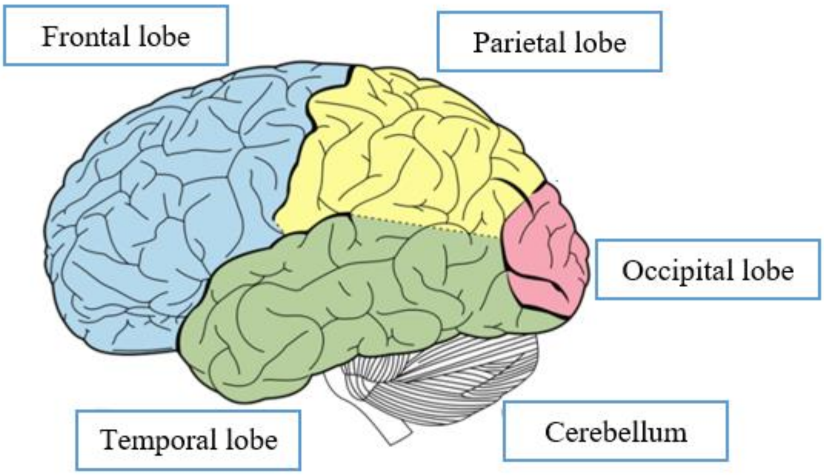
The human brain is one of the most difficult organs to investigate. Through the past decades, researchers have discovered its anatomy, functions, and processes. From the 20th century onwards neuroimaging studies help us to understand the structure of the bilingual brain. How it functions can be detected with different neuroimaging procedures. The use of EEG for Event-Related Potentials (ERP) is one of them, which makes it possible to measure the electrical brain activities of bilingual individuals while completing certain tasks. Researchers may use some further methods for measuring brain activities, such as (i) CT (computer tomography), which is a diagnostic imaging test used to create images of internal organs; (ii) fMRI (functional magnetic resonance imaging), which measures the brain activity by detecting changes associated with blood flow, and it assesses the topography of the human primary visual cortex; (iii) MEG (magnetoencephalography), which measures the magnetic fields of the brain; and (iv) PET (positron emission tomography), which is an imaging technique that uses radioactive substances to visualize and measure metabolic processes. These imaging techniques allow neuroscientists to see the electrical activities while the individual is completing different types of tasks.

Over the recent decades, scientists have found that the brain has certain regions, which are in charge of specific tasks, such as understanding and producing speech or processing visual and spatial information (Sukel, 2019).

1.2.1 The anatomy of the brain

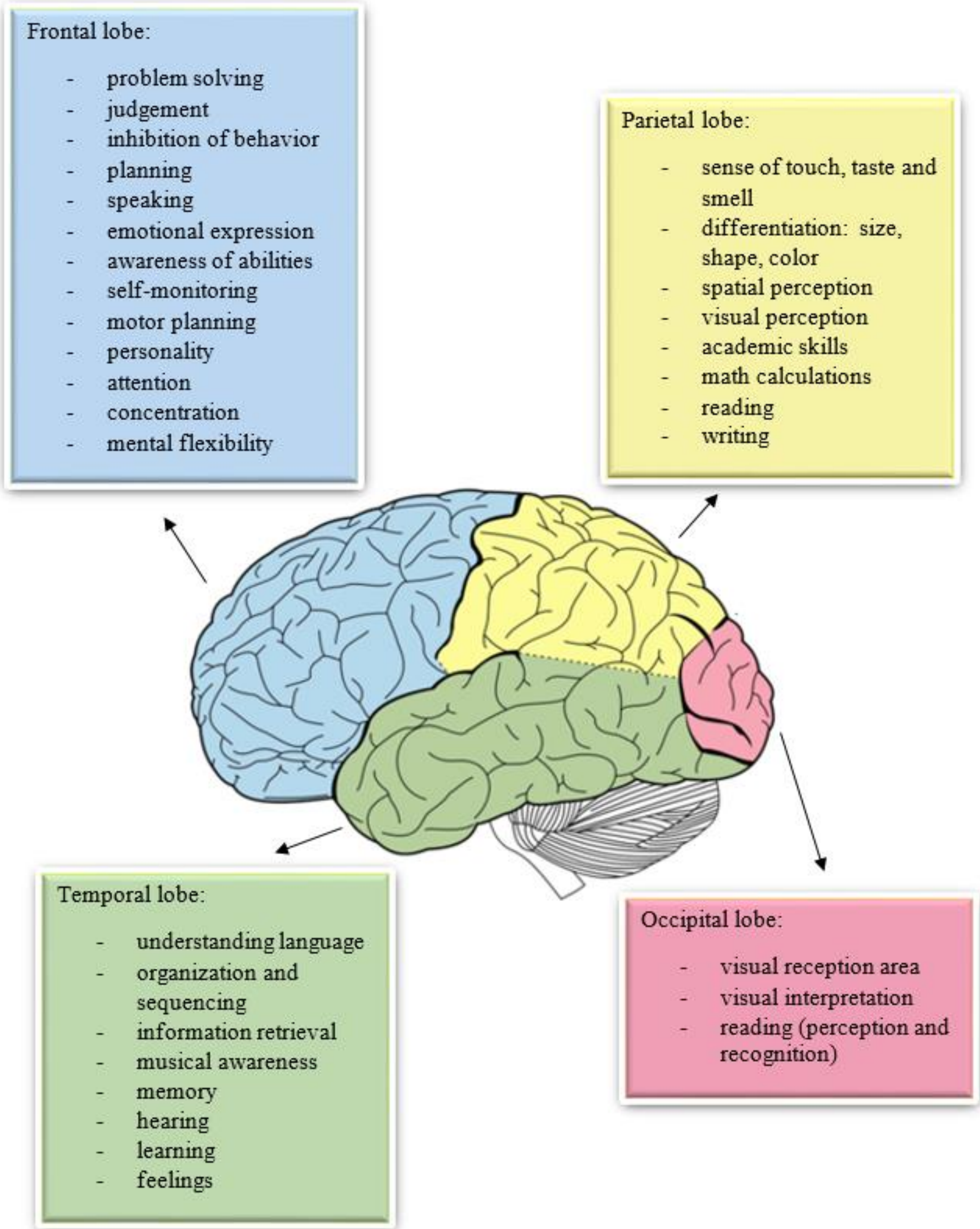
The brain has an extraordinarily complex anatomy, with several layers in it. Inside the skull is the biggest part of the brain: the cerebrum (Carter, 2009). The cerebrum can be further divided into two main parts, the left and right hemispheres. The two hemispheres are connected to each other by nerve fibers, the corpus callosum, which carries messages from one hemisphere to the other. Both hemispheres control the opposite side of the body; both hemispheres are responsible for certain cognitive tasks (Damasio, 1995). In general, the left hemisphere is responsible for speech, comprehension, calculation, and writing. The right hemisphere controls creativity, spatial ability, artistic, and musical skills (Carter, 2009). The cerebrum, including the hippocampus and the amygdala, is also known as the telencephalon. Within the cerebrum, the thalamus, and hypothalamus can be found, which are collectively known as the diencephalon. It includes the main brain division known as the forebrain. Below the forebrain is the midbrain, which is a small division including the groups of nerve-cell bodies, called nuclei, such as basal ganglia. Below the midbrain, the hindbrain can be found (Carter, 2009).

Figure 1. The anatomy of the brain (based on Carter, 2009)



The cerebral cortex is the outer layer of the cerebrum, also known as gray matter due to its color. It can be divided into lobes (Fig. 1). Each hemisphere has four lobes: frontal, temporal, parietal, and occipital (Carter, 2009, Carreiras, 2013; De Groot, 2011), and they all are designated to different functions (Fig. 2). The frontal lobe is the center of executive functions, such as speaking, personality, emotions, problem-solving, behavior, judgment, planning, body movement, intelligence and concentration. The temporal lobe is where understanding languages takes place, furthermore, this lobe is responsible for hearing and memory. The parietal lobe controls the body sensation, and this is the area of spoken and written language. The occipital lobe is the visual processing center of the visual cortex. This is where the identification of letters takes place (Carter, 2009). The visual cortex is a crucial element of visual language processing.

Figure 2. Brain lobes and their functions (based on Carter, 2009)



1.2.2 The relationship between the brain and language

Humans have an inherent ability to learn and speaking languages (De Houwer, 1995). The entire process takes place in the brain, and each hemisphere is responsible for certain tasks regarding language functions. The two hemispheres are in constant interaction with each other. The human brain is less symmetrical in hemisphere localization in terms of functions compared to other species (Carter, 2009). Language is a great example of brain asymmetry, since most right-handed people have the main language areas on the left side of their brains, though different language functions can be distributed on both sides (Carter, 2009).

The main language skills, such as language production and language processing are located in the left hemisphere in most people. On the other hand, some other essential skills that contribute to appropriate comprehension are found in the right hemisphere. The left hemisphere is the center of articulation, comprehension, and word recognition, while the right hemisphere is responsible for recognizing tone, gestures and the speaker, rhythm, stress, and intonation.

1.2.2.1 The relationship between handedness and brain lateralization

Handedness reflects the structure of our brain, more specifically its asymmetry. While the left hemisphere controls right-handedness, the right hemisphere controls left-handedness.

In most cases, the left hemisphere is responsible for language-related perception and production as far as dominance is concerned; however, in some cases, the right hemisphere can also be dominant, which initiates the question of its freedom. As there are numerous examples of left-handed people having their right hemisphere dominant in language use, it seems more righteous to claim that this freedom is limited to certain features, thus emphasizing the fact that there must be a correlation between language dominance and handedness.

The 'Broca rule' suggests the concept of left-handers having a dominant right-hemispheric dominance based on the overgeneralization of the description of the typical example of the left-hemispheric dominance of right-handers. However, the thesis was first refuted when left-handed aphasic patients having had a lesion in the left hemisphere showed signs of inability of comprehending or formulating language, which proves that language alongside dexterity is able to shift to the right-hemisphere (Knecht et al., 2000).

With the help of functional transcranial Doppler ultrasonography (fTCD), which is based on the same physiological principles as functional MRI (fMRI), Knecht, et al. (2002) measured 326 healthy individuals with different degrees of handedness from -100 (strong left-handedness) to +100 (strong right-handedness), using a word-generation task. The study revealed that left-handedness is neither a precondition, nor a necessary consequence of right-hemisphere language dominance, although it increases the probability of right-hemispheric dominance. Researchers also found that there is no significant correlation between gender and handedness influenced hemispheric language dominance (Knecht et al., 2000).

Later, Mazoyer et al. (2014) carried out research with 297 participants, out of which 153 were left-handed. The hemispheric lateralization for language was examined through the covert production of sentences and word-lists during fMRI. According to the collected data, subjects were divided into three categories, typical (left hemispheric dominance), ambilateral (without clear hemispheric dominance), and atypical (right hemispheric dominance). The results showed that only 7% of left-handed participants fell into the atypical category. Mazoyer et al. (2014) have not found any significant chance-corrected agreement between hemispheric dominance for hand and hemispheric dominance for language production. Hence they drew a conclusion: the concordance between hemispheres for handedness and language is not always straightforward.

Having such results proves that knowing the individual's chosen handedness does not mean that we can determine their dominant hemisphere. The answers might lie further in the genetic memories of our cells, which could pose some further opportunities for researchers to analyze stem-cells accordingly. What can be taken for granted is that the dominant hemisphere for language cannot be absolutely determined by one's preferred handedness, so other individual factors have to be taken into consideration.

1.2.2.2 The main language areas in the brain and their functions

With the help of functional magnetic resonance imaging (fMRI), researchers are able to test the main language areas of the brain. FMRI is based on monitoring the regional changes in blood oxygenation resulting from neural activity (Ogawa et al., 1990, 1992). FMRI turned out to be a great method to localize primary sensory and motor areas (Kim et al., 1993; Rao et al., 1993). Preliminary studies have proven that language processing occurs mainly in Broca's and Wernicke's areas. Broca's area is involved in the production of coherent speech, while Wernicke's area is involved in speech processing and understanding language. The two areas are connected by a thick band of tissue, called arcuate fasciculus (Carter, 2009), to facilitate the whole process of language perception. Language activation tasks (Binder et al., 1997) reveal that each characteristic of language processing is represented by different parts of the brain. In the case of hearing, spoken language auditory signals are first processed in the primary auditory cortex, and then forwarded to the neighboring Wernicke's area. In the case of visual language processing, written language is perceived by the primary visual cortex, and then it is forwarded to the angular gyrus. From the angular gyrus, the information is sent to Wernicke's area, where the recognition takes place (Carter, 2009).

As for the specific linguistic levels, Broca's area is the center of phonological, semantic, syntactic processing, and working memory. The anterior region of Broca's area is more involved in semantic processing, while the posterior region is involved rather in phonological processing (Bohsali et al., 2015). Furthermore, Rogalsky et al. (2015) find that Broca's area shows higher activation in reading tasks than any other types of tasks. Broca's area is related to the thalamus and they are the center of language processing (Bohsali et al., 2015). The angular gyrus is a central element in processing abstract and concrete concepts. It also plays an important role in transforming written language into spoken language (Seghier, 2013).

A decade after Broca and Wernicke identified the major language areas in the brain, Lichtheim (1885) developed a functional model of language. According to this model, Broca's area stores the motor representations of words and Wernicke's area is responsible for the auditory forms of the words (i.e. their phonological representations). Lichtheim (1885) added a third center to this approach, the so-called concept center, which stores the conceptual representations.

1.2.3 The visual cortex and seeing

The visual areas are located at the back part of the brain. The visual cortex processes visual information. Two types of vision can be distinguished: (i) conscious vision – the familiar act of seeing something; and (ii) unconscious vision – which uses information from the eyes to guide us without knowing it is happening. These two types of vision are represented by different pathways in the brain. The dorsal route is responsible for the unconscious vision, and the ventral route is responsible for the conscious vision and it helps us to recognize objects (Carter, 2009). In terms of visual word recognition, the ventral pathway, which includes several cortical and subcortical areas, has greater significance. All these areas create neural activities in the visual processing areas, which process different aspects of perception, such as shape, color, depth, location, movement, etc. (De Groot, 2011). These pieces of information then go to the temporal lobe, where the recognition takes place. Later on, some information travels to the frontal lobe, where its significance and meaning are revealed. At this point, different components connect to each other, and at the end of the whole process, a conscious perception/recognition occurs (Yamins et al., 2014).

1.2.4 Reading

The initial stage of reading takes place in the visual cortex, which sends the information to the language areas of the brain. The information arrives at the visual word-recognition area, which is able to make a distinction between objects and written words. In the auditory cortex, written words are transformed into phonological elements so they can be 'heard' inside. Broca's area is the center of recognizing written words as meaningful utterances, by connecting written words and spoken words to each other. The information arrives at the temporal lobe, which matches the words to their meanings by retrieving memories (Carter, 2009).

Reading requires the cooperative activation of orthography, phonology, and semantics. To find out how the process of reading takes place has kept researchers busy through the recent years. They tried to discover whether the processes are independent of each other or they are strongly connected to each other, whether the processes are followed by each other or they are in parallel, and last but not least, whether they are automatic or strategic (Rastle, 2007). Price et al. (1996) and Price (2000) found that reading words with high frequency does not demand accurate phonological recoding. Tan and Perfetti (1999) found quite the opposite: phonological forms are accessed directly and automatically. Regarding lexical access, there are two presuppositions: on the one hand, there is direct access from orthography to semantics; on the other hand, there is an indirect one, which involves phonology as well, and is called the phonological mediation hypothesis (Tan & Perfetti, 1999).

MEG studies, which produce spatial and temporal information about brain activities, reveal that orthographical and phonological information of the words takes place in the intero-temporal area (Carter, 2009). This area responds to the visually presented words and pseudo-words (often referred to as the visual word form area). Thereafter the information is forwarded to the inferior-frontal gyrus, where the linguistic processing takes place.

1.2.5 The bilingual brain

Speaking more than one language can positively influence not only linguistic processing, but the development of non-linguistic cognitive skills, as well (Bialystok, 1999), which decreases the risk of dementia and other age-related cognitive decline. One of the reasons why bilingualism supports cognitive skills is that speaking a second language builds more connections between neurons (Carter, 2009). Studies (Bialystok et al., 2012; Bialystok, 2017) confirmed changes in the brain structure and function due to bilingualism bolster cognitive processes, especially executive function.

1.2.5.1 Language lateralization in the bilingual mind

For a considerable time, the question of storage has been in focus in the psycholinguistics aspects of bilingualism research (Navracsics, 2007; Pavlenko, 2009; Singleton, 1999). A recurring issue in the study of bilingualism concerns how languages are stored – in a unitary, or separated systems.

It is generally accepted that language is normally lateralized in the left hemisphere in most people, since the left hemisphere plays a bigger role in linguistic behavior (De Groot, 2011). Modern neuroscience techniques prove that the left occipito-parietal junction is significantly involved in visual word recognition compared to the right occipito-parietal junction (Cohen et al., 2002). Cohen et al. (2002) call this part of the brain the 'visual word form area' (VWFA), since the information from written words passes through this area in order to access the appropriate phonological, morphological, and semantic representations.

Although it is widely recognized that language is lateralized in the left hemisphere, in the case of bilinguals, certain factors might influence how the two languages are stored in the brain. These factors are age and manner of acquisition, linguistic competence, exposure, language dominance, etc. (Perani et al., 2003; Démonet et al., 2005).

Early research in aphasia shows that the right hemisphere is involved to the same extent as the left hemisphere in bilingual language production and perception (Zatorre, 1989; Solin, 1989). Neuroimaging studies in recent years have made it possible to become more acquainted with the structure of the bilingual brain. Recent findings indicate that the two hemispheres are not equally involved, and the relationship between L1 and L2 varies from individual to individual.

The five most common hypotheses on brain lateralization in the case of bilinguals (Hull & Vaid, 2005; Vaid & Hall, 1991) are the following:

(i) **L2 hypothesis**: the right hemisphere is more involved when bilinguals process their L2 than when they process L1. In the case of processing L1 their left hemisphere is involved to the same extent as in language processing by monolinguals.

(ii) **Balanced bilingual hypothesis**: during both L1 and L2 processing high-proficient bilinguals use their right hemisphere more than monolinguals.

(iii) **Stage of L2 acquisition hypothesis**: during the initial stages of L2 acquisition the right hemisphere is more involved in processing, and the involvement of the left hemisphere grows with the increase of L2 proficiency (Obler, 1981).

(iv) **Manner of L2 acquisition hypothesis**: if the bilingual individual acquires L2 in an informal manner, the right hemisphere is more involved than if it is acquired in a formal way.

(v) **Age of L2 acquisition hypothesis**: if the ages of acquisition of L1 and L2 are close to each other concerning time, the lateralization pattern will be similar for both languages, i.e. early bilinguals show a similar lateralization pattern for their two languages, while late bilinguals show a different pattern for their two languages (Vaid & Genesee, 1980).

The different lateralization theory was validated by Scoresby-Jackson (1867), who was examining a bilingual patient who suffered a selective loss of one language following an injury to his head. This let him discover that the two languages of a bilingual brain are stored in different cortical areas. Similarly, Albert and Obler (1978) in their research testing 108 cases found that early bilinguals experienced aphasia due to injuries to the right hemisphere. It proved that the right hemisphere of early bilinguals is significantly involved in the development of language skills. These results made Albert and Obler come to the conclusion that different languages are stored in different parts of the bilingual mind.

In providing further examples of the lateralization and the activated areas of the brain, the role of the scripts or the writing systems of the languages must be emphasized. Tan et al. (2011) discover that several areas in the right hemisphere are strongly activated during the processing of logographic Chinese characters. This high activation in the right hemisphere is due to the fact that it is more involved in processing visual-spatial information, which is needed to process the Chinese logographic characters. Buchweitz et al. (2009) have similar results when they test the reading of Japanese speakers. Their results show that reading Japanese logographic kanji is associated with a relatively high level of activation in occipito-temporal areas of the right hemisphere.

As a consequence, the left hemisphere is more involved in languages using the Latin alphabet. However, languages using logograms are usually represented in the right hemisphere. Stowe et al. (2005) discovers that the right hemisphere is associated with the processing of lexically ambiguous words and indirect forms of language use (metaphors, for instance), which supports the idea that the right hemisphere is the center of nonliteral meaning and ambiguity, pragmatic abilities and visuospatial information. Paradis (1997, 2004) and Fabbro (1999, 2001), in their investigations concerning the involvement of the right hemisphere in language processing, confirm that there is different right hemisphere involvement in the case of bilinguals and monolinguals.

Marrero et al. (2002) assume that if the second language is acquired in childhood, it is more semantics-based, which means the left hemisphere is more involved, and if the second language is learnt in adulthood, it is more acoustics-based, which means the right hemisphere is more involved in production and perception. If the second language is acquired informally, it is located in the subcortical structures, such as the basal ganglia and the cerebellum, so the two languages have common storage, while if the second language is learnt through an instructional way, it is stored in the cerebral cortex, hence L1 and L2 are stored separately. As a conclusion, the later the language acquisition is, the bigger the difference between the lateral organizations of the two hemispheres is (Fabbro & Paradis, 1995; Fabbro, 2000).

The study of Mechelli et al. (2004) reveals that bilingual adults have greater gray matter density, especially in the inferior frontal cortex of the brain's left hemisphere, which is the center of language and communication. This type of increased density was observable in the case of bilinguals who started learning their second language before the age of five. Hull and Vaid (2007) support this idea, since after they carried out a meta-analysis of 66 healthy subjects they discovered that functional lateralization is determined by the age of acquisition.

The Critical Period Hypothesis (or Sensitive Period Hypothesis) declares that an L2 learner encountering the second language after a certain age is no longer capable of attaining native-like levels of proficiency (pronunciation, grammar processing, articulation, etc.) in that language (Kilgard, 1998; Vyshedskiy et al., 2017), or if the learner is able to approach the proficiency, he/she needs more effort (Penfield & Roberts, 1959). There is no consensus on age, but most researchers estimate the age of 13 to be the critical year (Paradis, 1999; Loewen & Reinders, 2011).

By now, neurolinguistic data have shown that languages are stored in different areas in the brain of the bilingual individual, as different groups of neurons are used to generate each language. This helps the two languages remain separated from each other (DeLuca et al., 2020).

1.2.5.2 Lexicons 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 from memory; (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, declarative memory plays a crucial role as it contains the mental lexicon, which stores the lexical items. Being familiar with a word also means the ability to spell and pronounce it and to know its meaning(s), grammatical class(es), syntactic constraints, and its lexical and conceptual associations (Nation, 1990; 2001).

Every individual who speaks more than one language knows that the lexicon of a language differs from the lexicon of the individual. 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 emerged, and psycholinguists found that words have a way of existing in the mind, and it is not like a list of words in an alphabetical order (Aitchison, 1987).

The mental lexicon is the key to understand the nature of language organization among bilinguals. 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 – contains the mental representation of one's knowledge of the world. The episodic memory is based on the retrieval and formation of memories.

Research on the bilingual mental lexicon suggests that words are stored and retrieved in a network of associations (Nattinger, 1988). Brain mapping evidence shows that concepts are all across the brain in both hemispheres. Different parts of the brain get activated depending on the meaning of the word, which was discovered at UC Berkeley in 2016 (https://www.openculture.com/2016/04/becoming-bilingual-can-give-your-brain-a-boost.html). In this brain mapping study, participants read and listen to the same stories from a podcast series. By monitoring blood flow to different parts of the brain they found which places were responding to the meaning of the words – the semantics. They found that different parts of the brain responded to different kinds of words and concepts, and they could group them into different kinds of categories. Using functional MRI, researchers scanned their brains and found that the maps they created for both reading and listening datasets were identical.

When testing neuronal representations of word classes, Pulvermüller (1999) finds that function words (articles, auxiliary verbs, conjunctions, prepositions, etc.) are represented in the perisylvian cortex, which is located in the left hemisphere and is associated with the language. Content words (nouns, verbs, adjectives, adverbs) are phonologically and lexically represented in the perisylvian cortex, as well, but they have bilateral links to other areas of the cortex that represent their acoustic and auditory referents.

In the case of bilinguals, the relationship between an L1 and an L2 word varies from individual to individual, since the acquisition of the words varies, as well, and it depends on how the words have been acquired and how frequently the individual is exposed to the given language (Singleton, 1999). The knowledge of words seems to be in constant change throughout a bilingual's life. A bilingual is in the perpetual process of acquiring (and forgetting) words; therefore the connections between L1 and L2 alter, too. According to Navracsics (2007), bilinguals, who speak both languages with high proficiency, have conceptual representations that are shared across their two languages. L2 proficiency, culture, family background, education, and status within society are all influencing factors of bilingual language proficiency.

Scientific literature supports Grosjean's opinion (1989) on bilingualism. Bilingualism is not the combination of two monolinguals, and it is very exceptional to find someone who is balanced in their two languages and speaks both languages equally fluently, since different factors (family, society, religion, work, etc.) might influence the language use, that is why either of the languages will always be dominant. As the Complementarity Principle (Grosjean, 2010; Grosjean & Li, 2013) confirms, bilinguals acquire and use their languages for different purposes, in different fields of their life. Understanding the fundamental differences between the lexicon of a language and the lexicon of a person helps us understand how the bilingual brain works and how bilingual visual word recognition happens.

1.2.5.2.1 Neurolinguistic and psycholinguistic aspects of the bilingual mental lexicon

The neurolinguistic approach to bilingualism focuses on demonstrating the manner in which the two languages are stored in the brain and how differently (or similarly) they are processed.

Neurolinguistic research and imaging techniques increase our understanding of the mental lexicon, and from the 1960s and 1970s research on the bilingual mental lexicon has increased. The early studies focus 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 knowledge is common or separate, and (iv) how the lexicons are connected to each other and to the conceptual knowledge.

There are several variables that can affect a bilingual individual's memory. According to Aitchison (1997), who investigated the relationship between language and memory, memory is influenced by a great number of factors. Frequency is one of the greatest influencing variables; i.e. the more often the word occurs in the language, the easier it is to remember. Imagery is also considered to be one of the most significant factors that affect memory in the sense that high-imagery words (concrete words) are easier to remember than abstract words. Besides frequency and imagery, other linguistic variables, such as phonological structure, grammatical category may affect the development of the mental lexicon.

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. More recently, there is a widely accepted consensus that bilingual lexical access is characterized by non-selectivity (De Groot et al., 2000; Dijkstra & Van Heuven, 1998; 2002). This non-selective lexical access is true for orthographic (De Groot & Nas, 1991) and phonological codes (Duyck, 2005; Jared & Kroll, 2001). Researchers share the assumption that there is a parallel activation of the two languages in lexical access regarding language production and perception. A great number of studies have proven that the bilinguals' two languages are constantly activated, and they never fully deactivate the language that they are not using in a certain context (Dijkstra, 2005; Dijkstra & Van Heuven, 2002; Schmid, 2010). A set of eye-tracking studies reveals that bilinguals can engage both languages parallelly even when a direct linguistic stimulus is only in one language (Marian et al., 2003). A functional neuroimaging research finds that while general structures are engaged in both languages, variances within these structures exist across languages and processing levels. Marian et al. (2003) find that sublexical access appears to be language-independent in the first few hundred milliseconds of word recognition, but as time to analyze context information passes, irrelevant language components are suppressed. The findings indicate the importance of the Inferior Frontal Gyrus[1] in language processing, particularly single-word processing. Furthermore, it supports the importance of the Superior Temporal Gyrus[2] in phonological processing. The second language was found to activate a bigger surface area than the first language during both lexical and phonological processing in the Inferior Frontal Gyrus. Furthermore, different regions were detected during first language processing than during second language processing.

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[1] The Inferior Frontal Gyrus contains Broca's area, which is involved in language processing and speech production.

[2] The Superior Temporal Gyrus has been linked to emotion perception in face stimuli. Additionally, the Superior Temporal Gyrus is an important region involved in auditory processing.

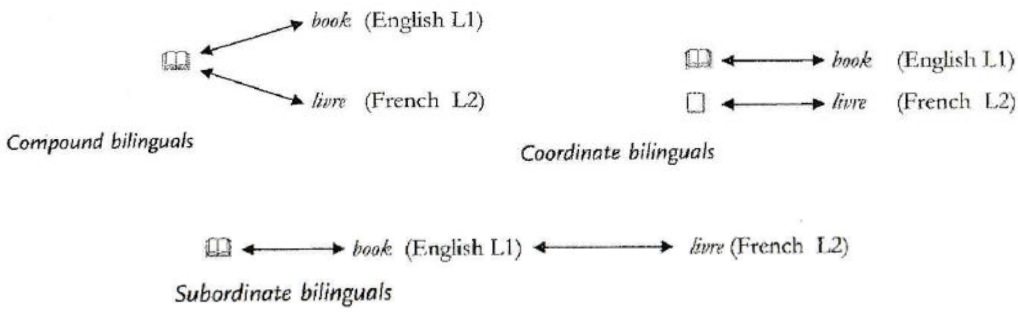
All in all, authors also agree that there is a continuous co-activation beyond the lexicon (namely, all linguistic levels, such as phonology, syntax, and semantics). For example at the phonological level, homophones activate the non-target language, too (Marian et al., 2003). As a consequence, the existence of activated words in the two languages requires lexical access.

1.2.5.2.2 Storage hypotheses: bilingual mental lexicon models

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). Thus the question is how the mind manages two linguistic systems: do they store information in a unified system and they have identical access to both languages, or is the information storage linked to separate languages, meaning two separate mental lexicons (Appel & Muysken, 1987)?

Weinreich (1953) lists three possible cerebral representations in the bilingual mental lexicon besides a shared conceptual representation: (i) compound (i.e. two unified systems, in which the meaning is shared while the words remain language specific), (ii) coordinate (i.e. the information of each language is stored in separate systems) and (iii) subordinate (i.e. L2 is accessed through L1) (Fig. 3). Compound storage can be established if bilinguals acquire their two languages at the same time in the same context, while coordinate storage will be observed in bilinguals who acquire their two languages in different contexts. Subordinate structure refers to the L2 learner, mainly in the initial stage. Many researchers refer to Weinreich's cerebral representations (1953), since the idea is suitable for storage, but no truly compound or coordinate person has ever been found, as storage depends on many things (c.f. Navracsics, 2007; 2011).

Figure 3. Compound, coordinate and subordinate bilinguals (Weinreich, 1953)

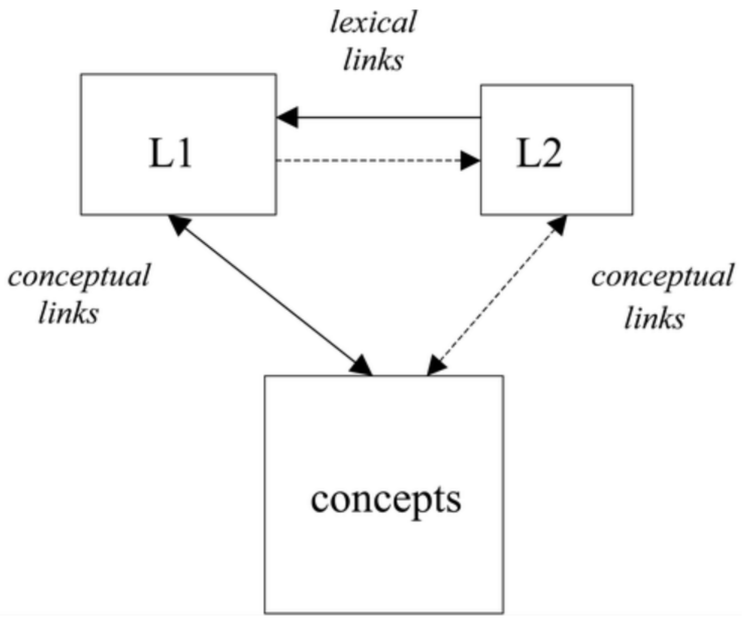


Paradis’ Subsystem hypothesis (1987) says that there is one common lexicon that contains all the grammatical, phonological, orthographic, etc. information about the two languages. When a stimulus is presented to the bilingual individual, words of both languages get activated. But since contexts are often language-specific, bilinguals can suppress the irrelevant language. It means that bilinguals are capable of speaking in just one language if they are in a monolingual language mode, which requires strong control over their languages. However, if they are having a conversation with a bilingual speaker, they can opt for bilingual mode in which the control over their languages weakens and they may switch between the languages (Grosjean, 2001). The amount of codeswitching depends on how proficient the interlocutors are. In order to make a decision on the other interlocutor’s language proficiency and competence bilinguals need an advanced metalinguistic awareness that helps them maintain the conversation.

According to the Concept Mediation Hypothesis (Potter et al., 1984), the words of the two languages are stored separately, but they are connected straight to the conceptual knowledge.

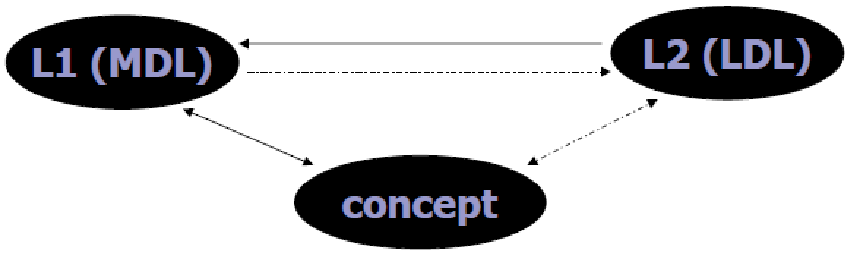
In the 1990s, language fluency was also taken into consideration. According to the Hierarchical Model of bilingual mental representation (Kroll & Stewart, 1994), less fluent bilinguals have a dual-store, while more fluent bilinguals have a single-store conceptual representation (Fig. 4).

Figure 4. Hierarchical Model of lexical and conceptual representation in bilingual memory (Kroll & Stewart, 1994)



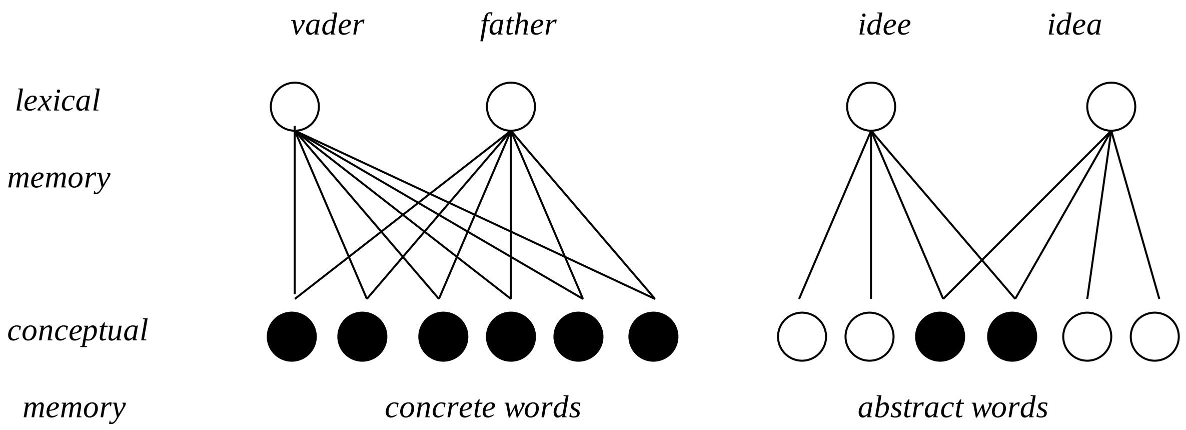
The model states that the conceptual representation is connected to both L1 and L2 lexicons, but not in a balanced way. The connections between the conceptual representation and the L1 lexicon are stronger and more dominant, while the connections between the conceptual representation and the L2 lexicon are weaker. This model suggests that L1 words are connected to the meanings and the conceptual knowledge, while L2 lexicon is associated with the L1 lexicon. Bilinguals, whose L2 proficiency is at an early stage, produce L1 words spontaneously, and they produce L2 words by translating L1 words. As they become more proficient, the strong connection between L1 and L2 decreases. The connection between the concept and its L2 equivalent becomes more direct, and they rely less on a mediating connection through the L1 lexicon. As a consequence, both L1 and L2 lexicons will be connected to the conceptual knowledge. Since bilingualism is a constantly changing state, and in many cases, L2 becomes the more dominant language, Heredia (1996) in his Revised Hierarchical Model initiates using the terms more dominant language (MDL) and less dominant language (LDL) instead of L1 and L2 (Fig. 5).

Figure 5. Revised Hierarchical Model (Heredia, 1996)



The Distributed Feature Model (De Groot, 1992) also discusses conceptual representations. The model seeks to draw attention to cross-linguistic differences. It also reacts to the general assumption that bilinguals translate concrete words and cognates faster than abstract words. The degree of meaning similarity between words and their translation equivalents determines the bilingual representational form as opposed to Weinreich's (1953) proposal. The more similar the meanings of the translations are, the more likely they are stored in a compound way in the mental lexicon. It means that representations of concrete words and cognates are shared across languages; however, the representations of abstract words have fewer semantic features in common. Words that share the same conceptual features are stored in a compound way, while words that share only a limited number of features are stored in a coordinated way (Fig. 6). In many cases, an abstract word of a language does not have a true equivalent in the other language.

Figure 6. The Distributed Feature model (adapted from De Groot, 1992; 1993)

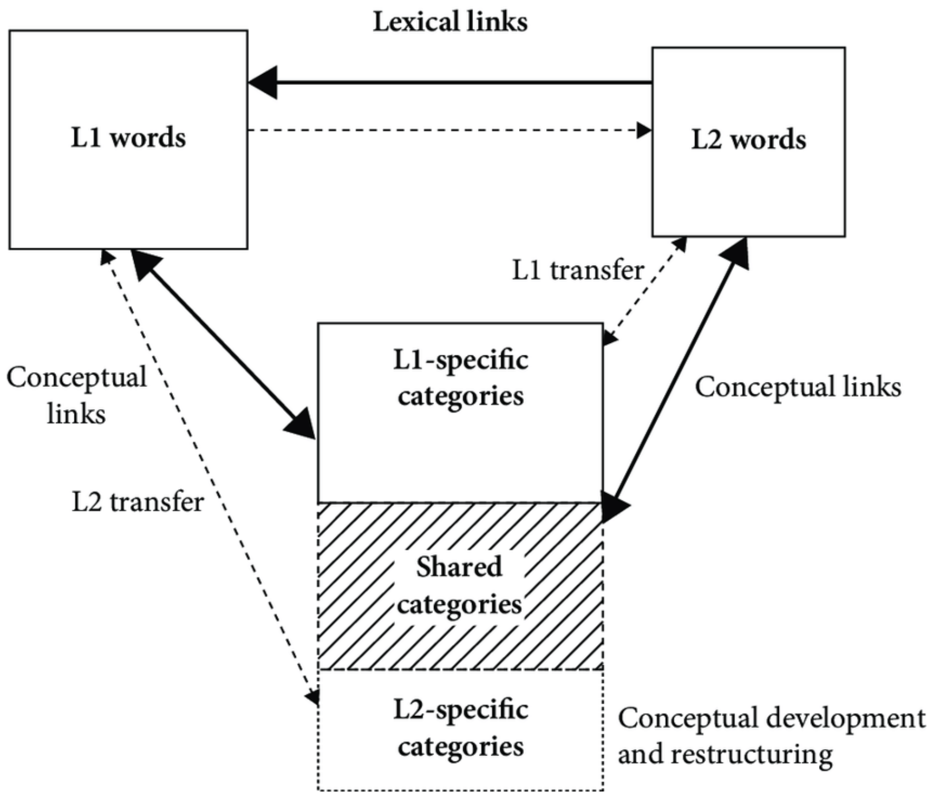


Concerning the cerebral cortical organization of languages based on the age of acquisition and manner of acquisition, EEG studies revealed that there is a difference between the cerebral representation of closed-class and open-class words in L1, however, this difference cannot be detected in L2, if it was acquired after the age of 7 (Weber-Fox & Neville, 1997). Kim et al. (1997) also support the idea of having differences in the activation of the two languages, and they also claim that the age of acquisition is crucial. They discovered different activations in the left frontal regions for L1 and L2 in the case of late bilingual individuals who speak both languages with the same proficiency, but acquired L2 at a later age. They did not find any differences in the case of early bilinguals.

According to Pavlenko (2009), in the case of early bilinguals words are more strongly connected to their L1 translation equivalents than to concepts. She also revealed that the links between L2 words and concepts become stronger, and bilinguals start to build direct links as the L2 proficiency increases.

Pavlenko's Modified Hierarchical Model (Fig. 7) suggests a dynamic account of conceptual and lexical processing with references to conceptual and semantic transfer (Jarvis & Pavlenko, 2008). Similarly to the Revised Hierarchical Model, the Modified Hierarchical Model maintains the developmental process from lexical to conceptual translation as the proficiency of L2 increases. The difference between the two models is that while the Revised Hierarchical Model presumes that there is a unified conceptual store, in the Modified Hierarchical Model conceptual representations are shared with some L1 and L2 specific representations.

Figure 7. The Modified Hierarchical Model (Pavlenko, 2009)



1.2.5.3 What neurobiology has to say about bilingualism

The study of how bilingualism influences the neural basis of executive control processes has recently begun. In the past few years, it has been found that bilingualism changes the functional involvement of certain brain areas in the performance of executive control tasks (Garbin et al., 2010; Abutalebi et al., 2012; Rodriguez-Pujadas et al., 2013).

Simultaneous acquisition of two languages ends up in different cortical structure as compared to that of monolinguals. The brain's blood perfusion and oxygen utilization increase, which generates neural connectivity improvement. As a result, bilingual individuals experience cognitive advantages (such as cognitive flexibility, inhibition, working memory, problem-solving, reasoning, and planning) that stimulate intellectual and social activities; furthermore, they are contributing factors to delay the onset of dementia, neurodegenerative disorders, and cerebrovascular diseases (Valian, 2015; Bialystok et al., 2007; Freedman et al., 2014; Adescope et al., 2010). Researchers also report on increased grey-matter density in the left hemisphere in the case of bilinguals, which is responsible for the linguistic and communication skills (DeLuca et al, 2020), especially in those starting L2 acquisition before age 5 (Mechelli et. al., 2004). Crinion, et al. (2006) tested typologically related (English and German) and typologically unrelated (English and Japanese) bilingual groups and they investigated whether the neuronal activation was language-specific or not. They had the assumption that if semantic activation was independent of the language of the stimulus, the neural adaptation would be identical regardless of whether the semantically related words belonged to the same or different languages. Furthermore, they also had the hypothesis that if the region reacted to both the semantic content and the language of the stimulus, the neuronal adaptation depended on whether the semantically related words belonged to the same or different languages. After the cerebral analysis, they discovered language-specific reaction only in the left nucleus caudate. Furthermore, they found that if the semantically related words were from the same language, the area indicated reduced activity. On the contrary, this reduced activity was not observable in words from different languages. Crinion et al. (2006) found that the language-dependent neuronal reactions were the most active in semantically unrelated words from different languages.

In bilingual processing, the caudate nucleus takes part in several tasks. Anatomically, the caudate nucleus belongs to the basal ganglia structures, and it gets the information directly from the parietal and the temporal and frontal lobes of the dominant hemisphere. The caudate nucleus fulfills linguistic duties, for instance, it is responsible for the bilingual language control (linguistic and semantic control), and it is also considered to be part of the brain’s general executive control system (De Groot, 2011). Besides linguistic tasks, it has an important role in automatic motor sequences (such as articulation) (Abutalebi et al., 2000).

Both structural and functional imaging studies (McLaughlin et al., 2004; 2010) show that the brains of adult L2 learners change before their behavior actually realizes the learning processes, and the authors confirm that these changes are dynamic over time. Furthermore, recent neuroscience evidence (Bice & Kroll, 2015; Chang, 2012; 2013) indicates that L2 begins to change L1, even at the beginner state of L2 learning, who obtain only low proficiency in the new language. For instance, Ameel et al. (2005) find that L1 does not look strictly the same for bilinguals as for monolingual speakers of the very same language. Even in bilinguals who are at the early stages of acquiring their L2 cross-language activation can be detected, no matter how proficient the language learner in L2 is (Sunderman & Kroll, 2006). Co-activation of both languages occurs at all levels of language processing, such as lexicon (Malt et al., 2015), grammar (Dussias & Scaltz, 2008), and phonology (Goldrick et al., 2014). Furthermore, effects of L2 on L1 have been observed at the levels of lexicon, grammar, and phonology (Van Hell & Dijkstra, 2002). Bice and Kroll (2015) carried out a lexical decision study among English-Spanish bilinguals, who were not profoundly proficient in their L2. During the experiment, they examined ERPs and found and emerging cognate effect in the L1 in spite of the fact that they were not highly proficient bilinguals.

Bilingualism has consequences on cognition, as well. Abutalebi et al. (2012) carried out an fMRI experiment using a variant of the flanker task[3]. They found evidence for greater activation of the anterior cingulate cortex in monolinguals than in bilinguals. The results suggest that bilinguals are capable of performing the task of resolving cognitive conflict more efficiently than their monolingual peers.

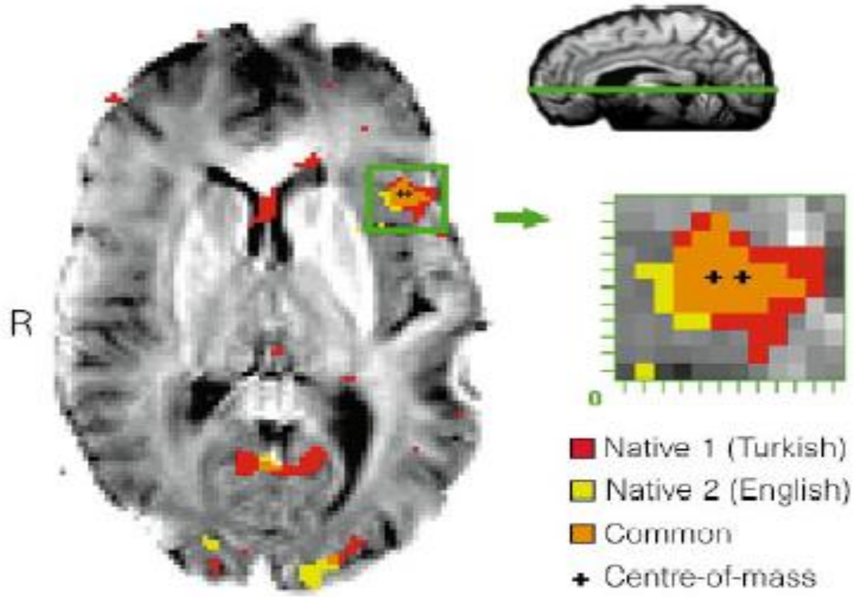
For highly skilled simultaneous bilinguals, a study by Tu et al. (2015) demonstrates that brief language exposure can mediate brain activation during language use. Li and Grant (2016) propose that the configuration and reconfiguration of brain networks as a result of L2 experience depend on a number of factors, such as the type of learning input (such as the linguistic features and similarities of the two languages), the timing of learning, the extent of the learning experience and the context and method of learning.

The existing literature concerning the neural background of bilingual lexico-semantic representation is contradictory. Previous neuroimaging research on the bilingual mental lexicon proved that the cerebral representation of L1 and L2 lexicons was quite similar in early and late bilinguals (Fabbro, 2001). Researchers also found evidence for L1 and L2 located in the same areas of the left hemisphere. On the other hand, fMRI and PET studies have shown that neural representations for L1 and L2 are dissimilar in the areas of the left hemisphere (Kim et al., 1997). Furthermore, Hervais-Adelman, et al. (2011) find that languages are represented in different ways regarding the occupation of the cortex of the bilingual brain. A parallel can be drawn with language proficiency and the age of L2

[3] Flanker task: in cognitive psychology, the Eriksen flanker task is a set of response inhibition tests that is used to determine the ability to restrain the irrelevant or unsuitable responses in a certain context. The target is flanked by non-target stimuli that correspond to the same directional response as the target (these are called congruent flankers), or to the opposite response (these are called incongruent flankers), or to neither of them (these are called neutral flankers) (Eriksen – Eriksen, 1974).

acquisition. As the following illustration presents (Fig. 8), L1 and L2 are not completely separated from each other (Leonard et al., 2010).

Figure 8. Cerebral activation of an early bilingual (Broca-area) (Kim, et al., 1997)



Kovelman et al. (2008) suggest that the neural processing of a bilingual person differs across the two languages, and they find different behavioral and neural patterns between English monolinguals and English-Spanish bilinguals in a sentence comprehension task. Navracsics and Sáry (2017) tested the phonological and semantic awareness of bilinguals, and they found that phonological processing required a greater cognitive activity than processing semantics. They conclude that typologically unrelated languages that have different phonological systems are represented in different parts of the bilingual brain. On the other hand, there is no difference in the cerebral representation of lexical semantics and sense relations. They also claim that the semantic representation is shared for both languages.

Similarly to Navracsics and Sáry's (2017) findings, Paulesu et al. (2000) in their fMRI experiment find unequivocal evidence for the fact that besides word frequency, regularity, and familiarity, the orthographic pattern of the language also influences brain activation.

1.3 Bilingual visual language processing

What happens when we see or hear a word and how does it make contact with the mental lexicon that contains the information which makes us capable of comprehending what it means? This chapter is intended to give an overview of written word recognition, which is no doubt the most important component of language comprehension. Words are elementary units of language, and they are present in both spoken and written language. Perception of the printed word is a fundamental skill in such basic everyday activities as reading. Due to this fact, the recognition of written words is among the most studied aspects of cognition. Although the identification of printed words is well-researched, bilingual written language processing is still an underresearched area especially with Hungarian as a component of bilingualism.

In bilingual visual language processing, we study the brain activations and the mental lexicon when processing two languages at a time, in a bilingual mode. Visual word recognition can be studied at the sentence and text levels, and also at the word level. This present 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. The mental lexicon, which includes all the syntactic and morphological information, and most importantly, the meanings of words, makes further processing available. 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). Studying written word recognition researchers intend to find out whether a written word leads to the activation in 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 (2011) also suggests that the presentation of a word to a bilingual often results in parallel activation in both linguistic subsystems.

1.3.1 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 neurocognition of multiple languages are 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. The present chapter provides insight into bilingual cognitive models and their neural evidence.

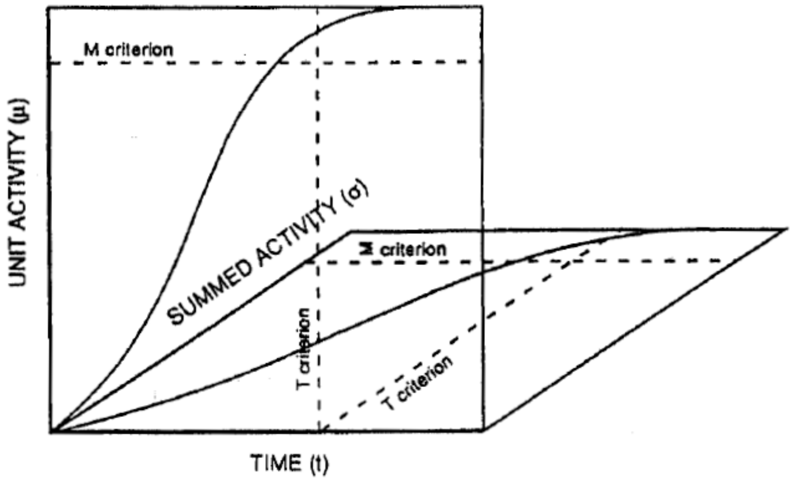
The presupposition that both languages of a bilingual individual are active most of the time led to the question of how bilinguals are capable of selecting the correct language that they are supposed to use in a certain context. Several studies claim that there is no constant co-activation of both languages (Schwartz & Kroll, 2006; Titone et al., 2011), 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).

The connectionist basic model of word processing is TRACE, which simulates speech perception on three levels: individual letters, phonemes, and words (McClelland & Elman, 1986). This model of word processing provided a basis for numerous further bilingual visual word recognition models.

1.3.1.1 The Multiple Read-Out Model (MROM)

Grainger and Jacobs (1996) designed a connectionist model, the Multiple Read-Out Model, which explains the characteristic features of word recognition in lexical decision tests. According to MROM (Fig. 9), lexical decision depends on three criteria. The first criterion is the activation level of words, the second is the global lexical activation, and the third is the time limit. The first two criteria are based on interlexical information that helps positive decisions (real words), and the third criterion is specified by the time starting from the onset of the stimulus, which increases the probability of negative decisions (non-words).

Figure 9. The three criteria of lexical decision in MROM (Grainger & Jacobs, 1996:522)

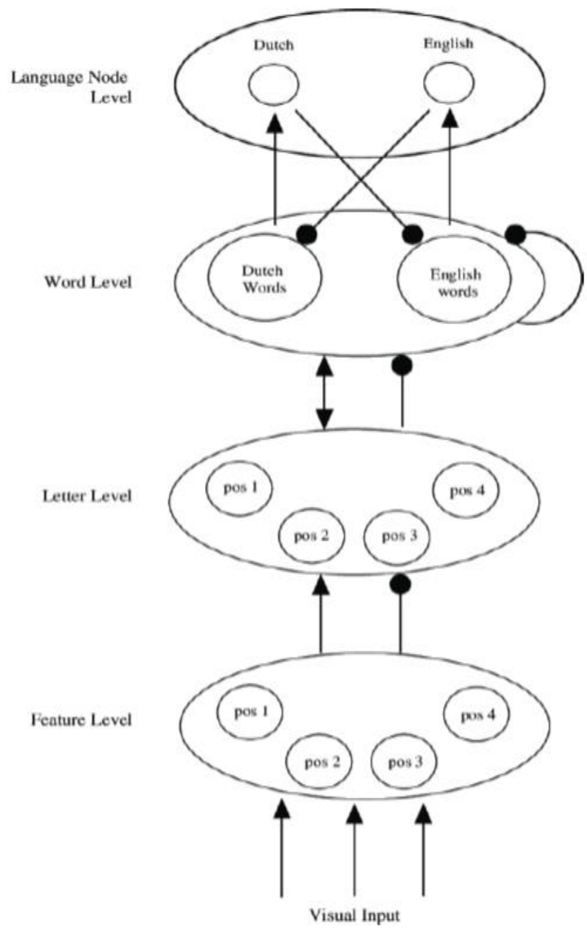


According to the authors, MROM is capable of predicting the reaction time based on the features of pseudo-words (orthographic neighbors, frequency). It provides a theoretical summary based on the previous results of lexical decision tasks and it describes the recognition of not just words but pseudo-words, as well. This model says that lexical decision is affected by different factors, which are the activation of individual lexical units, activation of global or summed lexical units. If a lexical word node is connected to any of the word nodes in the mental lexicon, the stimulus is identified as an existing word, which results in a 'word' decision. However, according to the authors, lexical decisions can also be done without lexical access to a certain word representation. This is the so-called fast-guess mechanism that relies on familiarity. The second factor is based on a summed, global lexical activation over all word nodes. When this summed or global unit is reached, 'word' response is given, and 'non-word' response is given when the temporal criterion is reached before either the local or the global criteria is reached.

1.3.1.2 The Bilingual Interactive Activation (BIA) model

Based on the interactive activation (IA) model for monolingual visual word recognition (McClelland & Rumelhart, 1981), Dijkstra and Van Heuven (1998) developed the Bilingual Interactive Activation (BIA) model (Fig. 10). 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. There are inhibitory connections between nodes that are responsible for activation within a level, and 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 Bilingual Interactive Activation 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 than the monolingual IA model, since the interaction occurs not 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).

Figure 10. BIA model on visual word recognition (Dijkstra & Van Heuven, 1998)

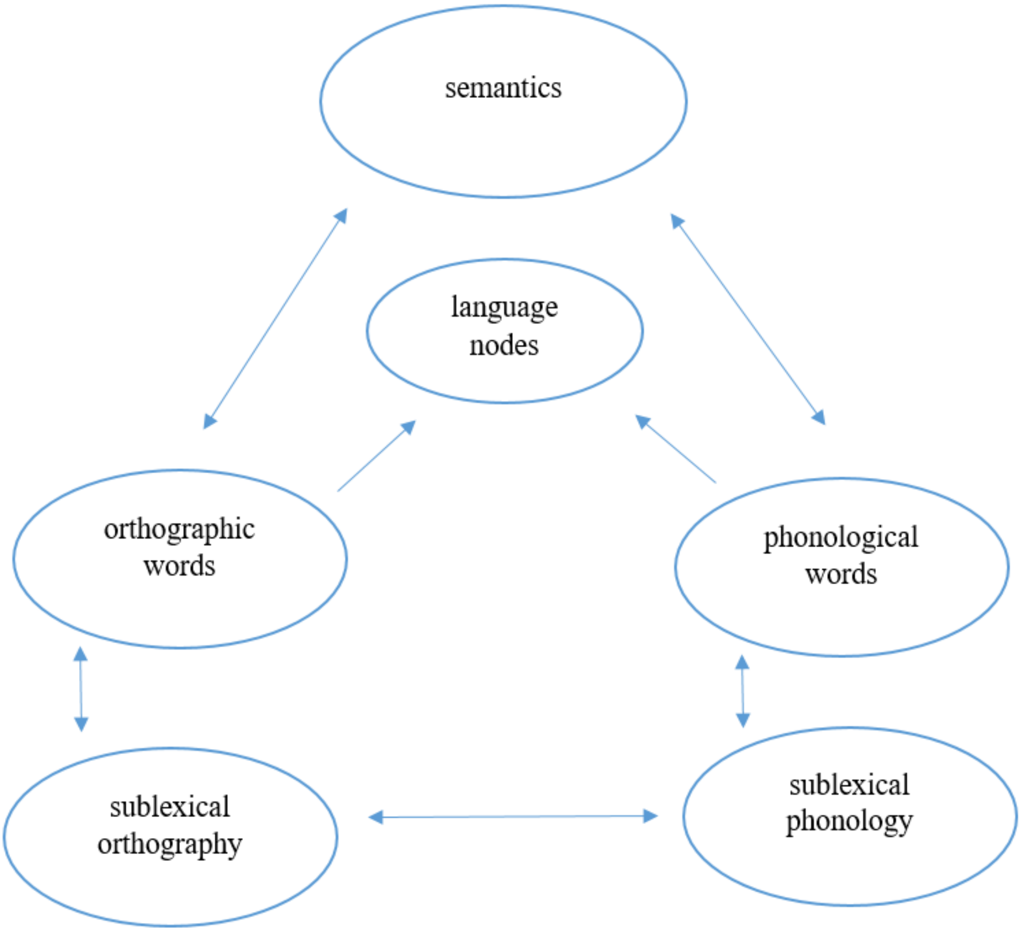


There are some further restrictions on the BIA model. For instance, it is influenced by the reader's proficiency in the language and the current state of language activation. Furthermore, language activation is affected by recent context, for example, previous items in the text. Since there is an interactive activation between the two languages, the activation of features and letters in one language spreads to the words of both linguistic systems. To conduct this cross-language activation, the BIA model suggests a top-down inhibitory control mechanism by using language nodes (Grant et al., 2019). Initially, the language nodes try to label which language each word belongs to. Later on, the nodes activate each language beyond the word level, and connected to the information.

1.3.1.3 The Semantic, Orthographic, and Phonological Interactive Activation (SOPHIA) model

Since the Bilingual Interactive Activation model did not represent semantics, Van Heuven and Dijkstra (2001) developed the Semantic, Orthographic, and Phonological Interactive Activation (SOPHIA) model (Fig. 11). 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 inappropriate word. The target language gets activated, and the semantic level is also significant at that point, since it is responsible for deciding whether the word has a meaning or not.

Figure 11. SOPHIA model (Van Heuven & Dijsktra, 2001)

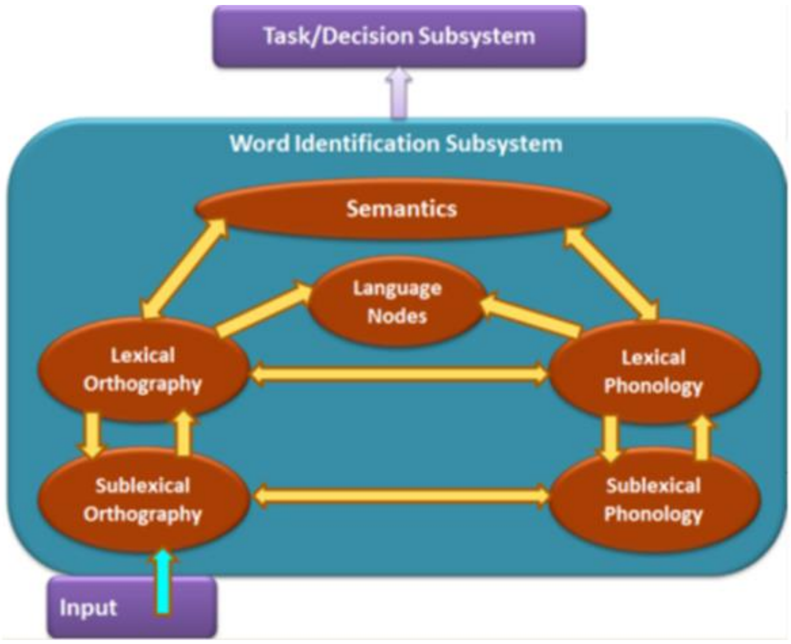


The only drawback of the SOPHIA model is that in the case of languages using different orthographic systems (such as Chinese and English), word recognition might be problematic. Hungarian uses language-specific vowels with accents, furthermore it has 8 graphemes made up of two characters and one grapheme made up of three characters, which are treated as one grapheme, correspondently, one phoneme. Consonants with two or more digits might cause reading difficulties, but if the reader is well aware of the grapheme-phoneme conversation rules, reading problems are avoidable even in the case of pseudo-words (Csépe, 2006).

1.3.1.4 The Bilingual Interactive Activation + (BIA+) model

The original bilingual interactive activation model was extended by semantic and phonological representations, and a non-linguistic task/decision system was added to the word identification system. It contains two subsystems, the word identification subsystem (linguistic context), and the task/decision subsystem (non-linguistic context). 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 interaction, as well (Fig. 12). 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 appropriate language is chosen, the semantics of the word is checked. The task/decision subsystem receives the input from the identification system, where the correct language is identified and gets activated (Dijkstra & Van Heuven, 2002).

Figure 12. BIA+ model (Dijkstra & Van Heuven, 2002)



When a bilingual reads, it is assumed that the visual input is processed first at the sublexical orthography level, which connects bidirectionally to the sublexical phonology level and up to the lexical orthography level. The information is passed bidirectionally to the lexical phonology level, and the nodes have a bidirectional relationship to a shared semantic system, as well as a bottom-up relationship to the language nodes (Grant, 2019). BIA+ differs from the original BIA model in the sense that BIA hypothesizes a complete interaction between word level and language node level, however, BIA+ hypothesizes unidirectional bottom-up processing, which means that the task/decision subsystem does not double-check the information in the word identification subsystem (Navracsics & Sáry, 2013).

1.3.1.5 The developmental Bilingual Interactive Activation-d (BIA-d) model

Based on the previous visual word recognition models, Grainger, et al. (2010) proposed the developmental Bilingual Interactive Activation-d (BIA-d) model. The main novelty compared to the former BIA model is that it describes the development of the inhibitory connections down from the language nodes. The structure is based on the Hierarchical Model of Kroll and Stewart (1994), in the sense that lexical processing happens through two routes: L1 to L2 form-based connections, and L2-form to conceptual store connections. The reason for this duality is that language learners with different language proficiency levels apply the routes to different extents. It means that low-proficient language learners are more likely to rely on form-based connections. For instance, an early language learner translates a word from L2 to L1 in order to make sure he/she understands it properly. On the contrary, high proficient language learners get the information straight from the conceptual store, since they are more exposed to the language and can omit the step of translating the word to their L1.

1.3.2 Most frequent psycholinguistic methods for measuring lexical processing

De Groot (2011) enumerated the most frequent and useful methods and tasks that researchers have applied in recent years to understand visual word recognition.

- Word naming tasks. In this task, participants read printed words aloud and their response latencies and reading accuracy are measured. The disadvantage of this task is that in languages using an alphabetic script, responses can be compiled by applying the script-to-sound, grapheme-phoneme correspondence rules, similarly to pseudo-words, which can be read out loud in spite of the fact that they have no representation in the mental lexicon, so the real recognition is omitted.
- Visual lexical decision tasks. The majority of studies on bilingual visual word recognition use this test, since the results cover a wide range of information about visual word processing. In lexical decision tasks written letter sequences are presented and participants have to decide whether or not they are words. If they

are, they press a “yes” button, if they are not, they press a “no” button. Response latencies and accuracy are measured, as well. Real words, pseudo-words and non-words are frequently used stimuli. Pseudo-words are letter strings which meet the requirements of the orthography and phonology of the test language, but they do not have a meaning. Presenting pseudo-words on the screen is useful, since the phonological awareness of the participants can be measured. The only problem with lexical decision tasks is that they might be unnatural, since in real-life situations language users do not have to decide whether the letter sequences are words or not. That is why lexical decision tasks do not always examine the real lexical access, but the temporal aspects and the cerebral aspects of the responses can be measured without any obstacles. Two types of the lexical decision task have been developed to study bilingual visual word recognition, which are (i) the generalized lexical decision task (language-neutral lexical decision task in other words); and the (ii) language-specific lexical decision task. In the generalized lexical decision task, participants are asked to press a “yes” response if the presented letter sequence is a word in either of his/her language, and a “no” response if the letter string is a non-word. In language-specific lexical decision tasks a “yes” response is required from the participants if the letter strings are real words in the target language. Otherwise, participants are supposed to press “no”, as if they were non-words.

- Perceptual identification. In this type of task, “data-limited” or “masked” stimuli are presented, which means that they are too vague to be clearly seen and participants have to predict what the stimuli might be.
- Word priming technique. An earlier stimulus (prime) is presented before the word target, and the relationship between the prime and the lexical representation of the target is measured. Cross-modal priming technique is a subtype of word priming technique, in which the prime is presented in an audible way, and the target is presented in a visual way.
- Progressive demasking. During this task, the visual representation of the target word alternates with that of a mask. In the meantime, the presentation time of the target and mask increases and decreases. The participant’s task is to press the button right away if the target identification occurs on the screen and the identity of the word is revealed.

- Language go/no-go tasks. These tasks differ from the previously described lexical decision tasks in a way that participants have to respond on trials in one of their languages (go) and deny pressing any button in their other language (no-go).
- Eye-movement recording. Participants usually read complete sentences or texts, but it is also used to study visual word recognition, and their eye movements are measured.

Bilingual word recognition has been the topic of extensive empirical effort, although studies on putative modulating variables, such as individual variations in L2 exposure, are scarce. In the study of Rodríguez et al. (2022), highly proficient bilinguals were divided into two groups based on their L2-exposure and asked to undertake a semantic categorization task while their behavioral reactions and EEG signals were recorded. Lower L2-exposure was projected to result in less effective L2 word recognition processing at the behavioral level, as well as neurophysiological alterations at the early pre-lexical and lexical levels, but not at the post-lexical level. Authors also discovered that L2 exposure influences early processes of word recognition not just in the L2 but also in the L1 brain activities, which suggests a complete language non-selectivitiy.

1.3.3 Event-Related Potentials in bilingual visual word recognition

In visual word recognition, after the onset of the stimulus, visual cortex gets activated. On the ERP curve, positive and negative amplitudes indicate brain activation. The bigger the amplitude is, the higher the brain activations are. P100 (positive deflection at 100 ms) is the first component in a series of components that reflects visual stimuli. This is where the identification of letter strings takes place. N170 (negative deflection at 170 ms) is an ERP component that reflects the neural processing of words. N400 (negative deflection at 400 ms) is a brain response that reflects visual words and other meaningful stimuli. This is when the identification of lexico-semantic processing takes place.

Pre-lexical processing occurs in the posterior areas of the left superior temporal cortex at 250 ms and is responsive to sub-lexical frequency but not lexical frequency. The mental lexicon is active at 350 ms. Processing is sensitive to characteristics such as lexical frequency at this phase, but not to competition among the representations engaged by the input. After activating the mental lexicon, the optimal match to the stimulus must be recognized (Embick et al., 2001; Pylkkänen et al., 2002).

In an EEG study, Ling et al. (2019) suggest that word frequency and the number of orthographic neighbors influence linguistic processing. They also claim that the peak of the time course of decoding and reconstruction occurs at around 200 ms, close to the N170 component, but achieves relevance much earlier, just after 100 ms. These results correspond with familiar words having access to lexical orthographic information between 100 and 200 ms.

Hauk et al. (2006) suggest that word length and word frequency are reflected in the electrophysiological response shortly before 100 ms. At this point, participants differentiate between written words and objects. In this study, longer words with lower frequencies generate bigger amplitudes than short words with higher frequency. The authors found the earliest lexical frequency effect at 110 ms. They discovered lexico-semantic processing of words at around 160 ms.

There is a significant interaction between predictability and frequency (Lee et al., 2012). Throughout the P200 time window, there is a strong predictability impact, with low-predictability words eliciting a less favorable P200 than high-predictability words. There is a strong prediction impact on the N400 component, as well, low predictability words evoke a higher N400 than high-predictability words. According to the authors, contextual information helps early the visual feature and orthographic processing in visual word processing and later the semantic integration in the process.

In language decision tasks, pseudo-words evoke larger amplitude N400s than words (Braun et al., 2006). The N400 is a negative-going deflection that peaks around 400 ms after the onset of the stimulus. N400 is a response to stimuli, such as visual words in this case. It is associated with lexico-semantic processing that activates word processing. According to Braun et al. (2006), the amount of neural activity depends on two important factors. On the one hand, it depends on the difficulty of the visual word processing itself, in the sense that there is more neural activity and greater N400 amplitude when the processing is more difficult due to the low frequency of the word or the low predictability of the word in a certain context. On the other hand, neural activity is affected by the global amount of information, in the sense that there is more neural activity and greater N400 amplitude when more information is being activated, for example in the case of concrete words that activate rich semantic representations.

1.3.4 The recognition of interlexical homographs and cognates

Psycholinguistic studies of bilingual language processing agree that representations from different languages (having alphabetic orthographical system) are simultaneously activated and bilinguals cannot completely deactivate either of their language, and the information in the other language is also being assessed (Kroll et al., 2015; Van Heuven & Dijkstra, 2010). Previous findings have confirmed that cross-language interaction exists in bilinguals during reading, listening, and speaking regardless of their proficiency levels (Kroll & De Groot, 2005). Event-related potential studies have also proved that there is a parallel activation of lexical information of the two languages (De Bruijn et al., 2001; Elston-Guttler et al., 2005), especially in the case of interlexical homographs, since they have unique cross-linguistic features (Studnitz & Green, 2002).

Interlexical homographs are orthographically identical, but phonologically and semantically different words in the two languages (e.g. *comb, eleven,* etc. in English and Hungarian). A special subcategory of interlexical homographs is cognates (e.g. *film, farm, park, opera, taxi,* etc.), which have not only identical spelling, but also shared meanings across languages (De Groot, 2011). To measure bilingual visual word recognition, interlexical homographs (and cognates) can be presented both isolated and in context. The focus of this sub-chapter is how bilinguals process interlexical homographs out of context.

The general purpose of presenting homographs is to discover if lexical activation is embedded in the language (language-selective) or not (language-nonselective). To be more specific, the question is whether both meanings are activated or only the contextually appropriate language when an interlexical homograph (having the same orthographic form but different meanings in the two languages) is presented to a bilingual.

Beauvillain and Grainger (1987) were the first to study bilingual lexical access by using the dual-meaning feature of interlexical homographs. They tested how bilinguals processed interlexical homographs in isolation. They used a cross-language primed lexical decision test, in which a set of stimulus pairs was presented to English-French bilinguals. The stimulus pairs contained a French prime word and an English target word (or non-word), and the words were presented successively. The participants were asked to read each prime and then make a lexical decision on the following target. Most primes were French words, but some of them were English-French interlexical homographs. The researchers were interested in whether the interlexical homographs facilitate the processing of the successive English targets that were related to the homographs' English meaning. They found that at the beginning both meanings of the interlexical homograph primes were activated, and after a little while, the inappropriate meaning was deactivated. Both lexicons got activated, since bilinguals participated in the task in a bilingual processing mode.

Although bilinguals' two languages are in constant co-activation, Green and Abutalebi (2013) introduce the Adaptive Control Hypothesis, according to which the degree of activation is dynamically adaptive. The hypothesis relies on the fact that the language mode the bilingual is in alters according to the context. This was also confirmed by Grosjean (1998, 2001), whose Language Mode model indicates that bilinguals experience different states of activation of their languages and language processing mechanisms at a given point in time. According to this model, the level of activation depends on the context and the environment bilinguals are in. Grosjean (2001) formulates three hypothetical positions regarding the language mode. In the monolingual mode, when the bilingual person talks to a monolingual, the base language of the interaction is active, and the other language of the bilingual is almost deactivated. In the bilingual mode, when two bilingual people, who share the same languages, are in interaction, both the base and the guest languages are highly activated. In between the two stages, there are intermediate language modes, when the activation level of the guest language depends on the partner in communication's guest language proficiency level. De Groot (2011) gives the Language Mode theory as an explanation for the language-nonselective processing of interlexical homographs.

Researchers intend to find proof for co-activation in the non-target lexicon without suspecting the dual meaning activation theory. In the study of Kerkhofs et al. (2006), responses to interlexical homographs and unilingual control words (words existing only in the target language) were compared with each other. Features that might influence word processing were monitored and word frequency turned out to be a salient contributing factor. Furthermore, they discovered that co-activation of the representation units in the non-target language was due to the fact that the only difference between the target and control words was that the homographs were present in both of the bilinguals' languages.

According to BIA+ (Dijkstra & Van Heuven, 2002), the visual presentation of a word leads to parallel activation of orthographic input representations in L1 and L2. Semantic and phonological representations are activated by these representations, and it ends up in a complex interaction between the codes. When the appropriate language gets selected, the input word is recognized. Moreover, according to BIA+, interlexical homographs have separate representations for each language. However, it is possible that cognates have shared representations (Dijkstra & Van Heuven, 2002). BIA+ furthermore emphasizes that the activation of various lexical representations is continuously audited by the task/decision system, which supports the task execution and decision (Green, 1998).

Studies indicate that bilinguals are quicker and more accurate in processing L1-L2 cognates compared with non-cognate control words. This phenomenon is referred to as the cognate facilitation effect (Dijkstra et al., 1999; Dijkstra & Van Heuven, 2002; Lemhöfer & Dijkstra, 2004; Peeters et al., 2013). Interlingual homographs, on the other hand, are frequently responded to more slowly and inaccurately than their matched monolingual control terms (Dijkstra et al., 1998; Van Heuven et al., 2008), which is often referred to as interlingual or interlexical homograph effect. Both cognate and interlexical homograph effects show that in the recognition of cognates and homographs, both languages are active (Zhu & Mok, 2018).

Peeters et al. (2013) studied the behavioral and electrophysiological processing of orthographically identical cognates. This kind of cognate is complex because it is uncertain whether bilinguals identify identical cognates as belonging to their dominant or non-dominant language while reading them. Peeters et al. (2013) found that N400 was more sensitive to word frequency.

Zhu and Mok (2018) also claim that lexical frequency, the number of orthographic neighbors, or language proficiencies of bilinguals might influence processing.

Based on the visual word recognition models, the conclusion can be drawn that both lexicons of a bilingual individual are active (Dijkstra et al., 1999). The processing of cognates and interlexical homographs confirms that besides orthographic awareness, phonological and semantic representations are needed to identify a visual word. In written word recognition, phonological activation occurs, as it was previously stated in the semantic, orthographic, phonological interactive activation model. When reading written words, phrases or texts, the auditory form of the word gets activated, as well (Haist et al., 2001; Carter, 2009; Kaushanskaya & Marian, 2009).

1.3.5 The recognition of words and pseudo-words

In visual word recognition and the identification of words, phonetics, phonology, and phonotactics play a crucial part. The different writing systems have a great impact on the quality of recognition. A shallow writing system (e.g. Hungarian) is built on a consistent mapping of graphemes to phonemes, while a deep one (e.g. English) has no grapheme-phoneme correspondence rule in it. The volatility in the mapping of graphemes to phonemes in deep or alphabetic writing has come to different conclusions about word identification (Share, 2008). For instance, the phonological principle declares that phonology is strongly involved in reading from the very beginning (Perfetti et al., 1992). Behavioral evidence underpins this early automatic phonological processing that begins right away when the reader interacts with a letter string (Halderman et al., 2012). This fact is also evidence for the increased reaction time in recognition of interlexical homographs, since phonological awareness gets activated, and one orthographic form activates two phonological forms in the mental lexicon (Pexman et al., 2001).

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). Furthermore, eye movement studies also proved that phonological awareness strongly contributes to the reading skills. Rayner et al. (1995) appraised that phonological information is processed within the first 200-250 ms of reading a word. ERP studies confirm that lexical processing begins in the first 200 ms (Pulvermüller et al., 1995).

Based on the eye movement studies of Fitzsimmons and Drieghe (2011), the phonology of words is automatically activated while words are just outside of fixation in the parafoveal region. Eye movement studies also demonstrate that readers process syllable-initial information parafoveally during silent reading. Moreover, readers use phonological syllable information to determine whether to fixate on a word. Fitzsimmons and Drieghe (2011) found in their experiment, in which sentences containing one- and two-syllable long five-letter words were presented, that participants were more likely to skip the one-syllable long words than the two-syllable ones during silent reading. They confirm Ashby and Clifton's (2005) results: there are more fixations on words that have two stressed syllables than words that have only one stressed syllable. As a consequence, it can be stated that a skilled reader uses phonological information during word recognition. That is why it is certainly important to have access to multi-layer phonological representations and to be familiar with the phonotactics of the language, including the rules that restrict the possible sound sequences and syllable structures, since they highly determine the decision-making processes in the recognition of words and pseudo-words. EEG correlates and ERP components of visual lexical decision tasks are efficient methods for displaying active brain regions and assessing multilingual visual word recognition. Phonological awareness is assumed to have a great role in this process. The two frequently researched types of lexical decision tasks are the ones that include pseudo-words and non-words and study their recognition processes. Non-words are nonsense letter strings. Pseudo-words are meaningless letter strings that meet the requirements of the orthography and phonology of the test language. Testing word recognition with non-words provides an insight into the word superiority effect, while using pseudo-words in the tests, sheds light on the phonological awareness of the participants. The psycholinguistic and neurolinguistic research into bilingualism has been focusing on (i) how languages are stored in the brain and how they are processed; (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 studies claim words are stored and retrieved in a network of associations (Nattinger, 1988), but recent brain mapping evidence shows that concepts are distributed all across the brain, in both hemispheres (Kiefer & Pulvermüller, 2012). The question is how the mind controls two linguistic systems: whether bilinguals store linguistic information in a unified system and have identical access to both languages, or the information storage is linked to separate languages, i.e. two separate mental lexicons (Appel & Muysken, 1987; De Groot, 2011). One of the most prominent questions concerning the bilingual mental lexicon is whether lexical access is selective or non-selective. According to the general agreement of researchers, bilingual lexical access is characterized by non-selectivity (De Groot et al., 2000; Dijkstra & Van Heuven, 1998, 2002). Non-selectivity is true for orthographic (De Groot & Nas, 1991) and phonological codes (Duyck, 2005; Jared & Kroll 2001). There is also a widely accepted consensus about continuous co-activation at all linguistic levels, including phonology, syntax, and semantics (Miwa & Baayen, 2021; Dijkstra, 2005; Dijkstra & Van Heuven, 2002; Schmid, 2010; Peeters et al., 2018).

Behavioral studies (Weber Fox & Neville, 1996) examining L1 and L2 support the idea of linguistic skills (phonological, semantic, grammatical, and syntactic) having an influence on bilingual visual word recognition. In human-spoken languages, phonology is strongly involved in reading from the very beginning (Perfetti et al., 1992). Phonological processing begins right away when the reader interacts with a letter string (Halderman et al., 2012).

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). Furthermore, eye movement studies also prove that phonological awareness strongly contributes to the reading skills. Rayner et al. (1995) appraise that phonological information is processed at as early as 170 ms, and Event-Related Potentials (ERP) studies also confirm that lexical processing begins in the first 200 ms (Pulvermüller et al., 1995).

1.3.5.1 Neurological aspects of pseudo-words

Pseudo-words cause greater activations in certain brain regions than words carrying a meaning (De Groot, 2011; Shaul et al., 2012, Carreiras et al., 2013; Ihász et al., in press). This greater brain activity clarifies that unknown stimuli that are incapable of accessing word associations might activate the neuronal network more than words that the individual is already familiar with.

Simos, et al. (2002) claim 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 ends up in higher activations in the posterior superior temporal gyrus, and in the interior parietal and basal temporal areas. Pseudo-words are associated with word-specific mental representations. In the recognition of pseudo-words and words that have rare equivocal orthography-pronunciation correspondence, the lexical representation generates the retrieval of the word. Hagoort et al. (1999) has similar results when testing the neural circuitry involved in the reading of German words and pseudo-words. Left posterior middle temporal gyrus display less neurophysiological activity and less regional cerebral blood flow in the recognition of pseudo-words, and they found that reading pseudo-words activated the left inferior frontal gyrus (Brodmann's areas 47/45) and the ventral part of Broca's area. This suggests that these parts of the brain are also involved in the sublexical decoding of orthographic input letter strings into phonological output codes. What is certain is that pseudo-words require a higher-level 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. The importance of word frequency was also proved in another study by Simos et al. (2000), in which they gained evidence for activations in different areas depending on the frequency of the word. Perea et al. (2005) examined how frequency influences lexical decision, and confirmed that the frequency of words that are used to create pseudo-words determines how participants recognize them. They found that pseudo-words that were generated by changing one internal letter of the original word, pseudo-words with high frequency showed slower latencies than pseudo-words with low frequency. In the case of high-frequency pseudo-words that were generated by changing two adjacent internal letters, the latencies were also slower than the ones with low frequency. But in the case of one-letter different pseudo-words the high frequent ones showed faster latencies than the ones with low frequency. Concerning the neurological background, Hagoort et al. (1999) found that the articulation of high frequent syllables requires the articulatory gestures from the primate cerebral cortex, more precisely from the supplementary motor area, and the articulation of low frequent syllables activates the left medial premotor cortex. Hagoort et al. (1999) found bilateral activation in medial and lateral extrastriate areas and in the left lower precentral gyrus in the case of silent reading of both words and pseudo-words, which proves the fact that the auditory form of the word gets activated in silent reading, as well. As for the neurological aspects of reading pseudo-words, we can make a distinction between silent reading and reading out loud. A PET study demonstrates (Hagoort et al., 1999) that reading aloud pseudo-words activates the superior temporal gyrus, the middle temporal gyrus. The right superior parietal lobule and the right anterior cingulate show more activation while reading pseudo-words out loud. Furthermore, there is more activation in the cerebellum in the case of reading aloud pseudo-words than in the case of words. In the silent reading of pseudo-words, the left and right angular gyrus, the medial posterior cingulate, and the superior and inferior frontal areas get activated. In silent reading of words, there is an increased regional cerebral blood flow in the left and right supramarginal gyrus and the right anterior fusiform gyrus, while in the silent reading of pseudo-words there is an increased regional cerebral blood flow in the medial precuneus.

In the case of pseudo-words, N400 is larger, since the mental lexicon needs greater effort to search for their lexical representations (Simos et al., 2000; Shaul et al., 2012).

1.3.5.2 The theoretical background of pseudo-words: phonotactic restrictions on English and Hungarian syllables

Hungarian and English are typologically non-related languages. Hungarian is a member of the Uralic (more precisely, Finno-Ugric) family of languages, while English is of Indo-European origin. From a historical point of view, the two languages are quite far from each other; however, they share quite a few characteristic features. The Hungarian language contains 44 letters while English has 26 letters. Both languages use the Latin alphabet. All letters of the English alphabet can be found in the Hungarian alphabet, but in Hungarian, in addition to them, there are some more vowels (vowels with accents: *á, é, í, ó, ö, ő, ú, ü, ű*) and graphemes consisting of two consonants (corresponding to one phoneme:, *cs, dz, dzs, gy, ly, ny, sz, ty, zs*). The Hungarian writing system is shallow, i.e. phonemic by default (grapheme-phoneme correspondence rules). Compound words and words with suffixes obey the principle of word analysis, i.e. morphemes of a word should be written the same way, disregarding the pronunciation assimilations (Kenesei and Vogel, 1989).

Unlike in Hungarian, in English, there are multiple ways to spell almost every phoneme, and most letters have several ways of pronunciation depending on their position in a word and the context, hence it is called a deep writing system.

Both languages have strict restrictions on what sounds can appear in what order and in what position (phonotactic rules). A sound sequence can be a potential word (pseudo-word) as it contains some combination that is systematically acceptable by either language system. The following stanza from Lewis Carroll's Jabberwocky (1871) along with its Hungarian translation by István Tótfalusi represents some great examples both in Hungarian and in English.

JABBERWOCKY	A GRUFFACSÓR
'Twas brillig, and the slithy toves	Nézsonra járt, nyalkás brigyók
Did gyre and gimble in the wabe:	turboltak, purrtak a zepén,
All mimsy were the borogoves,	nyamlongott mind a pirityók,
And the mome raths outgrabe.	bröftyent a mamsi plény.

There are several ‘potential’ words in the text with no meaning. These nonsense words are sometimes referred to as accidental gaps, or missing items in other words (Balogné Bérces & Szentgyörgyi, 2006) in the vocabulary, since they gained meaning later on.

For example, *plény* in Hungarian and *brillig* in English are acceptable, however, *lpény* or *rbillig* would not be acceptable in the languages, respectively, since they violate certain orthographic rules. No Hungarian or English words start with /lp/ or /rb/. In word final position the opposite happens, /lp/ and /rb/ are possible, like in words *folt* or *herb*. (Baloghné Bérces & Szentgyörgyi, 2006)

Although most languages are quite different from each other, they still share quite a few features in their phonotactic rules, which are called phonotactic universals. One of the most general phonotactic universals is that languages have both consonants and vowels within a syllable even if vowels are not represented with a letter (cf. schwa in Coratian: *Krk*). Furthermore, each language has vowels in syllable-final position, but this is not necessarily true for consonants, and each language has consonants in syllable-initial position, but this is not necessarily true for vowels (Eifring & Theil, 2005).

There are certain cases in which consonant clusters are acceptable in word-initial position. For instance, when three consonants occur adjacently, the first of them has to be [s] /sh/ or [sz] /s/, the second has to be [p], [t], or [k], and the third consonant has to be [r]. In the case of two consonants, there are more possible sequences, but certain combinations are excluded, such as [gd] or [pf] (Kálmán & Trón, 2007).

The following chart presents some of the most frequent two-member combinations of sounds on either of English monosyllabic morphemes. As Table 1 presents all consonants (except for /ŋ/) can start a morpheme.[4]

Table 1. Abbreviations: O=Obstruent, N=Nasal, L=Liquid, G=Glide, V=Vowel, F=fricative, P=plosive.

O+O	O+N	O+L	O+G	V+G	G+L	/r/+/l/	L+N	N+F	F+P
stick	sneak	trick	swear	eye	hire	swirl	barn	hence	grasp
skirt	snake	play	tune	bow	bowl	curl	arm	nymph	mask

As the examples (Table 1) present, each sound segment has its place within the syllable. The logical order that they follow in most cases is obstruents, nasals/liquids/glides, vowels, glides, /r/, /l/, nasals, fricatives, and plosives (Baloghné Bérces & Szentgyörgyi, 2006). In a symmetrical syllable it is obvious that the vowel is in the middle, obstruents at the beginning or at the end, and sonorants locate between them. Each syllable has a nucleus, which is the peak. In English phonotactics, nucleus is usually the vowel, and it is located in the middle of the syllable. This peak is called sonority peak, which relies on the sonority principle. It means that in each syllable sonority increases towards the vowel, and from the vowel it decreases. The degree of sonority is the following: oral stops and affricates, nasal stops, liquids, glides, and vowels (Carlisle, 2001).

According to Singleton (1999), the phonological and morphological form of the word determines which lexicon gets activated first and where the word recognition takes place. He claims that in bilinguals who speak two typologically unrelated languages, a language-specific letter string immediately activates the appropriate language, since the other language lacks that combination of letters. This is the situation in connection with Hungarian and English, as well, as the phonotactic rules and the restrictions on syllables for each language are quite diverse. The two languages do not share the same features

[4] Please note that these phonotactic rules refer to sounds and not to single letters. English spelling can be confusing sometimes. For instance, in case of the consonant combinations <kn>, <ps>, or <gn>, one of the letters remains silent in English (but in spelling they are acceptable), however in Hungarian these consonant clusters exist in pronunciation, as well.

regarding orthography, they do not have the same prefixes or suffixes, and the word formation works in different ways.

1.3.6 Orthographic neighborhood density

It is commonsense that words can still be recognized when some of the letters are mixed. As the popular statement goes "Aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it deosn't mttaer in waht oredr the ltteers in a wrod are, the olny iprmoatnt tihng is taht the frist and lsat ltteer be at the rghit pclae". However, the theoretical truth is beyond this common statement, since otherwise we would not be able to make a distinction between the words *bread* and *beard*. In an eye-tracking study, Rayner et al. (2006) had their participants' read jumbled sentences, and they found that it took longer for them to read such sentences than a normal text, i.e. their average fixation durations were longer and their eyes made a great number of regressions.

The effect of orthographic neighborhood density is among the most significant findings in visual word recognition. The terms 'orthographic neighbors' and 'orthographic neighborhood' were first introduced by Landauer and Streeter (1973). According to their original definition, an orthographic neighbor is a word with the same number of letters, and differs from the original word by only one letter. For instance, the neighbors of the word *read* include *bead*, *road*, *raid* and *real*, etc. Readers are able to identify individual words from among thousands of opportunities. Fast and efficient word recognition depends on the structure of the mental lexicon and the relationship between form-similar words, which are also referred to as neighbors. Previous research has shown that words having many neighbors produce different behavioral and electrophysiological patterns than words having fewer neighbors (Andrews, 1997; Van Heuven et al., 1998). What can be taken for granted is that in lexical decision tasks, words tend to induce faster responses than pseudo-words (Braun et al., 2006; Holcomb et al., 2002).

Grainger and Jacobs' (1996) Multiple Read-Out Model (see 1.3.1.1) provides a theoretical summary based on the previous results of lexical decision tasks and it describes the recognition of not just words but pseudo-words, as well. According to this model, lexical decision is affected by different factors, such as the activation of individual lexical units, activation of global or summed lexical units. If a lexical word node is connected to any of the word nodes in the mental lexicon, the stimulus is identified as an existing word, which results in a ‘word’ decision. However, according to the authors, lexical decisions can also be made without lexical access to a certain word representation. This is the so-called fast-guess mechanism that relies on familiarity. The second factor is based on a summed, global lexical activation over all word nodes. When this summed or global unit is reached, ‘word’ response is given, and ‘non-word’ response is given when the temporal criterion is reached before either the local or the global criteria is met. The Multiple Read-Out Model also claims that words from high-density orthographic neighborhoods induce high levels of global lexico-semantic activity, and that is why ‘word’ response is faster. On the contrary, words from low-density orthographic neighborhoods cause less lexico-semantic activity, which results in slower responses, since the participant needs more time to identify the letter string.

Coltheart et al. (1977) find that orthographic neighborhood has no effect on ‘yes’ responses, but has a large inhibitory effect on ‘no’ responses. In other words, it takes longer for participants to reject non-words with more neighbors than with fewer neighbors. Later Sears et al. (1995) and Carreiras et al. (1997) prove that in lexical decision tasks, target words having many orthographic neighbors result in faster and more correct ‘word’ responses, but slower and fewer correct ‘not a word’ responses.

Neighborhood density is a significant factor in the neurological aspects of the recognition of pseudo-words, more precisely, the N400. Pseudo-words cause greater amplitude N400s than words due to the co-activation of orthographic neighbors (Meade et al., 2019). This is due to the fact that when a word appears on the screen, it is recognized by the participant, so the neighbors are inhibited, but when a pseudo-word is presented, neighbors remain activated.

As a conclusion, in visual word recognition, not just word frequency but neighborhood density is an influencing factor. Frequency and orthographic neighborhood affect the recognition of pseudo-words, but this is true for words and non-words, as well. Words with high frequency elicit faster reaction times than words with low frequency, and as for the orthographic neighborhood density, words from high-density neighborhoods elicit faster reaction times than words from low-density neighborhoods (Lim, 2016). Frequency and orthographic neighborhood density are determinant not just in lexical decision tasks, but in language decision tasks, too.

The definition of orthographic neighborhood by Landauer and Streeter (1973) was soon extended because it turned out to be too narrow. According to the original definition, the pseudo-word *gadren* has no lexical neighbors, since it differs from the word *garden* in two letters, not only one. Pseudo-words that are formed by transposing two letters are called transposition neighbors. Related to transposition neighbors, Chambers (1979) introduces the term near-word effect, which means that pseudo-words that are orthographically similar to real words are more difficult to reject in a lexical decision task than non-words with nonsense letter combinations.

Based on the new definition, Chambers (1979) compared the word recognition of transposition neighbors and single substitution neighbors. She found that internal transposition neighbors (for example *liimt*) took much longer to allocate than internal substitution neighbors (for example *lirit*). She found the opposite effect in the case of initial and final transpositions and substitutions (for instance *visti* was classified faster than *visin*). In another experiment, in which frequency was tested, participants had slower responses to pseudo-words like *mohter* (the transposition neighbor of the high frequency word *mother*) than pseudo-words like *bohter* (the transposition neighbor of the low frequency word *bother*) (O'Connor & Foster, 1981). This inhibitory effect was investigated in Davis and Andrews' experiment (2001), in which they found that inhibitory effect increases with the length of the stimulus word. For instance, there is a large inhibitory effect for pseudo-words such as *baclony*, but there is little or no effect for the pseudo-word *crad*, i.e. it is more difficult and takes more time to classify *baclony* as a non-word than *crad*. In another experiment, Perea and Lupker (2004) found that inhibitory effect of transposition neighbors was also observable when transposition occured in case of non-adjacent letters. For instance, a pseudo-word like *caniso* (the transposition neighbor of *casino*) takes a longer time to classify as non-word than *caviro*. They also observed that transposition neighbor effect was limited to cases in which consonants were transposed (for instance inhibitory effect was observed for *aminal* but not for *anamil*). This result may suggest that there is a difference in the recognition and coding of consonants and vowels.

In connection with the visual recognition of words, pseudo-words and non-words Davis (2012) agrees with the fact that word frequency, familiarity, age of acquisition, imageability and spelling-sound consistency are all influencing factors.

1.3.7 Word superiority effect

Word superiority effect relates to a superior processing and better recognition of words in comparison to pseudo-words and non-words (Sand et al., 2016). As a result of the word superiority effect, when written stimuli are damaged by noise or brief presentation, letters in words are recalled more accurately than single letters embedded in non-words (Johnston, 1981). 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.

Coch and Mitra (2010) observed word superiority effect in a study of words and pseudo-words, too. Effects of orthographic regularity and familiarity were detected at P150 (around 100-160 ms), an effect of lexicality was noted at N200, and peak amplitude of N300 and N400 also distinguished between word and pseudo-word as compared to baseline stimuli. Moreover, the magnitude of P150 and N400, word superiority effects were linked to behavioral fluency and reading assessments. The findings imply that in the case of fluently reading adults, orthographic fluency is reflected in both lower-level, sublexical, perceptual processing and higher-level, lexical processing.

1.4 The present study

Words are basic units of language that are found in both spoken and written language. Reading requires the perception of the printed word, which is a fundamental ability. Although the identification of printed words is frequently studied in monolingual situations, bilingual written language processing remains an unexplored topic, particularly with Hungarian as a component of bilingualism. At the same time, research on bilingual written word processing can provide crucial information not only for researchers but also for teachers who deal with bi- or multilingual children and facilitate their literacy development. The present study focuses on the recognition of isolated words coming from two languages: English and Hungarian. Research on visual word recognition of bilinguals is fundamental, since numerous bilingual students attend monolingual educational institutions, and teachers have to be aware of what is happening in a bilingual student's mind when they are facing reading or writing exercises, since they have to cope with two languages.

1.4.1 Research questions

Based on the literature of previous studies on bilingual visual word recognition, I formulate the following research questions:

- Q1 – Are there differences in P100, N170 and N400 in the processing of the two languages?
- Q2 – What kind of awareness is essential in written word recognition?
- Q3 – What is the brain activation pattern (modular or interactive) of bilingual visual word processing in L1 and L2?

1.4.2 Hypotheses

Based on previous psychophysical and electrophysiological research results (Navracsics & Sáry, 2013; Carreiras et al., 2013; Maurer et al., 2005; Laszlo & Armstrong, 2013; Yum & Law, 2021) I formulate the following hypotheses:

- H1 – No difference is expected in the latencies of Hungarian and English words' recognition processes.
- H2 – The processing time of non-homograph L1 and L2 words is faster than that of non-existing language-specific pseudo-words, due to the words' frequency and familiarity.
- H3 – The recognition of non-words is faster due to the word superiority principle.
- H4 – Orthographic and phonological awareness plays a crucial role in the ability of language selection in the case of pseudo-words.
- H5 – Homograph-effect results in prolonged recognition time.
- H6 – Language-specific characters must help with bilingual word recognition, and so difference around 170 ms is expected, as an indicator of orthographic and phonological processing.
- H7 – There is meaning related difference in the N400 components between the two languages, which displays semantic processing.

2 METHODS

2.1 Participants

Twenty-three Hungarian–English bilingual volunteers (10 males, mean age: 24.57 yrs, 19 right-handed) were tested in an EEG laboratory. The study was approved by the Ethics Committee. When choosing the participants, I focused on homogeneity. All of them are Hungarian native speakers with C1 level English proficiency, and use English at work or in their studies 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; no hearing impairment, language disability, learning disability, or any history of neurological illness was reported.

2.2 LEAP-Q questionnaire

The LEAP-Q questionnaire (Marian & Hayakawa, 2001) (Fig. 13), was used to investigate the language dominance and acquisition of the participants. The participants were requested to list what percentage of time they currently and on average are exposed to each of their language. They also had to state how much they read and speak in all their languages. Participants were required to report whether they had any vision problems, hearing impairments, language disabilities, or learning disabilities. They had to describe each language they know by certain parameters, such as the age of acquisition (AoA), the age of becoming fluent in the language, the time they spent in each language environment, and on a self-assessment basis, the level of proficiency in speaking, comprehension and reading. Furthermore, they were asked to declare on a scale from zero to ten how much certain factors contributed to their language learning, and to what extent they were currently exposed to certain contexts (interacting with friends and family, reading, watching TV, listening to radio and music, etc.).

Figure 13. Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian et al., 2007)

Northwestern Bilingualism & Psycholinguistics Research Laboratory

Please cite Marian, Blumenfeld, & Kaushanskaya (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research, 50* (4), 940-967.

Language Experience and Proficiency Questionnaire (LEAP-Q)

Last Name		First Name		Today's Date	
Age		Date of Birth		Male ☐	Female ☐

(1) Please list all the languages you know **in order of dominance**:

1	**2**	**3**	**4**	**5**

(2) Please list all the languages you know **in order of acquisition** (your native language first):

1	**2**	**3**	**4**	**5**

(3) Please list what percentage of the time you are *currently* and *on average* exposed to each language.
(*Your percentages should add up to 100%*):

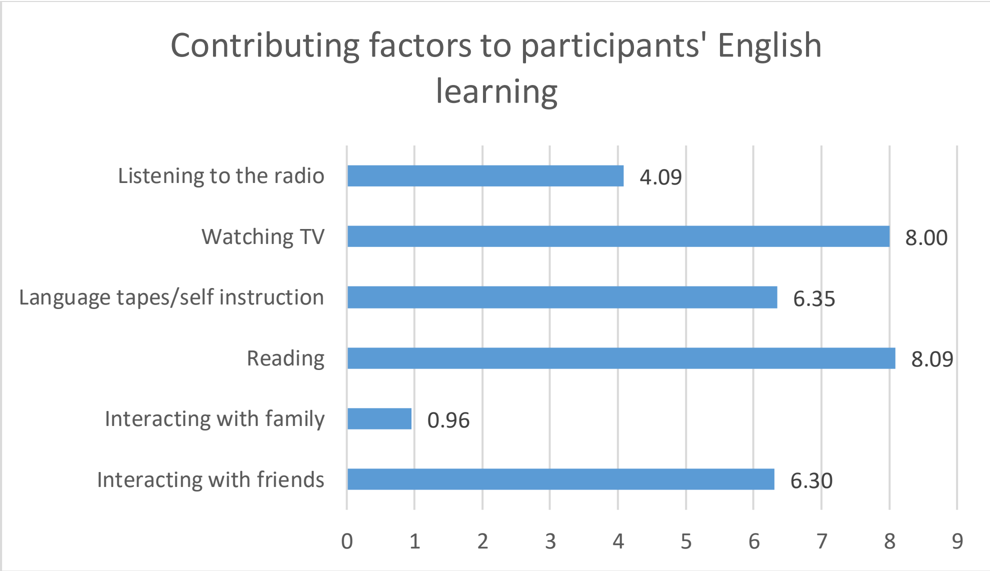
List language here:					
List percentage here:					

(4) When choosing to read a text available in all your languages, in what percentage of cases would you choose to read it in each of your languages? Assume that the original was written in another language, which is unknown to you.
(*Your percentages should add up to 100%*):

List language here					
List percentage here:					

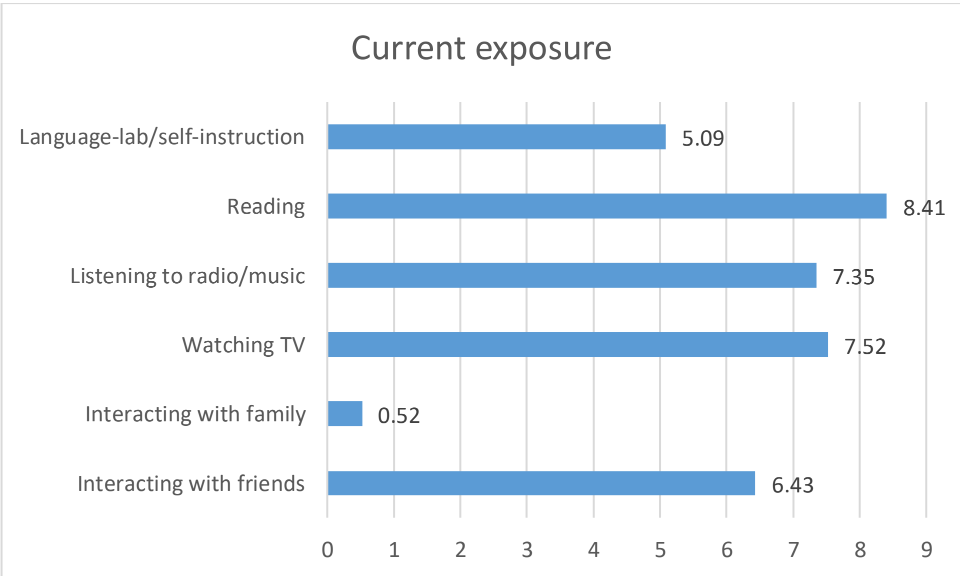
Seventeen participants considered themselves bilingual, and the mean age of becoming fluent in English was 17.78 years. On average they spent 63.96 months in L2 language environment (school and/or working environment where L2 is spoken). On a scale from zero to ten their speaking proficiency is 8.22, their understanding spoken language proficiency is 8.78, and their reading proficiency is 8.91. The main contributing factors to the participants' English learning are interacting with friends, interacting with family, reading, self-instruction, watching TV, and listening to podcasts. Figure 14 summarizes the distribution of the contributing factors.

Figure 14. Contributing factors to participants' English learning



The participants' current exposure covers the following contexts: interacting with friends, interacting with family, watching TV, listening to podcasts/music, reading, self-instruction. Figure 15 summarizes the participants' current exposure to English.

Figure 15. Participants' current exposure to English



Other foreign languages the participants are exposed to are German, Spanish, French, Russian, Dutch, Finnish, Japanese, and Norwegian (Table 2).

Table 2. Other foreign languages besides English that participants are exposed to

Other foreign languages	Number of participants
German	18
Spanish	8
French	3
Russian	2
Dutch	2
Finnish	1
Japanese	1
Norwegian	1

2.3 Test materials

2.3.1 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*). In the test, there are cognates and interlexical homographs mixed (examples in Table 3; see full word list in Appendix 4), since participants' task was to choose between two languages, and their brain responses were measured.

Table 3. Extract from the language decision test: the first 10 entries in the word list

	Homographs	English words	Hungarian words
1	add	age	ács
2	bank	aid	baj
3	be	air	bál
4	bent	arm	cél
5	blog	art	cikk
6	bolt	bath	cím
7	comb	bench	év
8	dug	boat	fej
9	fan	boot	fék
10	far	boss	föld

To control for word frequency, I used the Hungarian National Corpus (HNC) (http://corpus.nytud.hu/mnsz/index_eng.html) for Hungarian, and the Corpus of Contemporary American English (COCA) (https://www.english-corpora.org/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. We calculated the Zipf-frequencies of all items as the ten-base logarithm of the frequency per billion words. The Zipf-frequency of Hungarian words was 4.29 (±0.76 SD) and that of English words was 4.77 (±0.42 SD) in their respective corpora. The Zipf-frequency of homographs was 4.25 (±0.88 SD) in the Hungarian corpus, and 4.6 (±0.80 SD) in the English corpus, and the Hungarian-English frequency difference was -0.35 (±1.00 SD) (see details in Table 4).

Table 4. Language decision test: results of the frequency check (homographs). Homographs recognized as Hungarian are denoted by HHun, homographs recognized as English are denoted by HEng. The numbers indicate how many times the given word occurs in the Hungarian and in the English corpus. The second column summarizes the Zipf-frequency.

Homographs	HHun	HEng	Hungarian	English	Frequency
add	19214	116994	0.010242	0.010635818	ENG
bank	167655	102188	0.089368	0.009289818	HUN

be	1289270	5047494	0.687244	0.458863091	HUN
bent	33678	17934	0.017952	0.001630364	HUN
blog	16979	67697	0.009051	0.006154273	HUN
bolt	12215	6546	0.006511	0.000595091	HUN
comb	1315	3403	0.000701	0.000309364	HUN
dug	382	10403	0.000204	0.000945727	ENG
fan	9234	48508	0.004922	0.004409818	HUN
far	3950	331652	0.002106	0.030150182	ENG
farm	1866	48125	0.000995	0.004375	ENG
fax	5560	8171	0.002964	0.000742818	HUN
fed	11066	36325	0.005899	0.003302273	HUN
film	145068	138233	0.077328	0.012566636	HUN
fog	371308	9695	0.197925	0.000881364	HUN
gin	769	4185	0.00041	0.000380455	HUN
golf	6042	36335	0.003221	0.003303182	ENG
hall	14173	78109	0.007555	0.007100818	HUN
had	13159	2723729	0.007014	0.247611727	ENG
hang	39550	47794	0.021082	0.004344909	HUN
hat	207010	34200	0.110346	0.003109091	HUN
here	7299	1413940	0.003891	0.12854	ENG
hint	350	13645	0.000187	0.001240455	ENG
hit	39572	175117	0.021094	0.015919727	HUN
hold	32488	178423	0.017318	0.016220273	HUN
hull	8947	7022	0.004769	0.000638364	HUN
jazz	12109	20513	0.006455	0.001864818	HUN
jog	69314	2080	0.036948	0.000189091	HUN
kid	2627	110050	0.0014	0.010004545	ENG
kin	1383	4783	0.000737	0.000434818	HUN
kit	35958	14291	0.019167	0.001299182	HUN
lap	114265	15409	0.060909	0.001400818	HUN
lent	14808	4475	0.007893	0.000406818	HUN
lift	3690	27558	0.001967	0.002505273	ENG
lop	2947	359	0.001571	3.26364E-05	HUN
mind	380957	247382	0.203069	0.022489273	HUN
mint	2397440	6482	1.277953	0.000589273	HUN
mix	42975	40388	0.022908	0.003671636	HUN
most	1557889	997292	0.830431	0.090662909	HUN
must	3622	430715	0.001931	0.039155909	ENG
nap	438681	7033	0.233838	0.000639364	HUN
old	19409	425745	0.010346	0.038704091	ENG
pad	4476	10570	0.002386	0.000960909	HUN
park	47886	129466	0.025526	0.011769636	HUN
part	17868	485500	0.009525	0.044136364	ENG
per	35363	151760	0.01885	0.013796364	HUN
pink	5559	32571	0.002963	0.002961	HUN

port	14298	24186	0.007622	0.002198727	HUN
rest	2739	170402	0.00146	0.015491091	ENG
ring	4690	48031	0.0025	0.004366455	ENG
rum	1876	3834	0.001	0.000348545	HUN
sort	17136	164861	0.009134	0.014987364	ENG
sport	104772	41689	0.055849	0.003789909	HUN
tag	29440	15788	0.015693	0.001435273	HUN
tan	4753	7635	0.002534	0.000694091	HUN
tea	9891	46207	0.005272	0.004200636	HUN
test	31169	138243	0.016615	0.012567545	HUN
toll	4288	11838	0.002286	0.001076182	HUN
van	3373311	51178	1.79814	0.004652545	HUN
vet	1462	6868	0.000779	0.000624364	HUN

Since all the participants are Hungarian, they were familiar with all the Hungarian words. According to the Oxford dictionary (www.oxforddictionaries.com), all English words belong to A1-B1 levels, which means that the participants had to be familiar with the English words, as well.

The participants were asked to decide whether the word on the screen is Hungarian or English and click the left (English word) or right (Hungarian word) button of the computer mouse. Words appeared on the screen in a mixed, pseudorandom order to keep participants' both languages active. With this experiment, I checked language activation. This test is to check hypotheses number 1, 2, 5, 6 and 7.

2.3.2 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*). The Hungarian and English words contained 3 vowels and 3 consonants to make them more similar to each other. Both function and content words were selected and, similarly to the first test, chosen so that all participants understand them. Hungarian and English words did not include inflection or derivation; they were only root morphemes without any prefixes or suffixes. Non-words were created by randomly putting letters together in a way that they could not structurally resemble any meaningful words in either language, e.g. non-words containing only vowels or only consonants, nonsense vowel or consonant clusters, etc. The participants' task was to decide whether the letter string they saw on the screen was a word or not. With this test, I checked the word superiority principle. This test is to check hypotheses number 2 and 3 (see the first 10 examples in Table 5; see the full word list in Appendix 5).

Table 5. Extract from the first lexical decision test: the first 10 entries in the word list

	English words	Non-words	Hungarian words
1	abroad	adadad	áhítat
2	advice	aggaez	ajánló
3	amount	aiyaii	alapmű
4	animal	ayvbnn	baráti
5	appeal	bmziii	drámai
6	around	cdrfya	ebédlő
7	assume	ddddal	elárul
8	author	dioodf	fatető
9	became	dmfgkr	fizika
10	before	dzertz	főutca

2.3.3 Lexical decision test 2

This modified version of the 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. There were pseudo-words, orthographic neighbors, and transposition neighbors mixed in this task, but all pseudo-words carried the phonotactic features of either language. I did not differentiate between them, since here the task was to decide between English and Hungarian, and I tested the phonological awareness in the two languages. This test is to check hypotheses 2, 4 and 6 (See the first ten examples in Table 6).

Table 6. Extract from the second lexical decision test: the first 10 entries in the word list

	English pseudo	Hungarian pseudo
1	abtair	agirat
2	ackone	amagyi
3	adairt	arávús
4	antido	atyiga
5	aporte	barica
6	asrope	barila
7	balook	batéra
8	balour	bérali
9	beance	bugeri
10	bliney	élmebe

2.4 Experimental procedure

The participants were tested in the EEG laboratory of the Faculty of Information Technology at the University of Pannonia using a 128-channel Biosemi EEG device. All the participants were included in the analysis.

Starting the experiment, each participant was given basic instructions and had to read and sign a consent form (Appendix 1) for participation. The instructions included information about the length of the experiment (approximately one hour), the character of the test (non-invasive, which means that it does not cause physical pain or inconvenience), and it also stated that they can interrupt the experiment at any time without any consequences. With the completion of this step, participants were asked to fill in two questionnaires, the Hungarian-English questionnaire, and the proficiency test (Language Experience and Proficiency Questionnaire – LEAP-Q, by Marian et al., 2007). After the participants had filled in the questionnaires, they were ready to start the main part of the test.

Participants were asked to minimize their eye-movements, eye-blinks, and every other type of muscular movement, such as swallowing, coughing, gnashing of teeth, nodding, etc., during the test in order to reduce noise and artifacts in the EEG data recordings. After a 6-stimulus trial for each participant, the real experiment started. Every participant received a different randomization of trials. Stimulus words were doubled in order to increase trial count and signal-to-noise ratio. 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.

2.5 Custom-made program

A previously designed custom-made program (Navracsics & Sáry, 2013) written in MATLAB (MatLab Inc.) with the Psychtoolbox extension (Kleiner et al., 2007) running on a PC (Asus, UX303UB) was used for the experiments. Stimuli were presented on a white background, using black characters (Arial, font size 14) in the middle of the screen (display resolution 1920 x 1080). 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 second, the stimulus stayed on the screen for 2 seconds (exposure time). During this time participants were requested to press the right or left button according to the task instructions. Failure to respond within the allocated time interval resulted in the continuation of the task to the next trial. The task was machine paced to ensure a constant level of attention from the participants.

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

2.6 Measuring neural activity

Electroencephalography (EEG) is a non-invasive method to measure the electrical activity of the brain. Hans Berger produced the first EEG in 1924, which allowed to measure neural activity by electrodes placed on the scalp. These electrodes collect the electrical activities of the brain and convert them into digital records (Carter, 2009). Spontaneous and task-related activations of cortical neurons result in small current flows in the cortex perpendicular to the cortical surface. These activated neurons act as miniature current generators, also known as electrical sources. When a sufficiently large population of nearby neurons is activated simultaneously, the generated current fluctuations cause detectable changes in the electrical field of the brain. The scalp potential distribution, generated by the electrical field, can be measured by a suitable EEG measurement device and a set of scalp electrodes, and stored in a computer as digital data for later processing and analysis. The number and layout of the electrodes used in practice vary greatly, but 64 or 128-electrode systems arranged in the universal 10/10 or 10/5 layouts (Jurcak et al., 2007) are the most common in research laboratories.

The main advantage of EEG over other brain imaging methods (e.g. fMRI, PET) is its superior temporal resolution. Typical EEG sampling rates range from 512 to 4096 Hz, resulting in millisecond to sub-millisecond resolution view of brain activity. No other imaging method can provide this level of accuracy in time, thus it comes as no surprise that EEG is a central tool in cognitive science. The drawback of EEG, however, is its relatively poor spatial resolution caused by volume conduction.

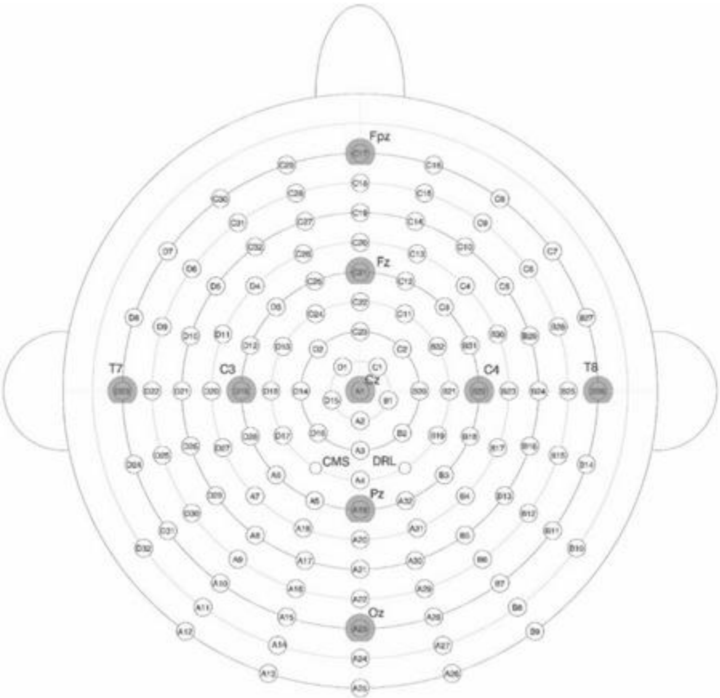
The head is made up of tissues (white and grey matter, cerebrospinal fluid, skull, and scalp) each having different conductivity properties. When the generated current flows from the cortex to the scalp, it must pass through the skull, which has a relatively low conductivity (high resistivity). Consequently, the current spreads out within the bone of the skull instead of passing straight through to the scalp. The result of this so-called volume conduction effect is the 'smeared' appearance of the cortical sources on the scalp. Various methods have been developed to increase the spatial resolution of the scalp potential map (resolution enhancement methods) or to recover the original cortical sources from the measured potential field (inverse methods). Since most of these methods are rather complex and time-consuming, waveform analysis is the traditional method of choice in most cognitive experiments (waveform method reference).

A technical problem encountered in EEG measurement and analysis is the presence of noise. Although the amplitude of cortical activations is in the 10 mV range, EEG measured on the scalp is in the range of 50 µV. This small-amplitude signal is embedded in relatively high noise generated by various biophysical sources (muscle activity, ECG, eye-movement and blinking), skin resistance changes, electrode malfunction, and so on. In order to increase the signal-to-noise ratio, the normal practice is to average several repeated experiments. Assuming random noise with zero mean, averaging a sufficiently large number of samples removes the added noise and leaves us with the original clean event-related signal. Successful averaging requires very precise synchronization of the datasets of the repeated experiments; therefore stimulus presentation and response triggers are used to mark the start and end of the experiment trials. Depending on which trigger is used for averaging, we can distinguish between stimulus or response-locked averaging. The resulting trigger-based average potentials are called event-related potentials, or ERP in short.

2.7 EEG measurement

EEG data were recorded using a 128-channel Biosemi ActiveTwo measurement device (https://www.biosemi.com/products.htm) with Ag/AgCl active electrodes placed and arranged in the Biosemi equiradial ABC layout cap (Fig. 16). Measurement was performed at f_s = 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 digitized EEG data is stored in raw reference-free Biosemi format in BDF data files.

Figure 16. Electrode layout of the 128 channel Biosemi measurement cap. Top view, nose pointing to top of the page. Gray electrodes mark the equivalent 10/20 system electrodes, such as Cz, Pz, Oz, etc.



2.8 Data analysis

2.8.1 Language decision test

Incorrect responses were excluded from the analyses (note, that for the homographs, all responses were regarded as correct, since they can be understood in both languages, but in the case of Hungarian and English words, non-words and Hungarian-like and English-like pseudo-words, incorrect responses were excluded from both the behavioral and the ERP analyses. Response times and response languages were averaged separately per condition (Hungarian, English, and homograph) for each participant. Language bias of homographs was tested by comparing the rate of Hungarian responses to 50% with Student's t-test. The mean response times were compared among conditions with repeated measures ANOVA, and post hoc testing was performed with multiple comparisons.

The ratio of Hungarian responses for the homograph words was calculated across participants. This item-wise mean language response was tested for linear correlation (Pearson) with the difference between English and Hungarian Zipf-frequencies of the items.

The response times of homograph trials were further divided into two groups based on the decision language, and averaged per participant. The means were compared with a paired Student's t-test. The linear relationship between response time bias (response time difference between Hungarian and English responses to homographs) and decision bias (the ratio of Hungarian responses to homographs) was assessed by calculating the Pearsons correlation coefficient.

The EEG data were preprocessed by re-referencing to the average of all channels, removing line noise with a band-stop filter around 50Hz and band-pass filtering with a 0.5-30 Hz FIR filter. Eye movement artifacts were removed manually observing and excluding noisy ICA components. Next, stimulus-locked epochs were extracted from -1 second to 2 seconds around stimulus onset time. Epochs were baselined to the mean amplitude in the -200-0 ms pre-stimulus window, and finally averaged in each channel to obtain ERP waveforms.

Data from each participant was processed individually, and group-level analysis took place with the FieldTrip toolbox in MATLAB. The data were compared between the critical conditions (Hungarian vs. English words; homographs with Hungarian vs. English responses). To identify significant differences in the grand averaged ERP waveforms, we used a dependent samples t-test with permutation-based cluster correction (1000 Monte-Carlo permutations) across all channels in the 100-600 ms time window. In this correction method, data points are analyzed in the context of their neighbors in the time and location dimensions. Clusters with significant t-statistic ($p < 0.05$) were considered truly significant if the cluster size exceeded 97.5% of the randomly permuted cluster sizes.

To compare the N400 component amplitudes, I averaged voltage levels in the time window between 380 and 420 ms post-stimulus onset at the D14 electrode (central part of the brain, roughly corresponding to C1 in 10-10 system). These amplitude values were then averaged by condition (Hungarian, English, and homograph) for each participant. Condition effects were evaluated by repeated measures ANOVA and multiple comparisons, similarly to the response time analyses above.

2.8.2 Lexical decision tests

The EEG data were preprocessed by re-referencing to the average of all channels, removing line noise with a band-stop filter around 50Hz and band-pass filtering with a 0.5-30 Hz FIR filter. Eye movement artifacts were removed manually observing and excluding noisy ICA components. Next, stimulus-locked epochs were extracted from -1 second to 2 seconds around stimulus onset time. Epochs were baselined to the mean amplitude in the -200-0 ms pre-stimulus window, and finally averaged in each channel to obtain ERP waveforms.

Data from each participant was processed individually, and group-level analysis took place with the FieldTrip toolbox in MATLAB. The data were compared between the critical conditions in both experiments (words vs. non-words; Hungarian-like vs. English-like pseudo-words). To identify significant differences in the grand averaged ERP waveforms, we used a dependent samples t-test with permutation-based cluster correction (1000 Monte-Carlo permutations) across all channels in the 100-600 ms time window. In this correction method, data points are analyzed in the context of their neighbors in the time and location dimensions. Clusters of significant t-statistic ($p < 0.05$) were considered truly significant if the cluster size exceeded 97.5% of the randomly permuted cluster sizes.

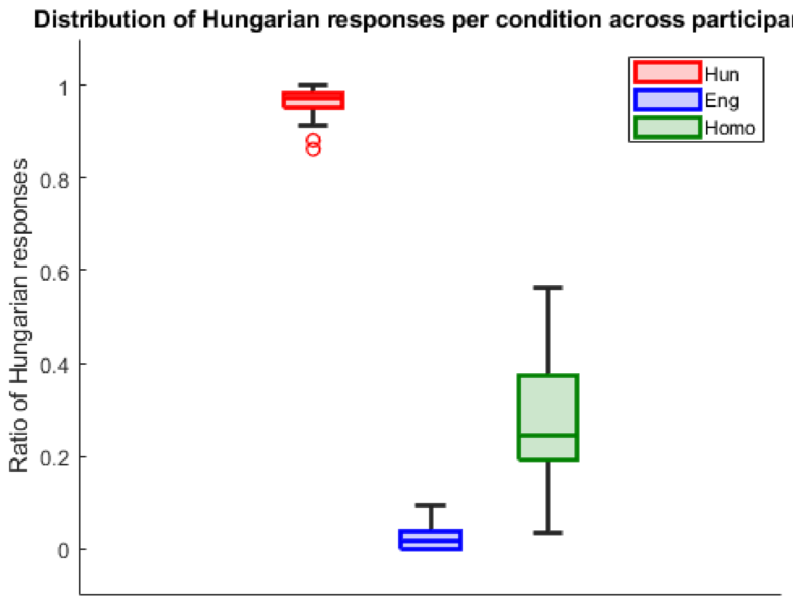
3 RESULTS

3.1 Homographs, Hungarian and English words

3.1.1 Behavioral analysis: reaction times

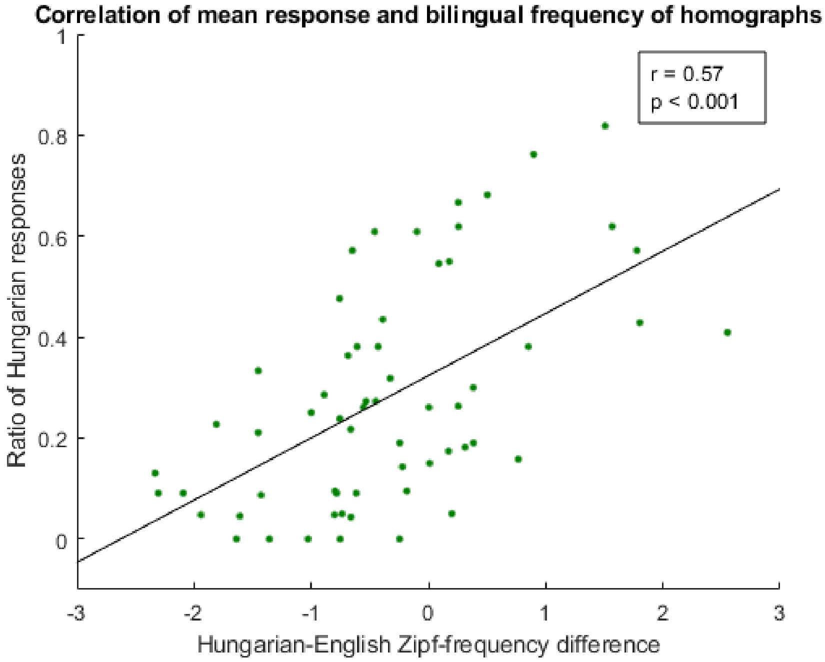
The mean response language per participant indicated high accuracy for both Hungarian (96% correct) and English conditions (98% correct), whereas the homographs indicated a bias towards English responses (29% Hungarian response; $t(21) = -7.21$, $p < 0.001$) despite the balanced homograph frequencies between the two languages (Fig. 17).

Figure 17. Distribution of Hungarian response ratios averaged by participant. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.



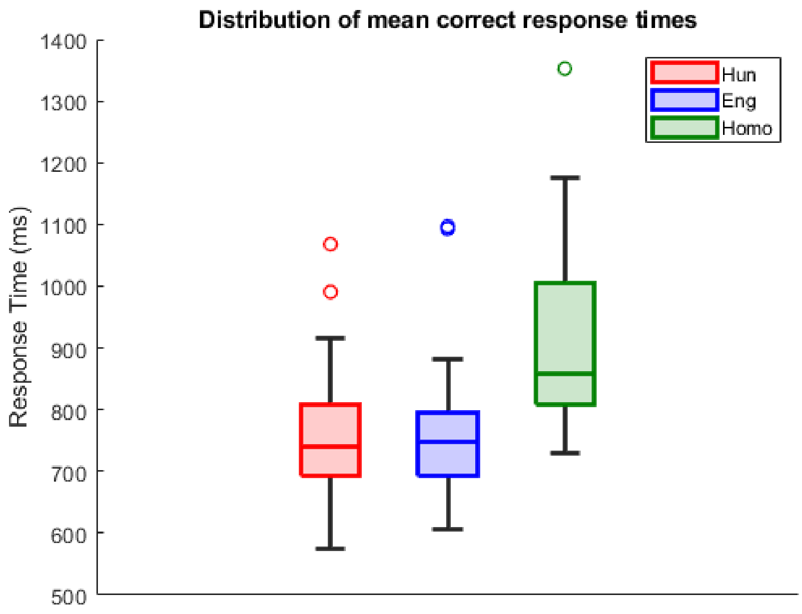
I assessed the relationship between the mean response language and relative frequency for each homograph word with a Pearson's test. The coefficient showed a correlation between the ratio of Hungarian responses and the Hungarian-English Zipf-frequency difference (Fig. 18; $r(59) = 0.57$, $p < 0.001$).

Figure 18. Linear correlation between relative frequency and ratio of Hungarian responses for each homograph item, averaged across participants. The fitted line has an intercept of 0.32 and a slope of 0.12. Note, that the frequency difference is of a logarithmic nature, thus a value of -1 means that the item is 10 times more frequent in English than in Hungarian, and a value of 2 means that the item is 100 times more frequent in Hungarian than in English.



Mean correct response times were 768 ms, 772 ms, and 922 ms for the Hungarian, English, and homograph conditions respectively (Fig. 19). The ANOVA yielded a significant effect of language condition ($F(2,21) = 52.59$, $p < 0.001$). No significant difference was found in the mean response times of Hungarian and English words ($p = 0.94$, CI = [-34.39, 26.13]), whereas the homographs produced around 150 ms longer responses than the unambiguous words (Hungarian-homograph: $p < 0.001$, CI = [-211.30, -98.47]; English-homograph: $p < 0.001$, CI = [-190.09, -111.42]).

Figure 19. Distribution of correct response times averaged by participant. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.



The comparison of homograph response times based on decision language revealed a difference between Hungarian and English responses (Fig. 20). Hungarian responses took on average 995 ms, whereas for English they took 916 ms, a difference that proved to be significant upon analysis ($t(20) = 3.85$, $p < 0.001$). One participant was excluded from these calculations due to having an extremely low number of Hungarian responses (2 out of 60). The Pearson test revealed a very strong linear correlation between the language bias and response time bias of the participants (Fig. 21; $r(20) = -0.84$, $p < 0.001$). This shows that the less a participant responds to homographs as Hungarian, the slower the Hungarian responses get.

Figure 20. Distribution of homograph response times averaged by participant, based on decision language. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.

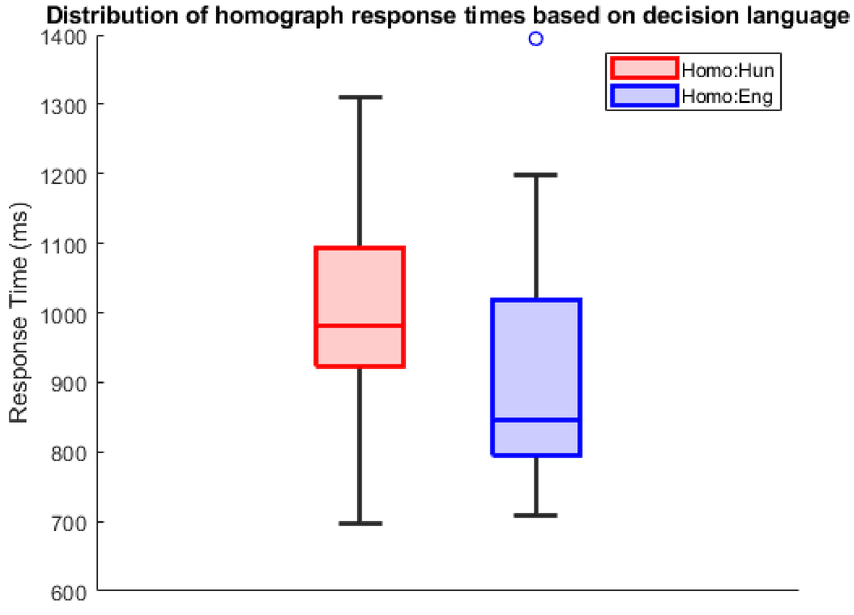
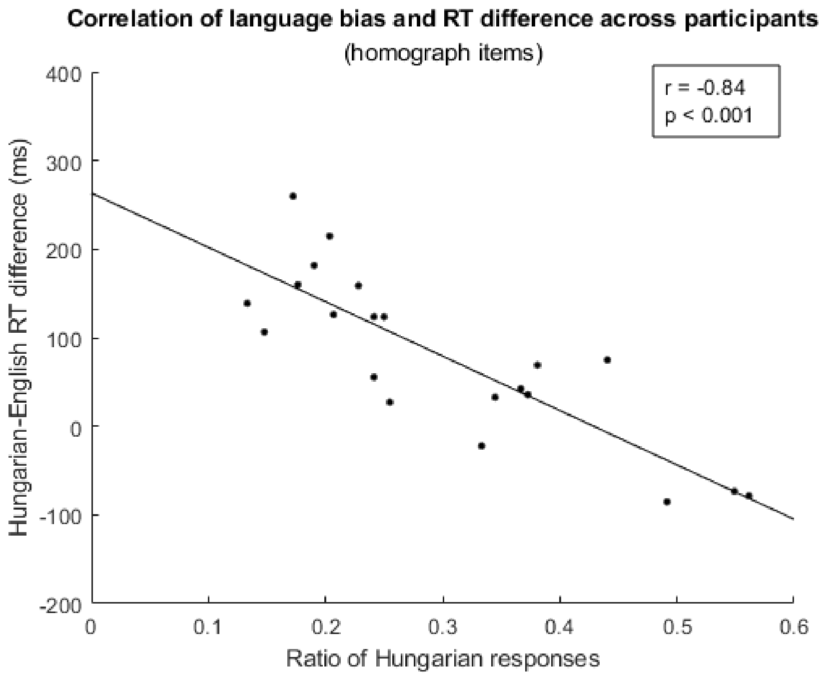


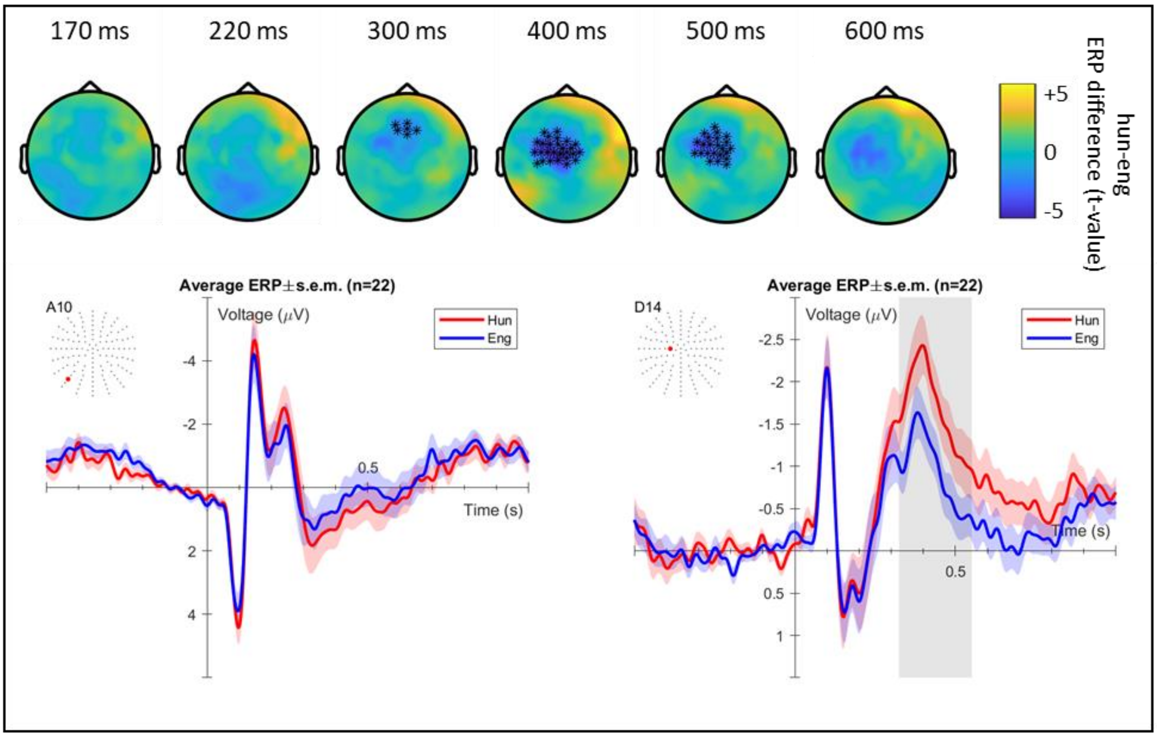
Figure 21. Linear correlation of language bias and response time difference of homographs. The fitted line has its intercept at 263 ms and the slope is -614 ms.



3.1.2 ERPs of non-homographs

The ERP waveforms elicited by Hungarian and English words did not seem to differ in the early stages of visual word recognition. The occipital P100 and N170 components are clearly identifiable in the occipital regions (Fig. 22, bottom left), and the cluster-based statistics indicate no differences in this time window between the two conditions. The central electrode sites, however, show a difference in the N400 component (Fig. 22, bottom right), with the Hungarian words producing a larger (more negative) amplitude. This difference belongs to a significant cluster, spanning from 300 ms to 500 ms (Fig. 22, top).

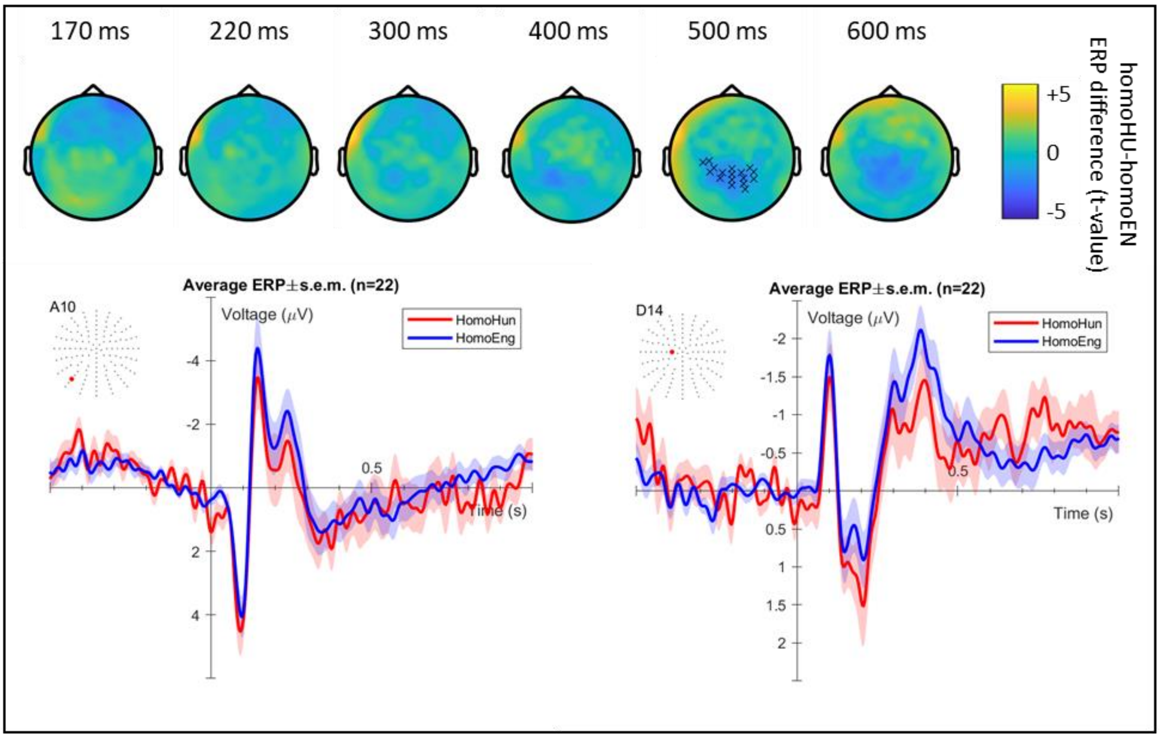
Figure 22. (Top) Topoplots representing the ERP difference between Hungarian and English at denoted times. Channels with significant contrast are denoted by asterisks ($p < 0.01$). (Bottom) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels. The shading represents times of significant difference ($p < 0.05$).



3.1.3 ERPs of homographs

The recognition of homographs did not trigger different processing patterns; however, various cognitive efforts could be observed. The N400 difference could not be reproduced with homographs recognized as Hungarian or English, although a weak centro-parietal cluster emerged around 500 ms after stimulus onset (Fig. 23, top). The occipital and central ERP waveforms were not found to differ at any timepoints (Fig. 23, bottom).

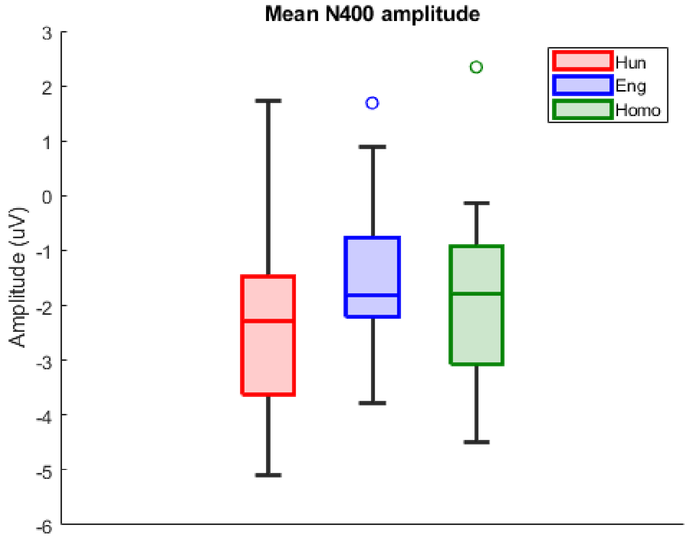
Figure 23. (Top) Topoplots representing the ERP difference between Hungarian-regarded and English-regarded homographs at denoted times. Channels with marginally significant contrast are denoted by crosses ($p < 0.05$). (Bottom) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels.



3.1.4 N400 components

The comparison of the mean N400 components revealed a significant effect of language condition (Fig. 24; $F(2,21) = 7.79$, $p = 0.001$). The mean component amplitudes were -2.34 µV for Hungarian words, -1.49 µV for English words, and -1.78 µV for homographs. The only significant contrast upon multiple comparisons was seen between Hungarian and English non-homographs ($p < 0.001$, CI = [-1.33, -0.39]).

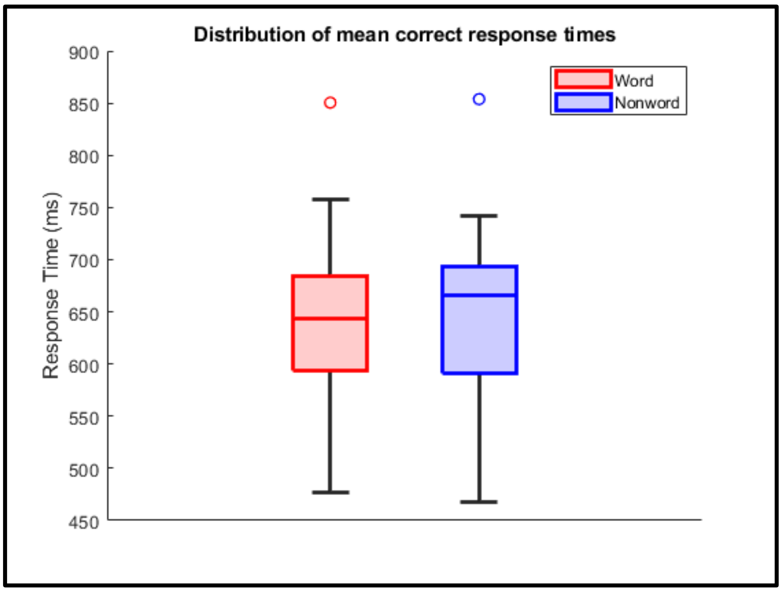
Figure 24. Distribution of mean N400 component amplitudes averaged by participant. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.



3.2 Words and non-words

3.2.1 Behavioral analysis: reaction times

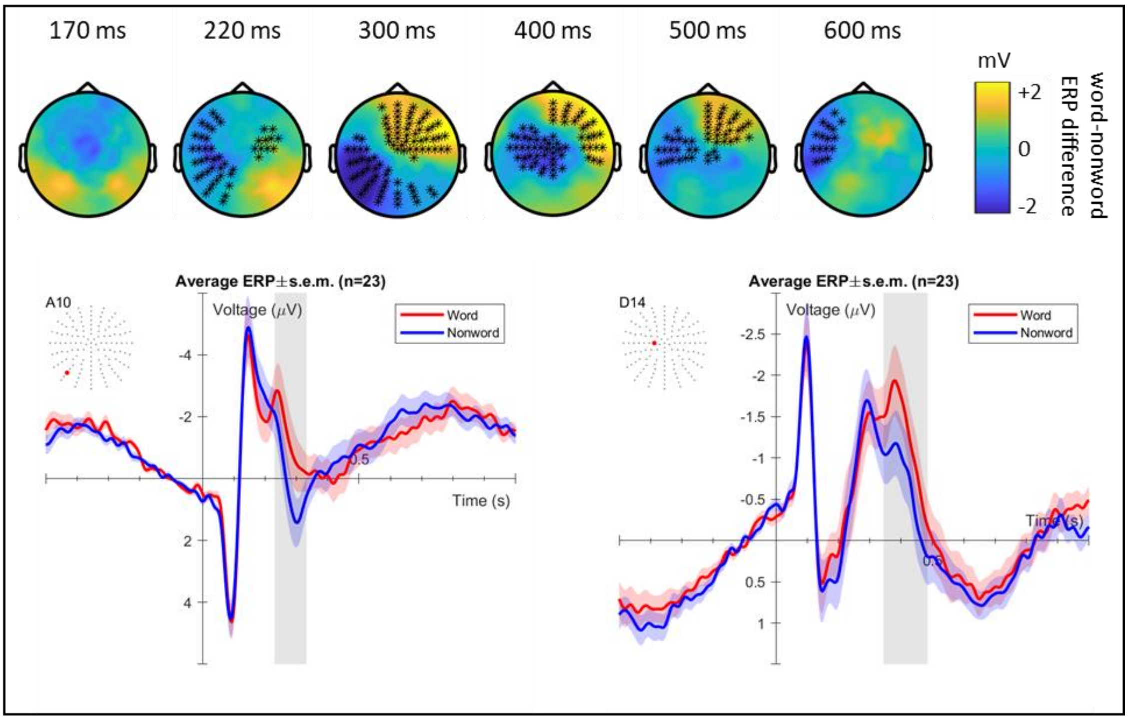
Figure 25. Distributions of correct response time means across participants in the first experiment. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.



The group mean response times were 649 ms and 648 ms for the Word and Non-word conditions respectively (Fig. 25), and the difference was clearly not significant.

3.2.2 ERP analysis

Figure 26. (Top) Topoplots representing the ERP difference between words and non-words at denoted times. Channels with significant contrast are denoted by asterisks (p < 0.01). (Bottom) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels. The shading represents times of significant difference (p < 0.05).



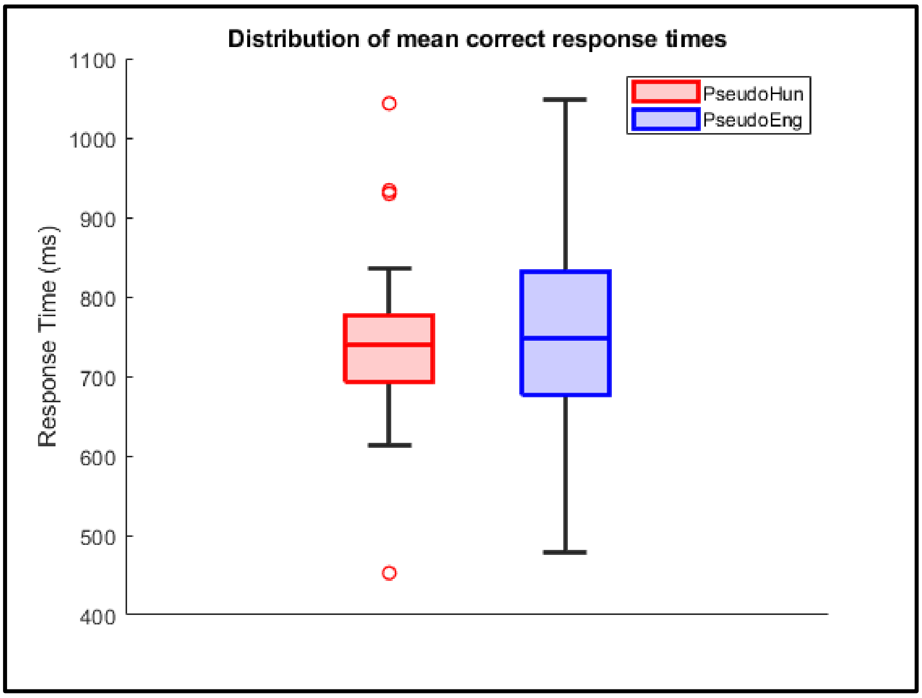
The ERP waveforms do not seem to differ in the first 200 ms, then they start to diverge in multiple regions (Fig. 26, top). The earliest differences between word and non-word processing are apparent in the late parts of the N170 component around 220 ms. This can be observed as a clear second peak in the late N170 (Fig. 26, bottom left). The central N400 component is more pronounced for the word condition (Fig. 26, bottom right).

A significant difference occurs between the recognition of words and non-words at the early phase of word recognition (200-350 ms) at the temporal electrode sites (Fig. 26, bottom left). Channel D14 representing the central parts of the brain (Fig. 26, bottom right) depicts a significant difference between the recognition of the two categories at 350-500 ms, which indicates the semantic processing of words. Central parts of the brain show higher brain activity in the case of words than non-words, which means that the recognition of real words requires greater cognitive activity. This explains that semantics has a role in visual word recognition.

3.3 Pseudo-words

3.3.1 Behavioral analysis: reaction times

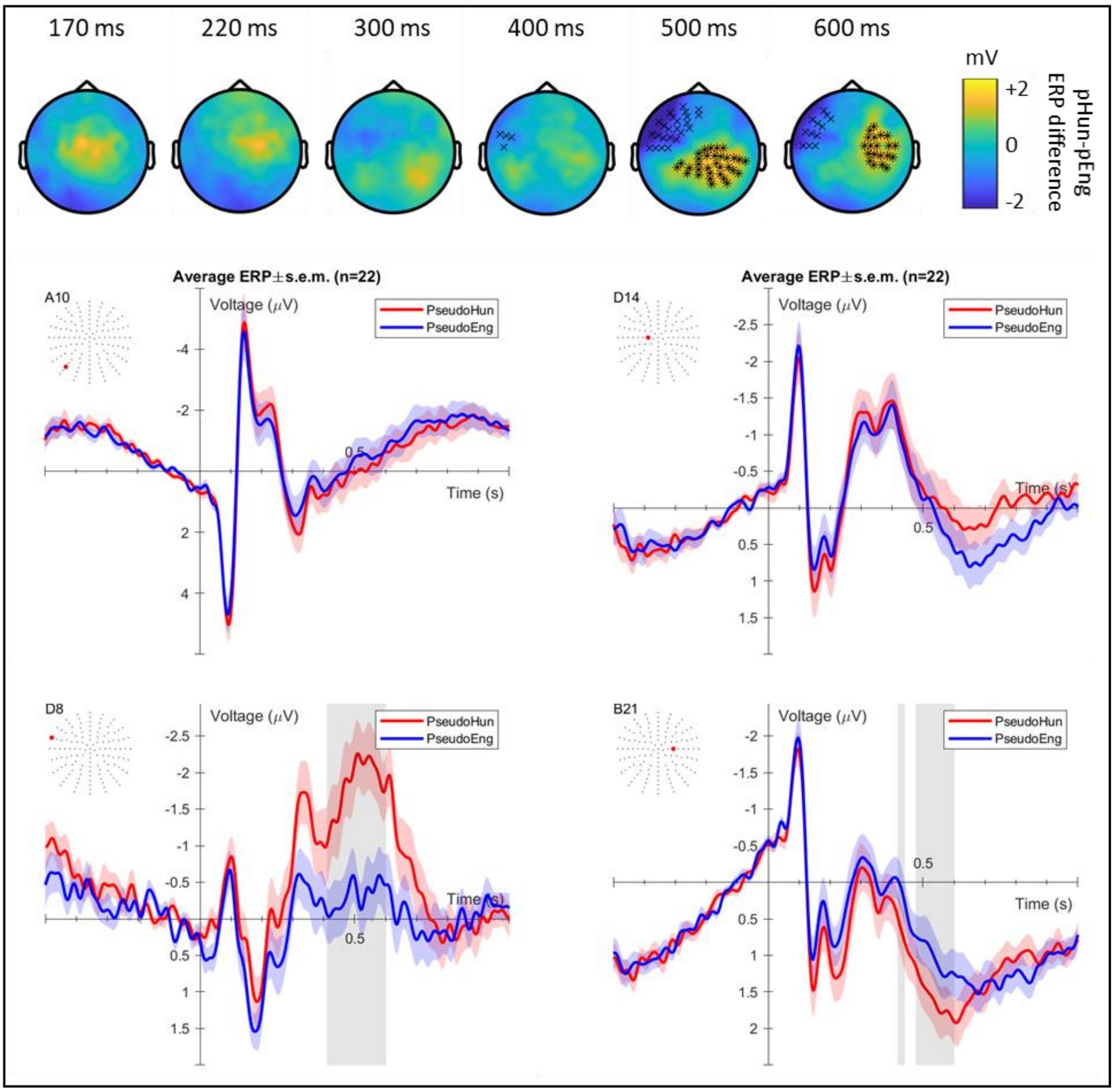
Figure 27. Distributions of correct response time means across participants in the second experiment. The boxes display the median, lower, and upper quartiles, and the whiskers reach to the non-outlier minima and maxima. Outliers are defined as data points that are at least 1.5 inter-quartile range from the top or bottom of the boxes.



The group mean response times were 743 ms and 763 ms for the Hungarian-like English-like pseudo-words respectively (Fig. 27). Apparently, the latter condition is 20 ms slower on average than the former. However, the T-test has found that this difference is not significant ($p = 0.62$). The quicker inclination for Hungarian-like strings could be explained by the presence of language-specific letters (e.g. vowels with accents, such as á, é, í, ó, ö, ő, ú, ü, ű).

3.3.2 ERP analysis

Figure 28. (Top) Topoplots representing the ERP difference between Hungarian-like and English-like pseudo-words at denoted times. Channels with significant contrast are denoted by crosses ($p < 0.05$) and asterisks ($p < 0.01$). (Middle) ERP waveforms at the left occipital A10 (left panel) and the central D14 (right panel) channels. (Bottom) ERP waveforms at the left temporal D8 (left panel) and the right central B21 (right panel) channels. The shading represents times of significant difference ($p < 0.05$).



Compared to the previous tests, the temporal aspect of word recognition in the lexical decision test with pseudo-words is delayed. Significant difference occurs only at 420 ms. Channel D8 (frontal electrode site) (Fig. 28, bottom left) shows high brain activity.

The ERP waveforms elicited by pseudo-words resemble that of real words, in that the late N170 and the N400 components are more pronounced than for non-words (Fig. 28, middle). In these occipital late N170 and central N400 components, no differences were found between Hungarian-like and English-like pseudo-words. However, I can find significant differences later at the left temporal and frontal electrode sites around 500 ms post-stimulus onset (Fig. 28, top and bottom left). Perhaps this reflects the activation of the articulatory network (left inferior frontal area), checking the pseudo-words for pronounceability, producing more negative signals for Hungarian-like items.

Figure 29. The distribution of Hungarian and English pseudo-words

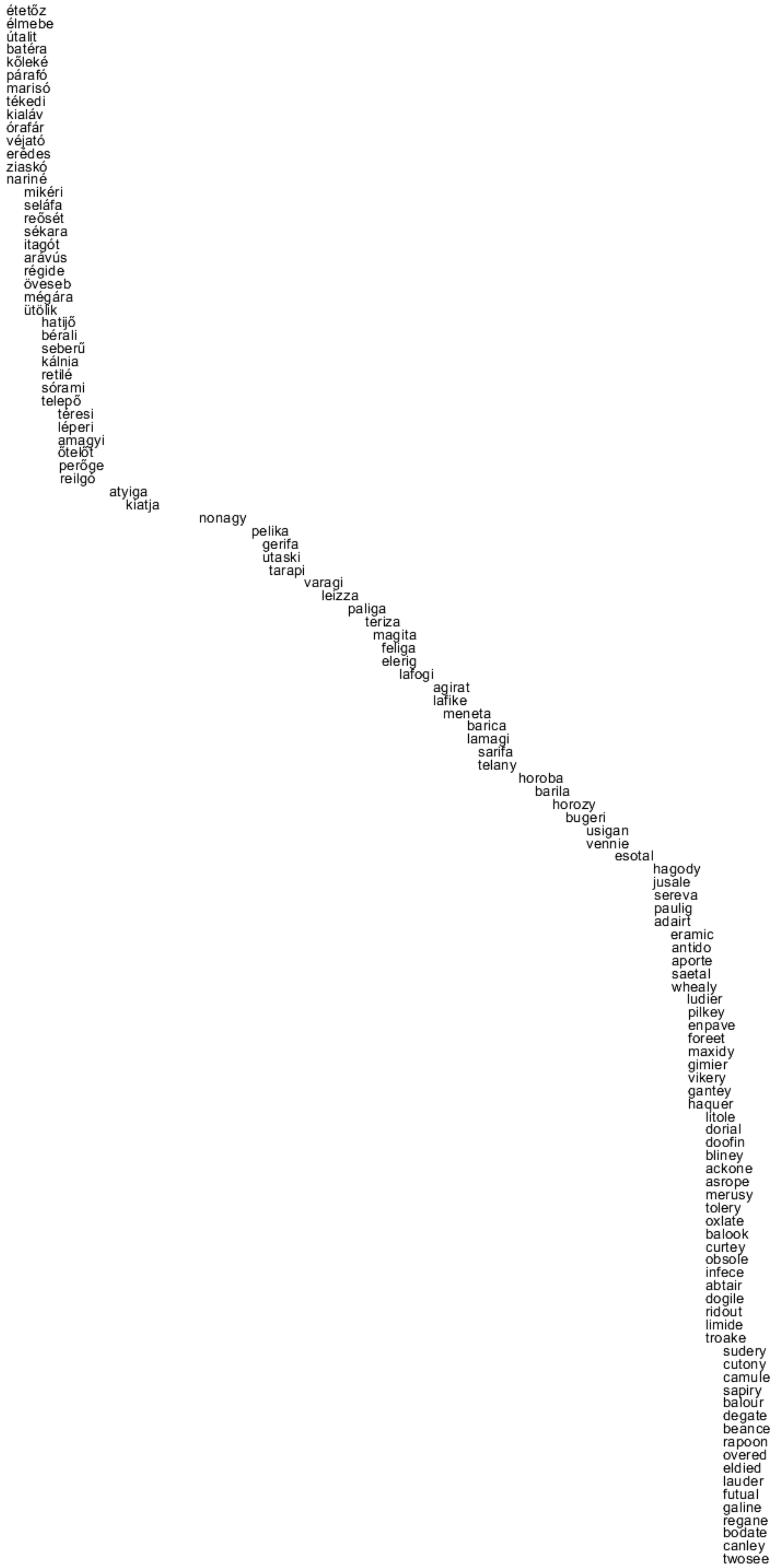


Figure 29 represents how much participants recognize pseudo-words as Hungarian (left) and English (right). It is clear that in the case of words that carry Hungarian phonotactic features such as vowels with accents, the decision was easy. The recognition of English pseudo-words did not cause any difficulties when they carried language-specific letter strings, such as double vowels next to each other, two different vowels adjacently, *y* in word-final position, or the repetitive use of *w* or *x*. Furthermore, some English pseudo-words resemble verbs in the past simple (*-ed*) or past participle (*-en*) form, which also helped the decision. However, both languages have strict restrictions on what graphemes can appear in what order in what position, there are certain combinations that are possible both in Hungarian and English. These are words with consonant-vowel-consonant-vowel-consonant-vowel (or vowel-consonant-vowel-consonant-vowel-consonant) sequences, or words with double consonants. These pseudo-words can have both Hungarian and English pronunciations, which explains why it was a bigger challenge for participants to make the decision.

Figure 30. The distribution of items per experiment. ExperimentA refers to the language decision task, including homographs, Hungarian and English words, experimentB refers to the first lexical decision task, including words and non-words, experimentC refers to the second lexical decision task, including Hungarian pseudo-words and English pseudo-words

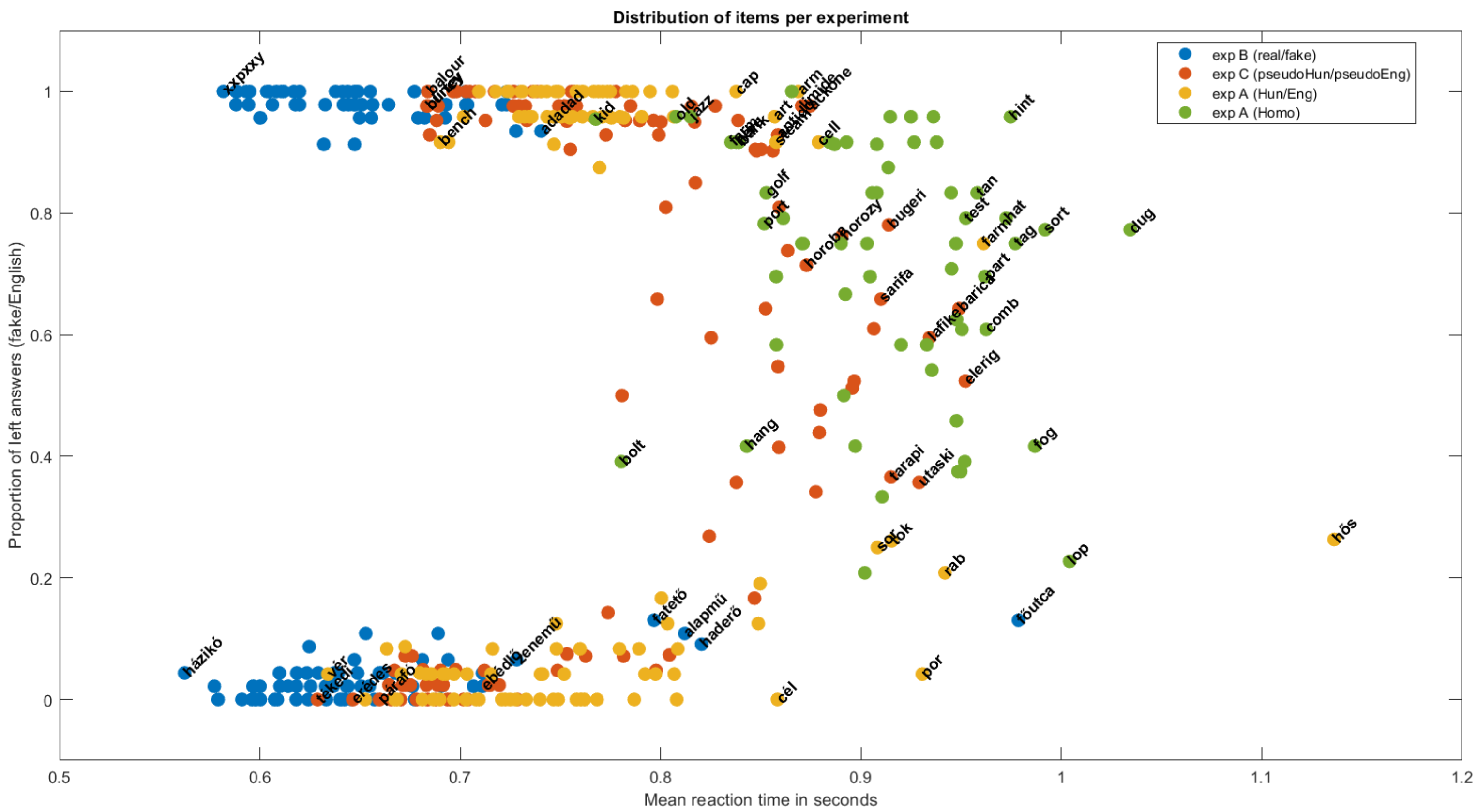


Figure 30 represents the average reaction time and the frequency of the chosen category. Hungarian and real words can be seen at the bottom, English and non-words are at the top. The x-axis represents the mean reaction time in seconds. It is obvious from the distribution that the decision between words and non-words (blue) was the least challenging. The longest reaction times relate to some Hungarian compound words, but other than that no other significant difference can be identified. In the case of Hungarian and English words (yellow), participants' decisions are also clear. The recognition of homographs (green) tends towards English. In the case of the recognition of pseudo-words (red) several words were obvious. These pseudo-words are the ones that contain vowels with accents (Hungarian) and the ones that resemble real Hungarian or English words. In the middle area, there are several pseudo-words that caused some efforts to decide, in this case, the reaction time is prolonged, too. Comparing the recognition of Hungarian and English words (yellow) and pseudo-words (red), the connection between reaction time and decisions shows similar patterns.

4 DISCUSSION

The dissertation uncovers the effects of bilingualism on the phonological, lexico-semantic aspects of visual word processing. It also seeks to find out whether the language neural network differs between first and second-language processing. I conducted a comprehensive evaluation of research that used neuroimaging methods to investigate the effects of bilingualism on brain structure and function.

The importance of bilingualism research was not in the focus for long; however, the increasing number of bilinguals has contributed to the importance of bilingual studies. Studies concerning visual word recognition of bilinguals are essential, on one hand, because of the increasing number of bilingual students in monolingual schools, on the other hand, to raise the consciousness of teachers about this process. Research on English and Hungarian word processing provides fundamental information that contributes to the literacy development of bilinguals.

Bilinguals often have the experience of accidentally reading something in a language other than the intended one. Occasionally, it causes inconvenience for them to suppress their irrelevant language. The present dissertation seeks to discover the activations of the brain and the mental lexicon when processing two languages in a bilingual mode. Studies on bilingual written language processing describe the relationship between a printed word or a phrase and their orthographic form in the mental lexicon, how languages are stored in the bilingual mind, and how the cerebral organization builds up.

I intended to find out the neurolinguistics 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. I also aimed at discovering the temporal characteristics of recognition at the orthographic, phonological, and semantic levels of processing. The thesis also explores the role of word superiority effect, and whether word frequency and linguistic typology are influencing factors in bilingual word recognition.

One of the most efficient methods for testing bilingual visual word recognition is EEG correlates and ERP components, since they demonstrate the active areas of the brain in real time. Moreover, research with EEG has quite a few advantages as it is non-invasive, low-cost, and fast.

There are several psycholinguistic methods for measuring bilingual word recognition. From these, I selected language decision, lexical decision, and a modified lexical decision test for testing the Hungarian-English bilingual participants' brain activations.

Word recognition patterns of orthographically related languages (e.g. English and Dutch) are presumably the same on lower levels (orthographic and phonological), but at higher cognitive levels, in semantics, recognition is strongly language-specific. In orthographically unrelated languages (e.g. Hungarian and Chinese), language-specific characters help the recognition process with the language decision. The two languages investigated in this thesis use the Latin alphabet. The majority of letters are identical, but there are some language-specific characters with diacritics in Hungarian, which makes it easy to recognize Hungarian words at the orthographic level. However, in words lacking language-specific characters, phonological awareness is important in the word recognition process.

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 the 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 this study, in the 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.

Results suggest that word recognition activates different parts of the brain from the moment of the stimulus onset until the identification of the word. 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. At 100 ms, the visual cortex gets activated, and the visual system responds to the letter strings. Although there is high-level semantic 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 this measurement, as well.

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 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).

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.

In the recognition of Hungarian and English words, there is no significant difference between the two categories on the orthographic-phonological level (between 100 and 300 ms). It means that 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 by Assadollahi and Pulvermuller (2003), Dambacher et al. (2006), and Yum and Law (2021). Significant difference can be seen between the recognition of the two languages, especially between 320 and 520 ms in the central region (Appendix 7).

In the case of homographs, there is no significant difference between the two languages, which means that homographs are processed equally, regardless of the language. However, some difference can be identified between 400 and 600, but the difference is not significant. It can be explained by the fact that 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 (Appendix 8).

Dijkstra et al. (2010) claim that when processing cognates, in comparison to non-cognates, bilinguals recognize cognates faster. In an ERP study, Midgley et al. (2011) investigate cognate facilitation effect. The authors presented English and French partial cognates and non-cognates to English (L1) learners of French (L2). Participants were instructed to read words quietly for comprehension and to complete a go/no-go semantic classification assignment. The researchers discovered that variations in cognate and non-cognate processing occurred mostly in the N400 time window for both L1 and L2 items. The N400 component is a typical ERP component that has been connected to lexical access and semantic processing. The negative-going deflection peaks around 350-400 ms following the stimulus onset. In this study, the N400 peaks triggered by the presentation of L1 non-cognate items were more negative-going than those elicited by the presentation of L1 cognates, and this was equally true for the N400 effects produced by L2 cognates vs non-cognates. These results support language-independent lexical activation, since the recognition of cognates profited from the ortho-phonological overlap with their non-target language counterparts.

Durlik et al. (2016) also found a substantial homograph interference effect in their study. Their findings show that the extent of inhibition expanded from the homograph's irrelevant meaning to a full semantic category, demonstrating the adaptability of the inhibitory processes.

When testing bilingual visual word recognition with lexical decision tasks, reaction time and a number of errors are measured between interlexical homographs and control words (Navracsics & Sáry, 2013). Homograph effect (De Groot, 2011; Navracsics & Sáry, 2013) depends on the demands of the task and the structure of the stimulus set. In the Hungarian-English bilingual visual word recognition study of Navracsics and Sáry (2013), homograph effect was observable: the reaction time of recognition in the case of homographs was significantly longer than that of non-homographs. They also found that the reaction time increased when participants recognized them as Hungarian words (0.94-1.04s), while the recognition of homographs as English words took shorter (0,86s), but there was no significant difference between the two languages. They concluded that the increased reaction time in the recognition of homographs is due to the fact that more semantic areas are involved. The accuracy rate of homographs was lower than that of non-homographs, which means that participants were exposed to a greater cognitive burden. Furthermore, they also discovered that decision-making in the case of homographs highly depended on the frequency of the word. Another study on interlexical homographs carried out by Dijkstra et al. (2000) proves the reaction time of homographs depends on their frequency in the two languages. In addition, De Groot (2011) emphasizes that there is a longer reaction time in the case of homographs if their meaning is more frequent in the non-target language than in the target language. It is due to the fact that the representation of the more frequent non-target meaning is accessed first. The rejection of the non-target meaning and the access to the appropriate language result in an increased reaction time.

In the case of the recognition of Hungarian, English words, and homographs, I found that the responses to unambiguous words were equally fast and accurate for both Hungarian (L1) and English (L2) items. However, the responses slowed drastically (~150 ms) for homograph words, and showed a bias towards English responses, despite on average the homograph items were equally frequent in both languages. Although the variation in the response language can be partly explained by the relative frequency between the two languages, the skewed nature of the homograph responses is clear, showing a bias towards English.

The reaction times for homograph items were found to be slower for Hungarian responses, in line with the findings of Navracsics and Sáry (2013). This seems to agree with the previously mentioned response bias, an advantage of English over Hungarian. The two effects line up nicely, with a very strong correlation between the decision language preferences and the time cost of Hungarian responses. I propose that this bias is indicative of the underlying strategy that participants developed during the experiment. It is likely that the task was reformulated in many (at least those with a stronger bias) to a decision if a word could be English or not.

This strategy theory might be further supported by the ERP results, showing a more pronounced N400 component for Hungarian words, than for English. The N400 is widely understood as a surprise signal, having higher amplitudes for unexpected stimuli. I suggest that the more negative N400 could be a sign of a mismatch between the expected language and the actual language of an item. Since the homographs could apparently easily be seen as English, they met the criteria of the expectation, hence the in-between N400 component.

Alternatively, the elevated N400 could also be a sign of more rich semantic representations and neighborhoods for Hungarian words. I argue, however, that this is less likely, since the homographs had an equally high frequency in the Hungarian corpus, as the non-homograph Hungarian words; if the recognition is invariant to language expectation, then these words should also show an N400 at least as prominent as the Hungarian ones.

The lack of any early differences between the ERP waveform shows that the first stages of word recognition do not differ for Hungarian, English, and homograph words, or at least not in this experiment. This might be due to both of them being Latin-based scripts, requiring similar processing steps (perhaps N200 differences would arise when comparing alphabetic scripts to syllabaries, or left-to-right writing systems to right-to-left ones). The most obvious visual difference between Hungarian and English scripts is the absence of diacritics in the latter. This, apparently, is not enough to elicit a large-scale neural difference, detectable with ERP (Appendix 9).

Cross-language interference arises during understanding interlexical homographs because two separate representations are active simultaneously in the bilingual brain. Neurolinguistic data supports this concurrent activation of both languages (Hsieh et al., 2017). The N400 amplitude is impacted by word frequency during the reading of homographs, which indicates the simultaneous activation of two languages. According to Hsieh et al. (2017), homographs activate the left inferior frontal gyrus more than reading control words.

Based on the visual word recognition models, the conclusion can be drawn that both lexicons of a bilingual individual are active (Dijkstra et al., 1999). The processing of interlexical homographs confirms that besides orthographic awareness, phonological and semantic representations are needed to identify a visual word. In the case of written word recognition, phonological activation occurs, as it was previously stated in the semantic, orthographic, phonological interactive activation model.

In the recognition of Hungarian and English words, there is no significant difference between the two categories on the orthographic-phonological level, which means that participants with C1 level English proficiency do not need any special effort to identify the words. However, their decisions are influenced by word familiarity and word frequency (Appendix 10).

The recognition of Hungarian and English words shows identical patterns of activation with the successful discrimination of languages at N400-600 components (which is the semantic processing of words), however, the recognition of homographs requires longer time. This can be explained by the homograph effect, which means that the reaction time is longer for homographs than for non-homographs (c.f. Navracsics & Sáry, 2013) due to the fact that during the recognition of homographs, both lexicons are active.

For the co-activation of both lexicons Lemhöfer and Dijkstra (2004) gave the BIA+ model as an explanation. According to BIA+ (Dijkstra & Van Heuven, 2002), the visual presentation of a word leads to parallel activation of orthographic input representations in L1 and L2. Semantic and phonological representations are activated by these representations, and it ends up in a complex interaction between codes. When the appropriate language gets selected, the input word is recognized. Moreover, BIA+ says that interlexical homographs have separate representations for each language. However, it is possible that cognates have shared representations (Dijkstra & Van Heuven, 2002). BIA+ furthermore emphasizes that the activation of various lexical representations is continuously audited by the task/decision system, which supports task execution and decision-making (Green, 1998).

The reaction time of the recognition of homographs is slower for bilinguals, since they are exposed to two meanings of homographs. Hsieh et al. (2017) also give the BIA and BIA+ models (Dijkstra & Van Heuven, 1998, 2002; Thomas & Van Heuven, 2005) as an explanation, since all nodes between languages are interconnected at the word level, and they mutually inhibit each other. Slower reaction times for interlexical homographs suggest that bilinguals face a competition of representations from their L1 and L2 during the processing of homographs (Hsieh et al., 2017). The data support language non-selectivity, which means that there is an automatic co-activation of information in both linguistic subsystems.

The response time of homographs is also longer because the processing of printed words continues until the orthographic word unit is recognized, and the orthographic representation meets the linguistic properties (phonology, morphology, semantics). According to Carreiras (2013) at this point, the boundary line between orthographic processing and linguistics processing is fuzzy. Nazir et al. (2004) furthermore explain that high-level considerations form the distributional characteristic features of letters in the given language, and the word recognition system learns these properties that make reading successful. Words with high-frequency result in perceptual learning that helps fast and effective word recognition, which means that word frequency also influences word recognition (Frost, 2012; Kronbichler, 2004). Neurolinguistic evidence (Simos et al., 2002; Solomyak & Marantz, 2010; Szwed et al. (2012) suggests that although high-level linguistic information already exists at approximately 100 ms from stimulus onset, the visual system responds only to the frequency of letter strings, and lexical and phonological features are taken into consideration much later. It also explains why the recognition of cognates and interlexical homographs takes a longer time.

In the 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 at the temporal electrode sites with higher brain activity in the case of words (Appendix 11).

The recognition of real words requires greater cognitive activity, and semantics has a role in recognition. The results suggest higher brain activity in the 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 the recognition of words and non-words, ERP waveforms do not differ in the first 200 ms. ERP curves separate from each other in the late parts of the N170 component around 220 ms, hinting at marked differences in later periods of orthographic processing. Based on the pronounced N400, we suspect that word recognition requires greater cognitive activity, which supports the hypotheses related to the reaction time (Navracsics & Sáry, 2013). Non-words are recognized more easily in terms of perceptual processing speed and visual short-term memory capacity (Starrfelt et al., 2013) (Appendix 12).

In the 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 electrical sites 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 helps them to decide (Appendix 13). 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).

When deciding on the perceived language of pseudo-words, occipital late N170 and central N400 components do not show any significant difference between Hungarian-like and English-like strings. Significant difference can only be observed at the left temporal and frontal electrode sites around 500 ms post-stimulus onset. These electrical signals and also the increased reaction times compared to the first experiment indicate that participants need quite a huge cognitive effort to decide which language the pseudo-words belong to; however, phonological awareness could play a key role in helping them with the decision. I propose that this task activates the left inferior frontal gyrus (projecting to frontal-temporal electrode sites), a part of the brain that is involved in the sublexical decoding of orthographic input letter sequences into phonological output codes as suggested in the study of Hagoort et al. (1999). Although it takes longer for participants to recognize pseudo-words than real words, in the case of highly proficient bilinguals pre-lexical activation helps word recognition. Rodríguez et al. (2022) having similar results claim that higher L2-exposure bilinguals can process L2 more automatically.

The analysis of the recognition of words vs. non-words implies that response times are quite fast, and this is underlined by the fact that the ERP waveforms differ as early as 220 ms post-stimulus onset. On the contrary, for pseudo-words, the responses are delayed. Significant difference occurs only at around 500 ms at the left temporal and frontal electrode sites. Pseudo-words elicit pronounced N400s due to the co-activation of orthographic neighbors, as was found similarly in Meade et al. (2019). Whenever a real word appears on the screen, recognition is quick and successful because its neighbors are inhibited. Although, in the case of pseudo-words, the language-specific letter string activates the appropriate language (Singleton, 1999), but neighbors are not inhibited, which leads to a longer reaction time. The Bilingual Interactive Activation+ (BIA+) model (Dijkstra & Van Heuven, 2002) describes this process. The model contains two subsystems, the word identification subsystem (linguistic context), and the task/decision subsystem (non-linguistic context). In the word identification subsystem, the input is processed on the level of sublexical orthography and phonology, and then on the level of lexical orthography and phonology. In this subsystem, the sublexical orthography and the sublexical phonology are in continuous interaction with each other. Then the information is forwarded to the next level, where the lexical orthography and lexical phonology are in connection, as well. The model is interactive, since there is transparency between the subsystems, and the information can be sent back to the previous subsystem to confirm.

When the appropriate language is chosen, the semantics of the word is checked. The task/decision subsystem receives the input from the identification system, where the correct language is identified and gets activated (Dijkstra & Van Heuven, 2002). Pseudo-words carry the phonotactic characteristics of a language, but do not carry a meaning. This is why it takes longer to identify pseudo-words than words (Appendix 14), as the processing goes on longer without reaching a semantic target. In the case of the recognition of English and Hungarian pseudo-words, reaction time is longer in the recognition of L2 pseudo-words, since participants' language decision strategy depends on their phonological awareness and changes due to the insecurity of their second language (Vargha, 2010).

As the results suggest, phonological awareness is indispensable for sublexical word recognition processes, i.e. for the ability to identify if a letter string is a word or non-word, or if it is an English or a Hungarian pseudo-word. Our results also prove that phonological awareness is a necessary pre-reading skill, since there is a significant difference between the recognition of words and non-words at the early phase of word recognition (220 ms) at the occipito-temporal electrode sites (Appendix 14), which indicates that nonsense letter strings can be identified immediately after the stimulus onset. In terms of reaction time, there is no significant difference between the recognition of English and Hungarian pseudo-words, which supports the idea of highly proficient bilinguals having equally high phonological awareness in their two languages.

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).

5 CONCLUSIONS

Psycholinguistic studies of bilingual language processing usually agree that representations from several languages are active concurrently and compete with one another. Bilinguals are assumed to be capable of selecting a target language by extremely efficient cognitive control, which means that they select or suppress an activated mental lexicon dependent on certain conditions.

In the present dissertation, I investigated the temporal characteristics of written word recognition of bilinguals at the orthographic, phonological, and semantic levels of processing. The current research has succeeded in highlighting the most important aspects of bilingualism, which must be crucial for both language teachers and bilinguals.

My results suggest parallel activation of Hungarian and English during bilingual visual word processing. The present study provides evidence for co-activation and competition between languages in bilingual word processing. In the case of the recognition of homographs, answers indicate a bias towards English responses. The coefficient revealed a high relationship between the ratio of Hungarian replies and the Zipf-frequency difference between Hungarian and English. Multiple comparisons confirmed that there was no difference in the mean response times of Hungarian and English words, whereas homographs produced response times that were approximately 150 ms longer. In the early stages of recognition, corresponding with the orthographic-phonological level, there was no significant difference between the two categories, indicating the relative ease with which the participants can process letter strings from both L1 and L2. The brain representations of the two languages, however, diverged later, between 320 and 520 ms in a frontocentral electrode cluster. The ERP waveforms did not demonstrate any significant variations between items regarded as English or Hungarian in the case of the Hungarian-English homographs. Although there is a difference in brain activation between temporal and frontal electrode sites, it is not significant statistically. Furthermore, the results illustrate that although Hungarian and English have different writing systems, and they are typologically unrelated languages, processing patterns are very much alike. Although there is always a dominant language, C1-level bilinguals cannot inhibit either of the languages, which leads to the parallel activation of both mental lexicons. The recognition of interlexical homographs does not trigger different processing patterns; however, different cognitive efforts can be observed according to the judgment of languages.

I could replicate the homograph effect and found that the differences can be at least partly explained by the decision-making strategies of the participants. To test my theories, I propose future experiments to control the strategy by rephrasing the participants' task to concentrate on one or the other language and see if the response bias changes direction. Possibly this would also change the direction of the N400 component difference, based on the target language.

The results furthermore 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 neurolinguistics and temporal characteristics of bilingual visual word recognition. During visual recognition of words, non-words, and pseudo-words, not only word frequency and familiarity, but also grapheme-phoneme consistency is an influencing factor. Although Hungarian and English have different writing systems, and they are typologically unrelated languages, the language-specific letter strings immediately activate the appropriate language and the recognition patterns are identical in the two languages. Our findings suggest that participants in both linguistic subsystems rely on phonological processes, which proves the hypothesis that phonological awareness has an important role in visual word recognition, and it is a precursor skill to successful reading.

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 of the typology, there is no difference between the recognition of L1 and L2 words in the case of highly proficient bilinguals.

The present dissertation has confirmed that studies on visual word recognition are necessary. To better understand the implications of the results, future studies are needed.

I do believe that bilingual research is important in our quest to deepen our understanding of how bilingual word recognition takes place. I am confident that with my research I have contributed to the knowledge of the bilingual brain and bilingual visual written word recognition, and I have been able to help bilingual students and teachers in their work. It is worth studying bilingualism, as it is a phenomenon that has imperceptibly permeated our everyday lives. Although bilingualism has become well-known all over the world, many people consider themselves monolinguals, since they are not equally proficient in both languages. As Grosjean says in an interview (Navracsics, 2002), it is our role as researchers to change public misconceptions, and educate people about bilingualism. They are human communicators, like monolinguals, they just communicate differently.

Limitations of the study and further research

This study has a limited number of participants. To make sure the results are valid, I used a great number of words (180 words in the language decision test, 120 words in the first lexical decision test, and 120 words in the second lexical decision test) to compensate for the small number of bilinguals participating in the research. In the future, the number of participants should be increased. Also, if both the location of the activations and the recognition time is in focus, the use of fMRI and EEG could be the best choice in the methodology of the investigation.

I included both right-handed and left-handed participants, but I did not wish to indicate the difference between them. Based on a thorough literature review, I came to the conclusion that handedness does not influence visual word recognition. It could be a further goal of the investigation to divide participants depending on their handedness and get more information about brain lateralization.

In the language decision test, both interlexical homographs and cognates were included. In another study, a further aspect of word recognition could be tested, in which interlexical homographs and cognates are separated from each other.

In the present study, all subjects were given the same instruction regarding response buttons. The difference between the conditions in not only that one is English and the other is Hungarian, but different fingers and different buttons gave those answers. For instance, people use index finger more frequently to press something, that is why it can result in faster responses. Morever, people use the left button of the mouse more frequently. It should be counterbalanced in the future.

There are ways to control the eye movement (with ocular electrodes, eye cameras). In the future, they might be necessary for a well-controlled experiment.

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Appendices

Appendix 1: Consent form

Többnyelvűségi Nyelvtudományi Doktori Iskola/Multilingualism Doctoral School
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Modern Filológiai és Társadalomtudományi Kar/Faculty of Modern Philology and Social Science
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TÁJÉKOZTATÓ ÉS BELEEGYEZŐ NYILATKOZAT

Tisztelt Résztvevő!

Engedje meg, hogy röviden tájékoztassuk vizsgálatunkról, amelyben, ha beleegyezik, Ön is részt fog venni!

A kutatás témája az angol-magyar szófelismerés. A teszt két részből fog állni, melynek során a résztvevő fixációs pont – * – helyén 2 s múlva angol, illetve magyar nyelvű szavakat fog látni. Az Ön feladata az, hogy a jobb, ill. bal nyíl lenyomásával jelezze, hogy adott esetben angol vagy magyar szót lát-e. Ha a szót angolnak véli, a jobb nyilat, ha magyarnak, akkor pedig a bal nyilat kell lenyomnia. A teszt második felében el kell dönteni, hogy a megjelenő szó létező vagy nem létező szó. A harmadik tesztben az elsőhöz hasonlóan arról kell döntést hoznia, hogy a képernyőn látható szóról a magyar vagy az angol nyelvre asszociál-e. A vizsgálat átlagosan 1 órát vesz igénybe.

A szavak felismerésével egy időben egy EEG mérőkészülékkel mérjük az agyi aktivitás mértékét. Ehhez egy sapkát kell a fejére helyezni, amiben mérő elektródák találhatók. A kísérlet végén van lehetőség a felvétel során használt gél lemosására. A vizsgálat non-invazív, azaz fájdalommal vagy kellemetlenséggel nem jár, a részvételt bármikor, következmények nélkül felfüggesztheti.

Kérem, ha a fentiek ismeretében úgy dönt, hogy vizsgálatunkban részt vesz, töltse ki az alábbi mezőket:

NÉV:…………………………………………… KEZESSÉG: BAL JOBB

SZÜLETÉSI IDŐ:……………………………...

1. Hány éves korában kezdte tanulni az angol nyelvet? ___________
2. Hogyan tanulta az angol nyelvet?

a) iskolában b) természetes körülmények között c) mindkettő

Aláírásommal igazolom, hogy a tájékoztatást megértettem, és a leírt vizsgálatban önkéntesként részt kívánok venni:

…………………………………………..
résztvevő

Kelt:

…………………………………………..
A tájékoztatást adó aláírása

KÓD:

Appendix 2: Language Experience and Proficiency Questionnaire (LEAP-Q)

Northwestern Bilingualism & Psycholinguistics Research Laboratory

Please cite Marian, Blumenfeld, & Kaushanskaya (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech Language and Hearing Research, 50* (4), 940-967.

Language Experience and Proficiency Questionnaire (LEAP-Q)

Last Name		First Name		Today's Date	
Age		Date of Birth		Male ☐	Female ☐

(1) Please list all the languages you know **in order of dominance**:

1	**2**	**3**	**4**	**5**

(2) Please list all the languages you know **in order of acquisition** (your native language first):

1	**2**	**3**	**4**	**5**

(3) Please list what percentage of the time you are *currently* and *on average* exposed to each language.
(*Your percentages should add up to 100%*):

List language here:					
List percentage here:					

(4) When choosing to read a text available in all your languages, in what percentage of cases would you choose to read it in each of your languages? Assume that the original was written in another language, which is unknown to you.
(*Your percentages should add up to 100%*):

List language here					
List percentage here:					

(5) When choosing a language to speak with a person who is equally fluent in all your languages, what percentage of time would you choose to speak each language? Please report percent of total time.
(*Your percentages should add up to 100%*):

List language here					
List percentage here:					

(6) Please name the cultures with which you identify. On a scale from zero to ten, please rate the extent to which you identify with each culture. (Examples of possible cultures include US-American, Chinese, Jewish-Orthodox, etc):

List cultures here					
	(click here for scale	(click here for scale	(click here for scale	(click here for scale	(click here for scale

(7) How many years of formal education do you have? ____________________

Please check your highest education level (or the approximate US equivalent to a degree obtained in another country):

- ☐ Less than High School
- ☐ High School
- ☐ Professional Training
- ☐ Some College
- ☐ College
- ☐ Some Graduate School
- ☐ Masters
- ☐ Ph.D./M.D./J.D.
- ☐ Other:

(8) Date of immigration to the USA, if applicable ____________________

If you have ever immigrated to another country, please provide name of country and date of immigration here.
____

(9) Have you ever had a vision problem ☐, hearing impairment ☐, language disability ☐, or learning disability ☐ ? (Check all applicable). If yes, please explain (including any corrections):
____

Language:

This is my (please select from pull-down menu)language.

All questions below refer to your knowledge of .

(1) Age when you…:

began acquiring :	*became fluent* in :	*began reading* in :	*became fluent reading* in :

(2) Please list the number of years and months you spent in each language environment:

	Years	Months
A country where is spoken		
A family where is spoken		
A school and/or working environment where is spoken		

(3) On a scale from zero to ten, please select your *level of* ***proficiency*** in speaking, understanding, and reading from the scroll-down menus:

Speaking	(click here for scale	Understanding spoken language	(click here for scale)	Reading	(click here for scale

(4) On a scale from zero to ten, please select how much the following factors contributed to you learning :

Interacting with friends	(click here for pull-down scale)	Language tapes/self instruction	(click here for pull-down scale
Interacting with family	(click here for pull-down scale)	Watching TV	(click here for pull-down scale
Reading	(click here for pull-down scale)	Listening to the radio	(click here for pull-down scale

(5) Please rate to what extent you are currently exposed to in the following contexts:

Interacting with friends	(click here for pull-down scale)	Listening to radio/music	(click here for pull-down scale
Interacting with family	(click here for pull-down scale)	Reading	(click here for pull-down scale
Watching TV	(click here for pull-down scale)	Language-lab/self-instruction	(click here for pull-down scale

(6) In your perception, how much of a foreign accent do you have in ?

(click here for pull-down scale)

(7) Please rate how frequently others identify you as a non-native speaker based on your accent in :

(click here for pull-down scale)

Appendix 3: Hungarian-English Questionnaire

Hungarian–English Questionnaire

Sex: ………………………………….. Code: ………………….

Age: …………………………………..

Handedness: …………………………………………

Age at the onset of acquisition of English: …………..

Way of second language acquisition: natural school both

1. What language(s) do you use at home?
   a. Hungarian b. English c. other: ……………….
2. What language(s) do you use with your friends?
   a. Hungarian b. English c. other: ……………….
3. What is your mother's 1st language?
   a. Hungarian b. English c. other: ……………….
4. What is your father's 1st language?
   a. Hungarian b. English c. other: ……………….
5. In which language do you feel more comfortable?
   a. Hungarian b. English c. other: ……………….
6. In which language do you read more?
   a. Hungarian b. English c. other: ……………….
7. What do you like to read?
   a. books b. newspapers c. other: ……………….
8. How much do you read a day on average?
   a. half an hour b. 1 hour c. several hours
9. Why do you read?
   a. because I have to b. because I enjoy it
10. Do you consider yourself bilingual?
    a. yes b. no
11. Have you been to an English speaking country?
    a. yes b. no
12. Have you lived in an English speaking country?
    a. yes b. no
13. What was the longest period you lived abroad?
    ………………………………………………………………………………………
14. Would you like to work or study abroad?
    a. yes b. no

Thank you very much.

Appendix 4: Test materials – Language decision test

	Homographs	**English words**	**Hungarian words**
1	add	age	ács
2	bank	aid	baj
3	be	air	bál
4	bent	arm	cél
5	blog	art	cikk
6	bolt	bath	cím
7	comb	bench	év
8	dug	boat	fej
9	fan	boot	fék
10	far	boss	föld
11	farm	bowl	fül
12	fax	boy	gép
13	fed	breath	gyár
14	film	cake	haj
15	fog	camp	ház
16	gin	cap	hír
17	golf	card	hős
18	hall	care	íz
19	had	cash	jog
20	hang	cat	kár
21	hat	cell	kén
22	here	chain	kép
23	hint	chair	kert
24	hit	chance	kés
25	hold	chart	kéz
26	hull	cheek	kör
27	jazz	cheese	láb
28	jog	chef	lakk
29	kid	chest	lány
30	kin	child	liszt
31	kit	deer	lyuk
32	lap	desk	máj
33	lent	diet	nép
34	lift	dirt	nyelv
35	lop	dog	nyest
36	mind	edge	orr
37	mint	eye	párt
38	mix	farm	pék
39	most	frame	pénz
40	must	hair	perc
41	nap	ice	por

42	old	law	rab
43	pad	map	rész
44	park	neck	réz
45	part	night	rizs
46	per	nurse	sál
47	pink	past	sor
48	port	piece	szem
49	rest	rail	szint
50	ring	road	szó
51	rum	rule	szú
52	sort	sand	tál
53	sport	seat	tél
54	tag	sense	tény
55	tan	shoe	terv
56	tea	sky	tok
57	test	snake	ujj
58	toll	steam	vég
59	van	tool	vér
60	vet	world	víz

Appendix 5: Test materials – Lexical decision test 1

	English words	**Non-words**	**Hungarian words**
1	abroad	adadad	áhítat
2	advice	aggaez	ajánló
3	amount	aiyaii	alapmű
4	animal	ayvbnn	baráti
5	appeal	bmziii	drámai
6	around	cdrfya	ebédlő
7	assume	ddddal	elárul
8	author	dioodf	fatető
9	became	dmfgkr	fizika
10	before	dzertz	főutca
11	casual	dzsdzs	haderő
12	decide	easdcv	haladó
13	defeat	eeeerm	hazaér
14	define	eekkff	házias
15	degree	eiueia	házikó
16	desire	fcvhgk	hegedű
17	emerge	fghjkl	idegen
18	indeed	fgjikw	igazol
19	mature	ggggss	jégeső
20	option	iiaauu	jóképű
21	pursue	ioekfl	kabaré
22	raised	jlkjsa	kidobó
23	rarely	joofju	nevező
24	remain	kksnvb	okozat
25	repeat	klklkl	ráadás
26	secure	klorgg	robogó
27	series	mjurrt	takaró
28	unable	mmricn	uborka
29	useful	mnbpvc	vízóra
30	varied	mnfhzu	zenemű
31		mujkkk	
32		nvpvbb	
33		nyayry	
34		ofopws	
35		ollxrt	
36		oplkjb	
37		paaars	
38		pedrtg	
39		pisjkjs	
40		plcjfm	
41		plldds	

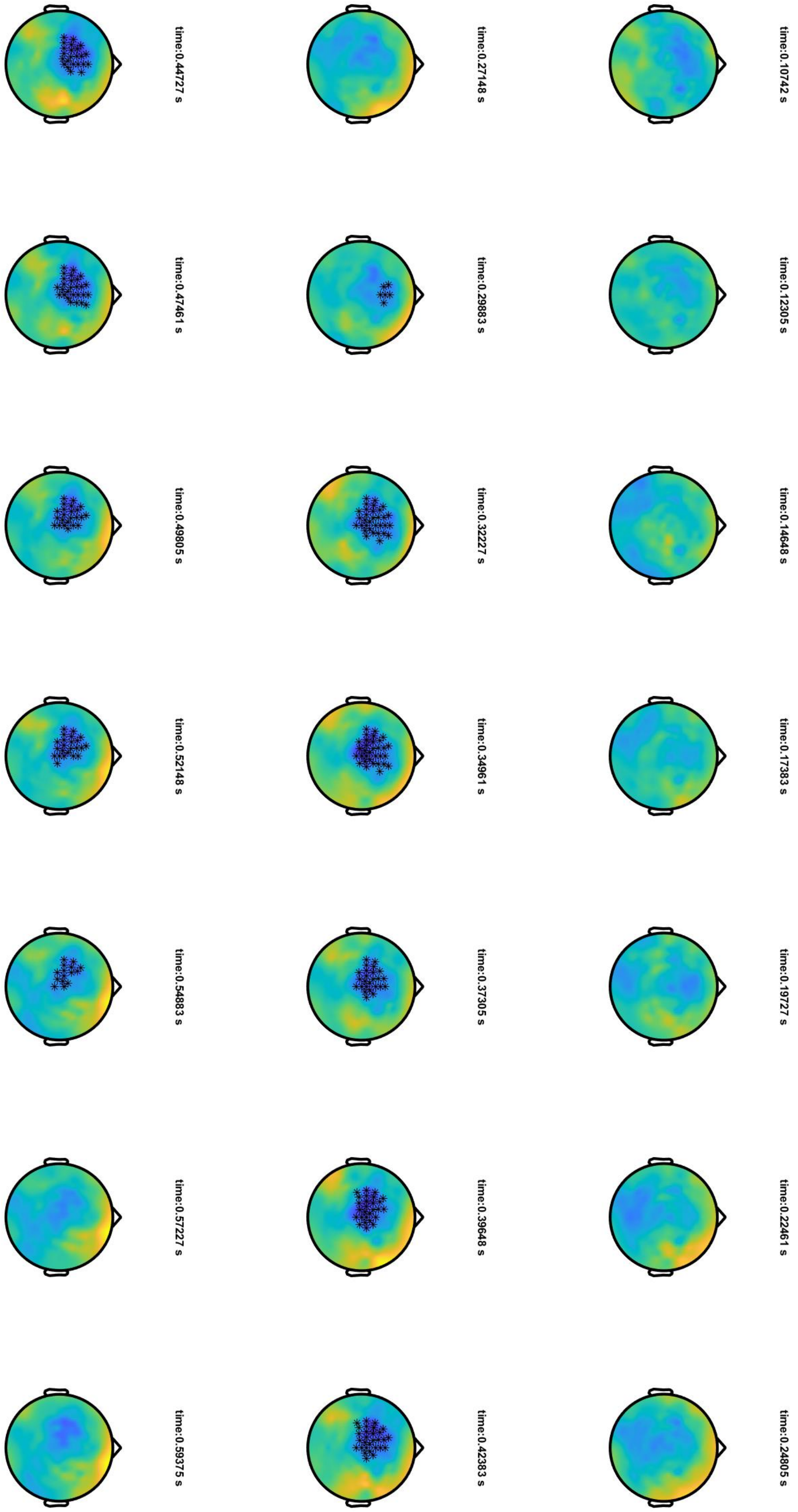
42		polltzu	
43		prrtzb	
44		pvhgfd	
45		rtyyyx	
46		sadkkg	
47		safjjj	
48		slggee	
49		sodkkk	
50		ssuuvv	
51		swgvsx	
52		vcmbnv	
53		vergvc	
54		vjduss	
55		wersasd	
56		wsddert	
57		wwsdfg	
58		xertwer	
59		xxpxxy	
60		ysyykk	

Appendix 6: Test materials – Lexical decision test 2

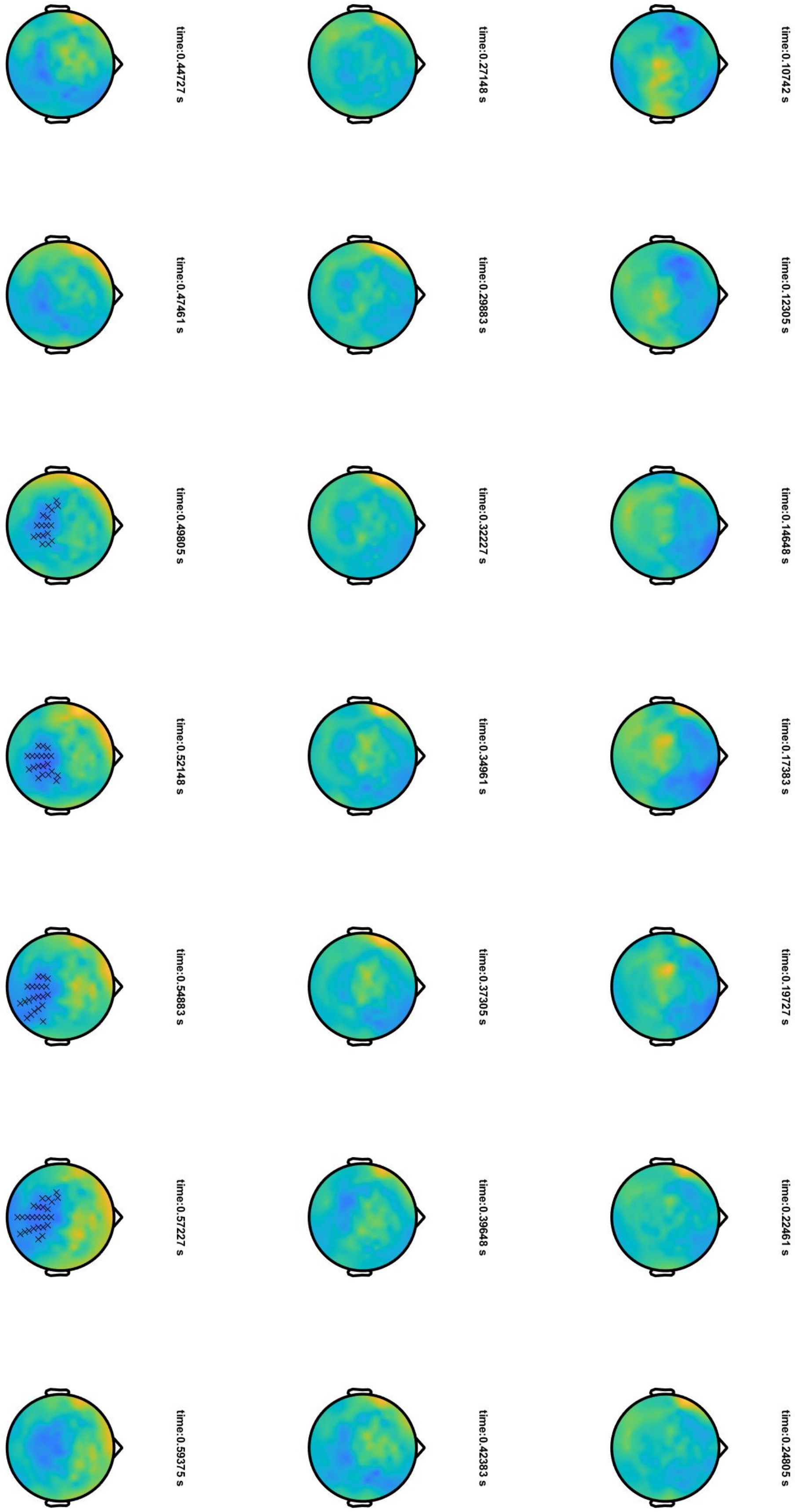
	English pseudo-words	Hungarian pseudo-words
1	abtair	agirat
2	ackone	amagyi
3	adairt	arávús
4	antido	atyiga
5	aporte	barica
6	asrope	barila
7	balook	batéra
8	balour	bérali
9	beance	bugeri
10	bliney	élmebe
11	bodate	erédes
12	camule	étetőz
13	canley	feliga
14	curtey	gerifa
15	cutony	hatijő
16	degate	itagót
17	dogile	kálnia
18	doofin	kialáv
19	dorial	kiatja
20	eldied	kőleké
21	elerig	lafike
22	enpave	lafogi
23	eramic	lamagi
24	esotal	leizza
25	foreet	léperi
26	futual	magita
27	galine	marisó
28	gantey	mégára
29	gimier	meneta
30	hagody	mikéri
31	haquer	nariné
32	horoba	órafár
33	horozy	őtelőt
34	infece	öveseb
35	jusale	paliga
36	lauder	párafó
37	limide	pelika
38	litole	perőge
39	ludier	régide
40	maxidy	reilgó
41	merusy	reősét

42	nonagy	retilé
43	obsole	sarifa
44	owered	seberű
45	oxlate	sékara
46	paulig	seláfa
47	pilkey	sereva
48	rapoon	sórami
49	regane	tarapi
50	ridout	tékedi
51	saetal	telepő
52	sapiry	téresi
53	sudery	teriza
54	telany	usigan
55	tolery	útalit
56	troake	utaski
57	twosee	ütölik
58	venney	varagi
59	vikery	véjató
60	whealy	ziaskó

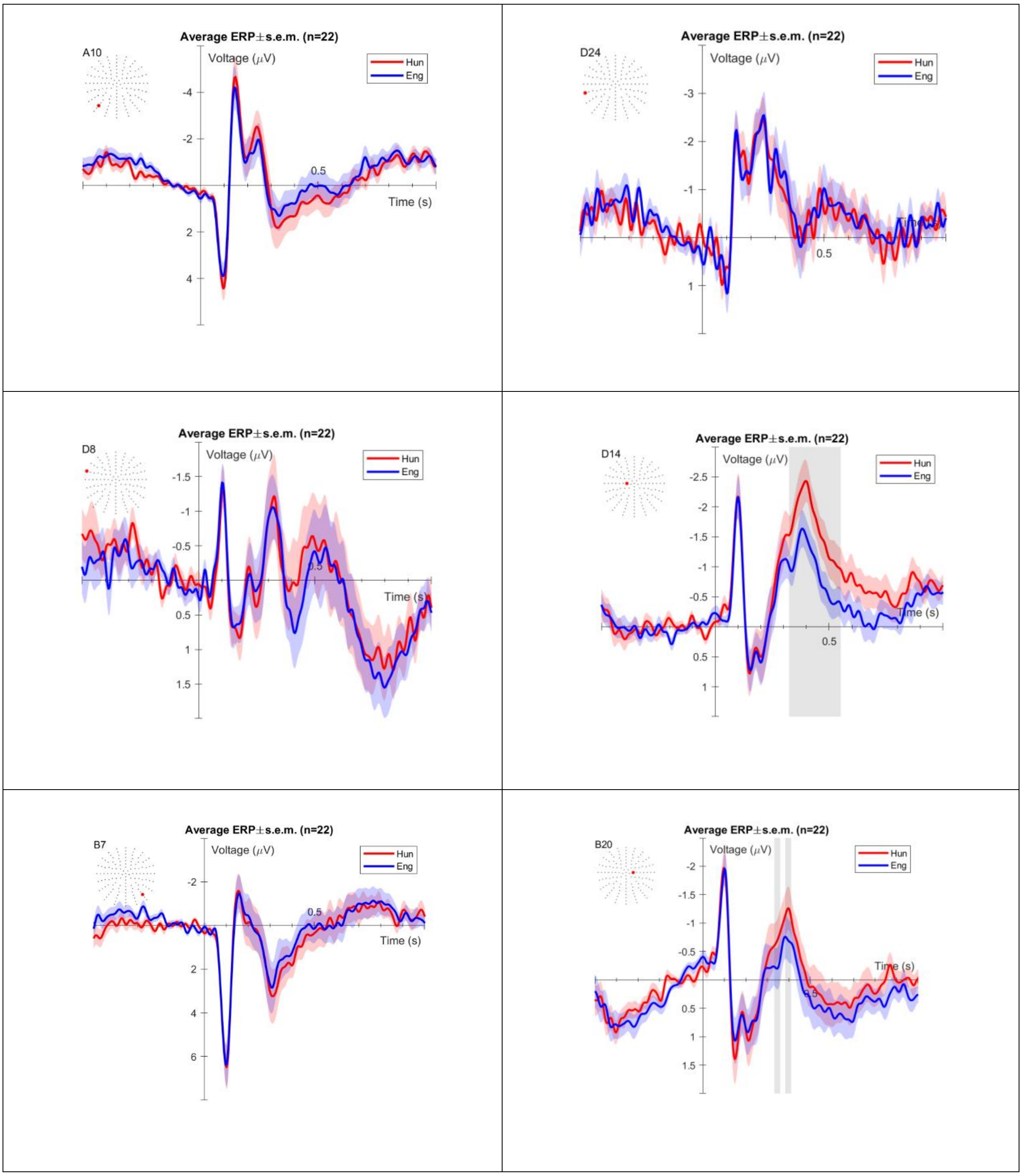
Appendix 7: Topoplots between 100 and 600 ms, in the recognition of Hungarian and English words. The topoplots show Cond1 and Cond2 voltage, and the markers designate channels belonging to significant clusters



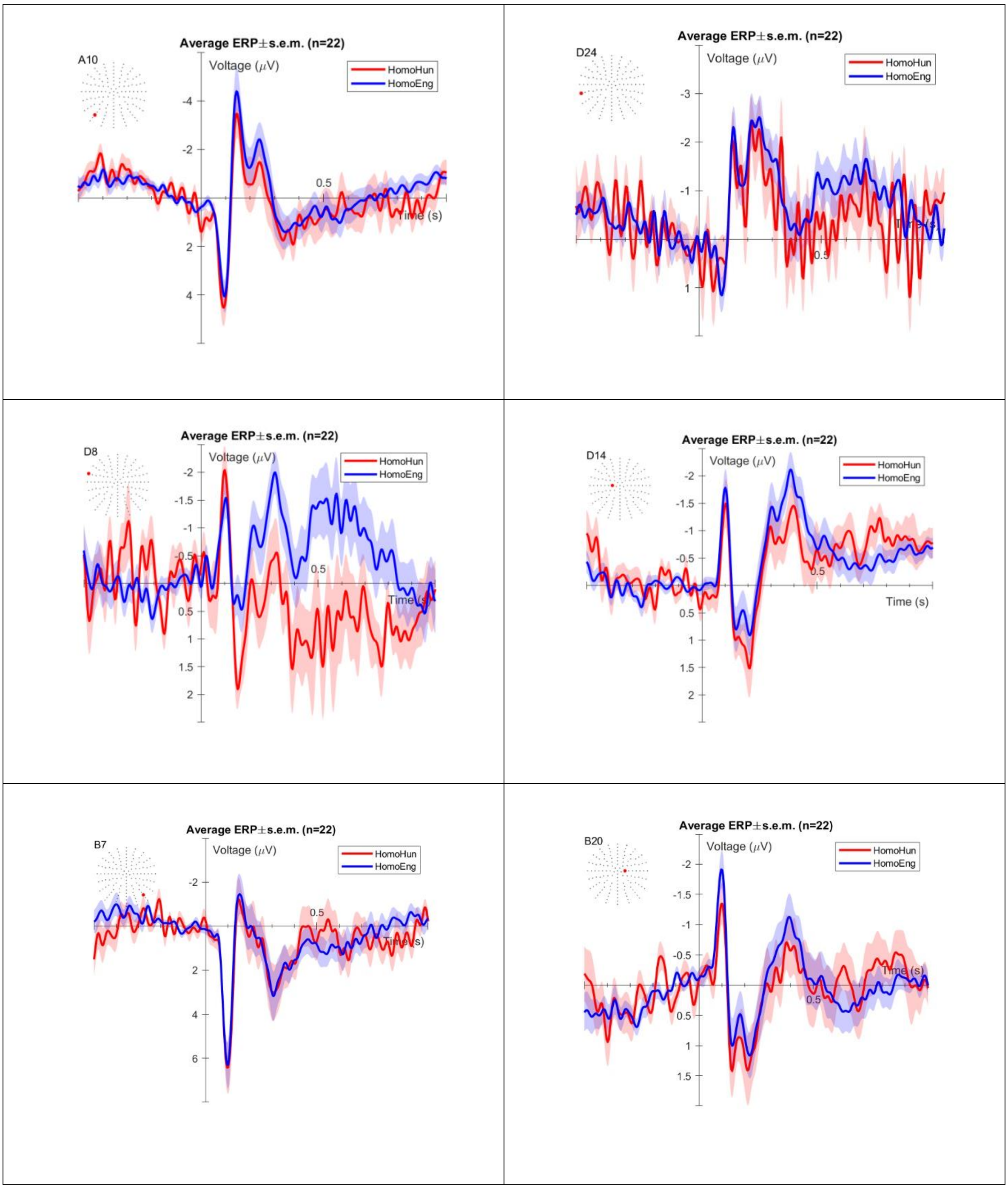
Appendix 8: Topoplots between 100 and 600 ms, in the recognition of homographs. The topoplots show Cond1 and Cond2 voltage, and the markers designate channels belonging to significant clusters



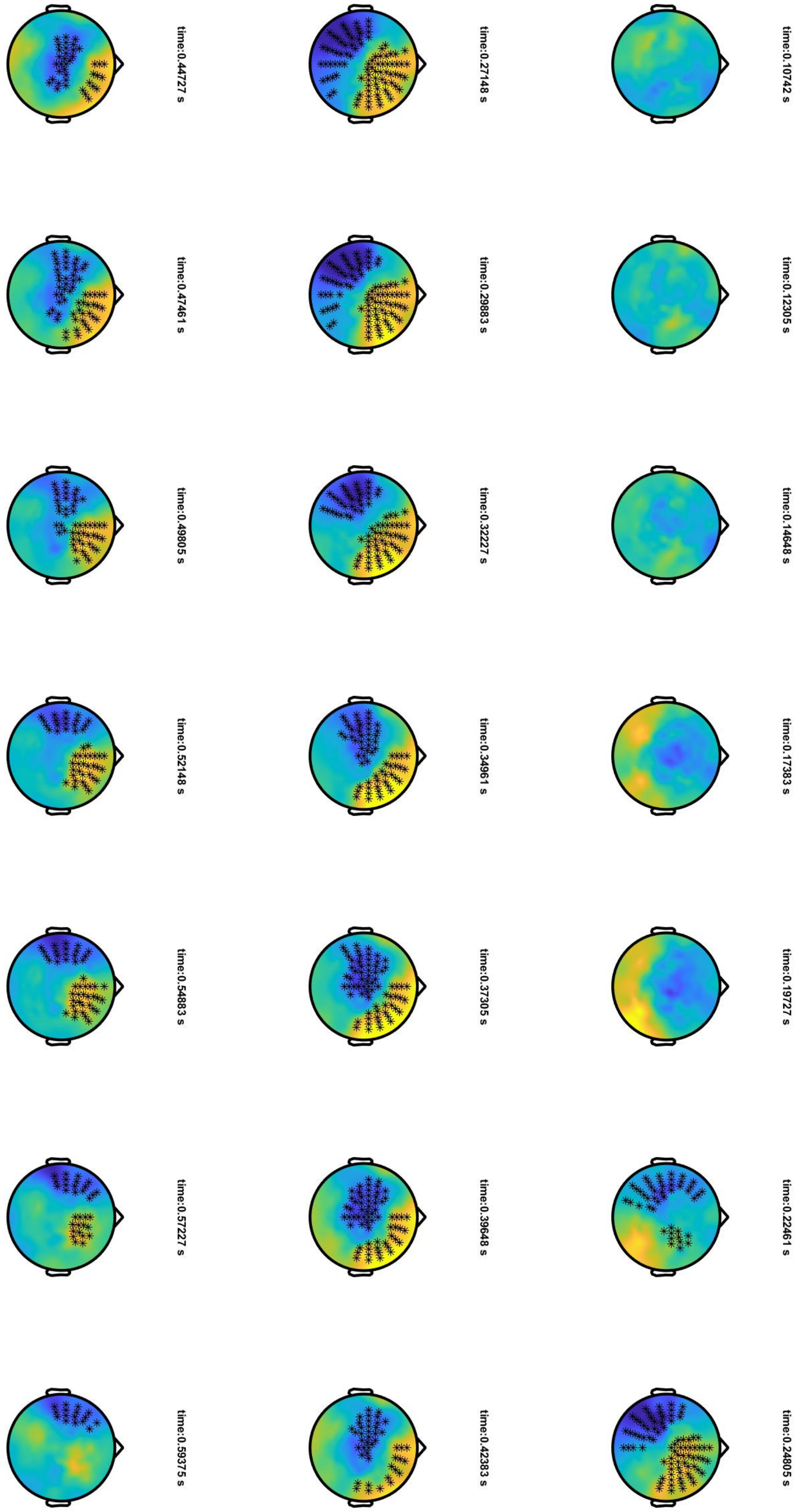
Appendix 9: Event-Related Potentials of the recognition of Hungarian and English words. Hungarian words are depicted by the red line, English words are depicted by the blue line. Significant difference between the categories is depicted by the grey column.



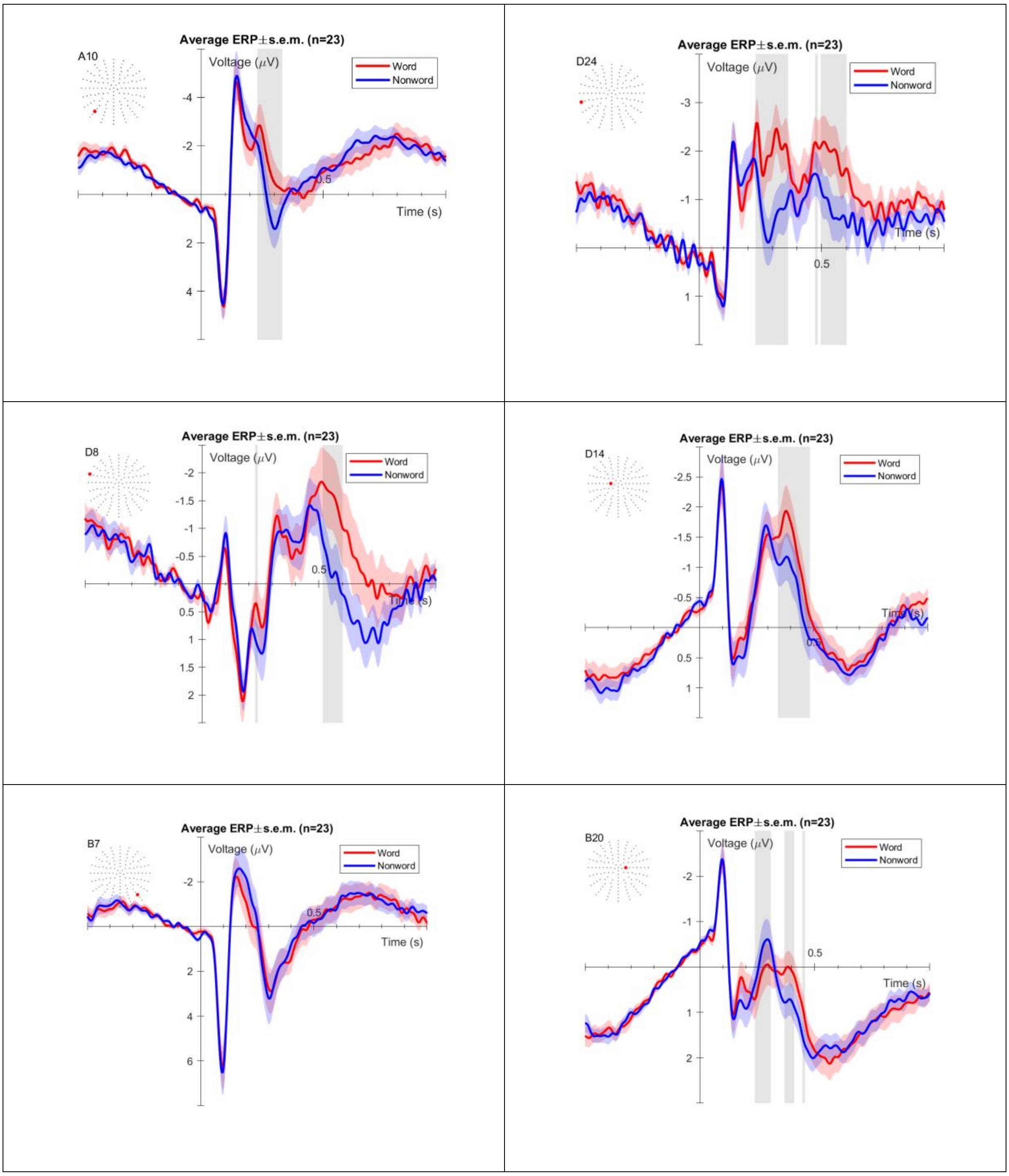
Appendix 10: Event-Related Potentials of the recognition of homographs recognized as Hungarian (red line) or English (blue line)



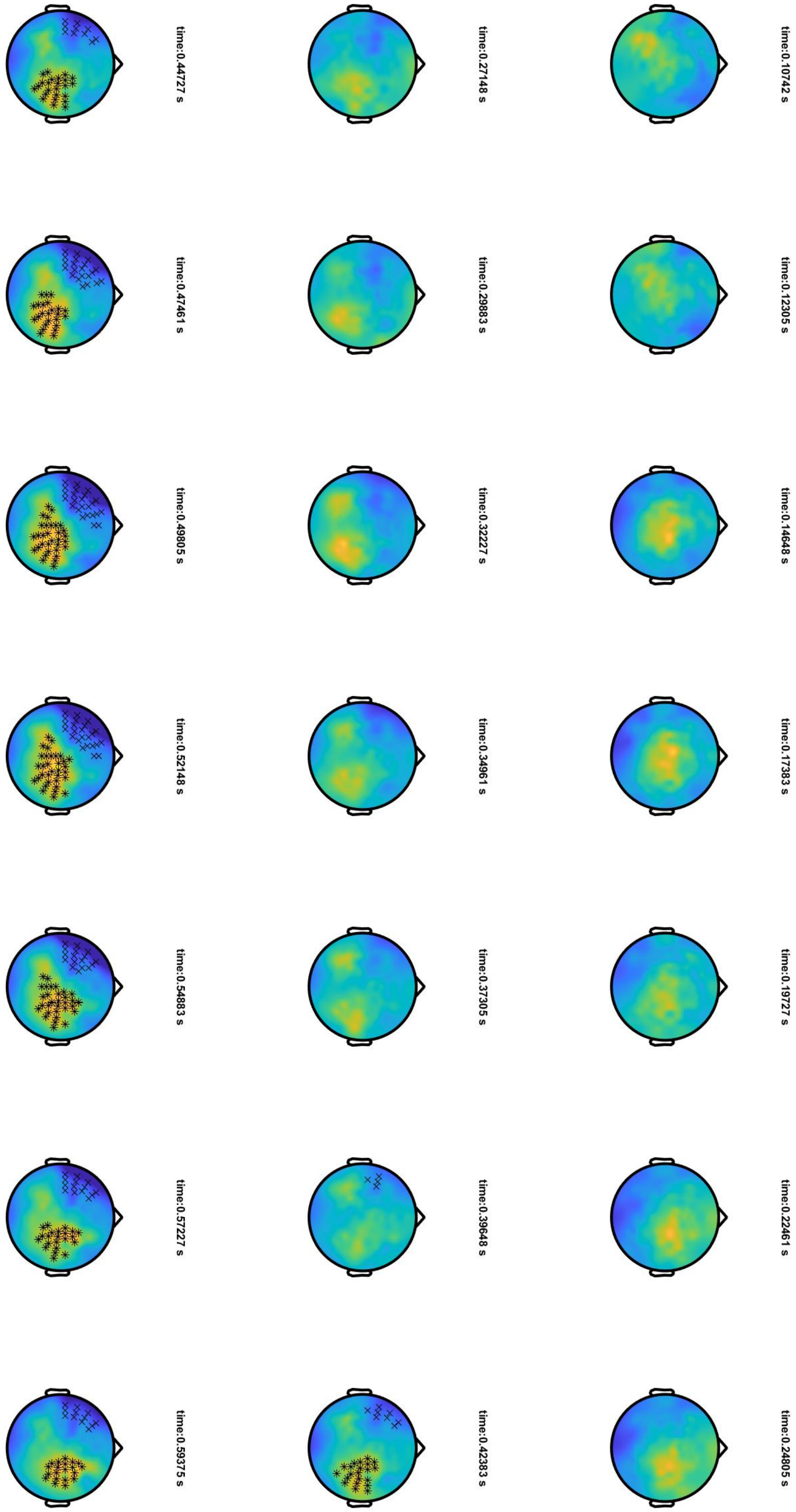
Appendix 11: Topoplots between 100 and 600 ms, in the recognition of words and non-words. The topoplots show Cond1 and Cond2 voltage, and the markers designate channels belonging to significant clusters



Appendix 12: Event-Related Potentials of the recognition of words (red line) and non-words (blue line). Significant difference between the two categories is depicted by the grey column.



Appendix 13: Topoplots between 100 and 600 ms, in the recognition of Hungarian and English pseudo-words. The topoplots show Cond1 and Cond2 voltage, and the markers designate channels belonging to significant clusters



Appendix 14: Event-Related Potentials of the recognition of Hungarian (red line) and English pseudo-words (blue line). Significant difference between the two categories is depicted by the grey column.